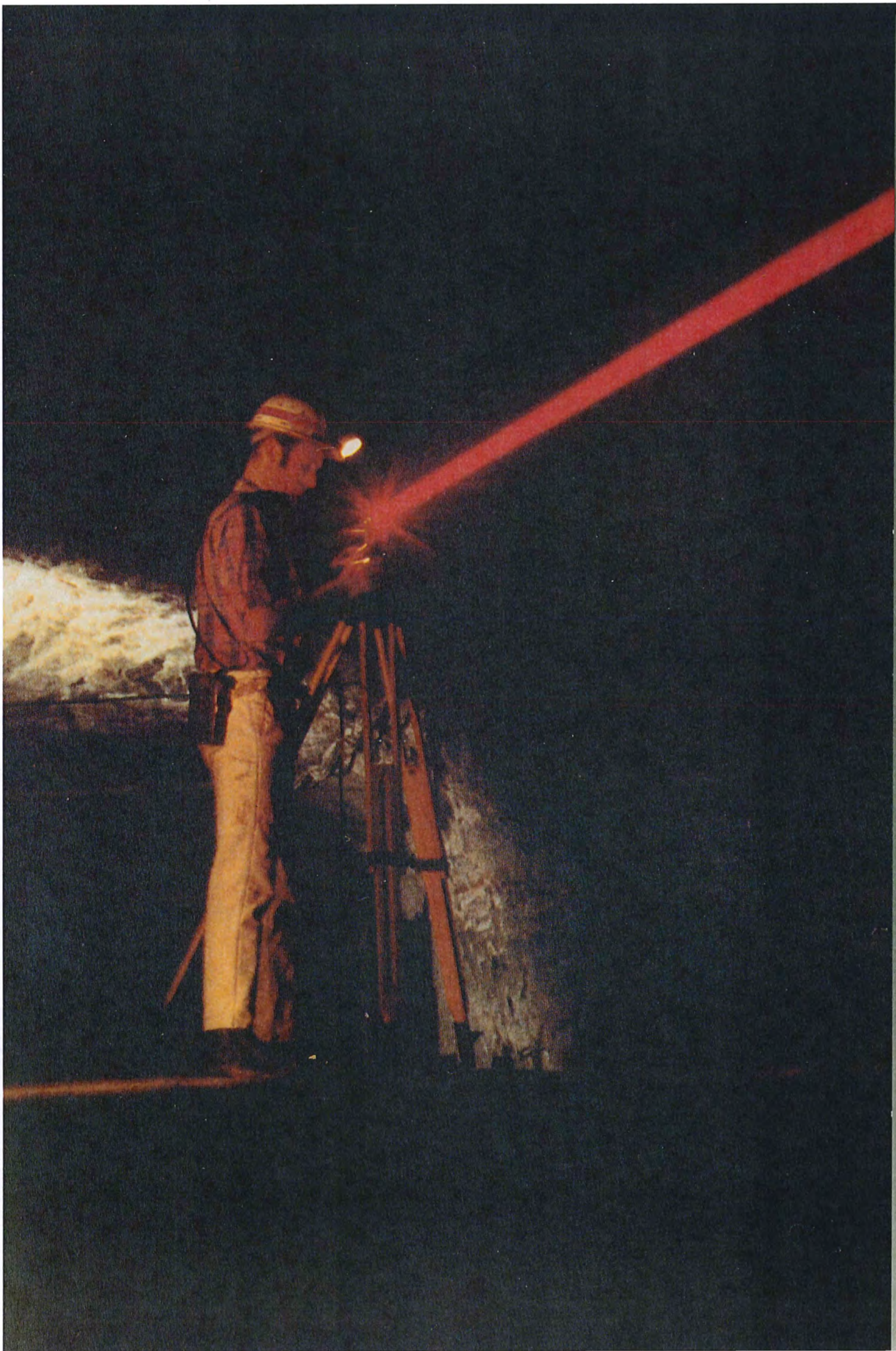
Potash

a product of nature

K+S Fertilizers

from the Federal Republic of Germany



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Federal Republic of Germany

Preface

This brochure provides up-to-date information on K+S production facilities, K+S fertilizers and K+S agronomic research. As a service to scientists, extension workers and farmers it presents recent information on basic research findings in plant nutrition as well as results obtained in the field by the application of potash, sulphur and magnesium fertilizers to various crops in both temperate and tropical climates all over the world.

Thus, it can be considered an up-dated edition of the K+S booklet "German Potash for World Agriculture".

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Who are K+S?

More than a century of tradition, experience and know-how established by the German potash industry is incorporated in Kali und Salz AG.

K+S stands for Kali und Salz. "Kali" is the German word for potash, and "Salz" means salt. Both are produced from raw material mined several thousand feet underground. Muriate of potash and table salt are just two of the many products of K+S. The list also includes fertilizers containing magnesium, sulphur and sodium, rock salt products for household and various branches of industry as well as chemicals for many purposes, such as bromine, magnesium chloride and magnesium sulphate.

Modern technology, modern research, modern thinking – coupled with our "old-fashioned" concept of reliability and efficient service – are held at the disposal of our customers for the benefit of crop yield improvements in agriculture.

Kali und Salz AG **K+S**

Friedrich-Ebert-Str. 160
P.O. Box 102029
D 3500 Kassel
Federal Republic of Germany
Phone: (0561) 301-1 · Telex: 99632 wuk d
Teletex: 561898=wuk · Cables: kalisalz kassel

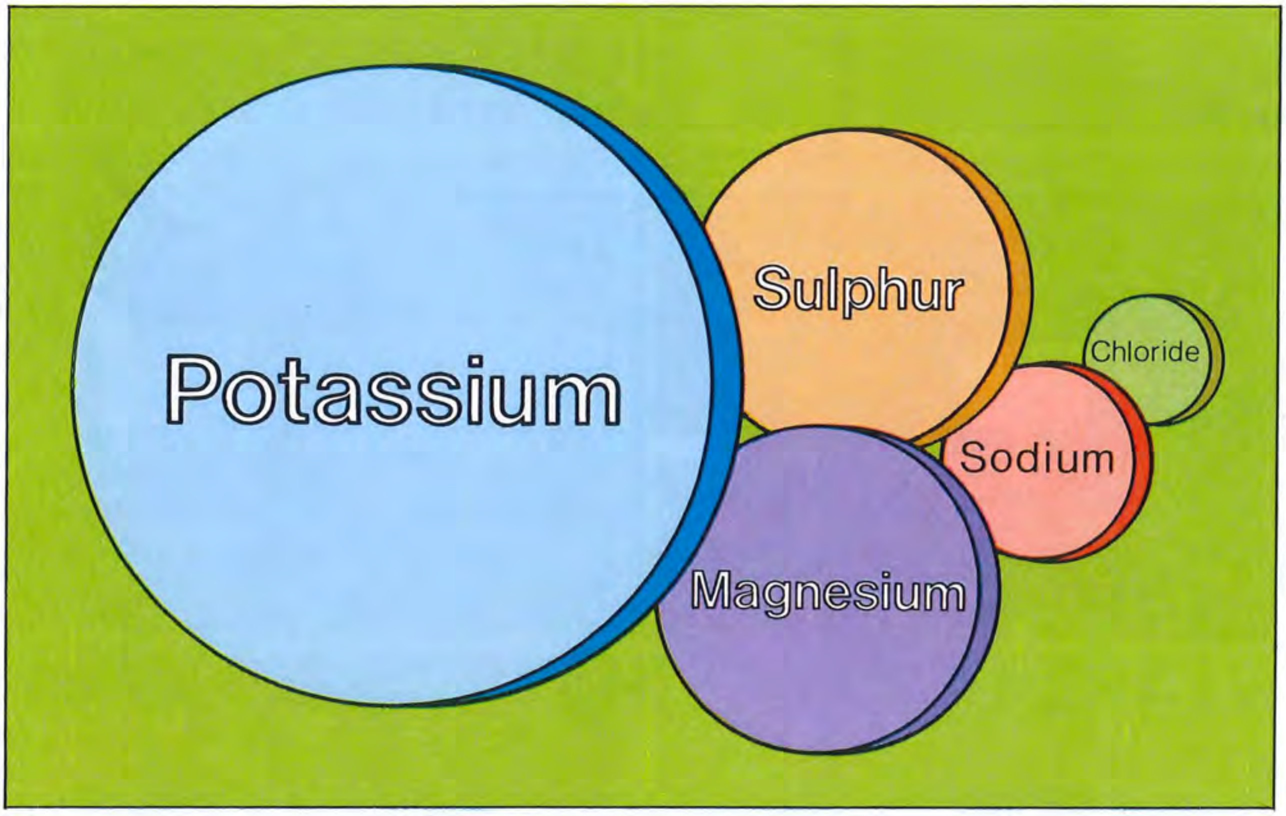
K+S fertilizers help to increase agricultural yields and to ensure the efficiency of expensive nitrogen and phosphate fertilization in countries with high fertilizer consumption. They also help to improve food production for an ever growing population and enhance the output of export crops such as oil palm or rubber, coffee or tea, cotton and many other

plants grown in tropical and subtropical regions.

About half of the potash produced in the Federal Republic of Germany is exported to more than 50 countries all over the world. Domestic consumption stood at 1.225 million t K_2O in 1983/84, corresponding to more than 85 kg per hectare of agricultural land including grassland.

In many parts of the world with intensive agriculture, the application of NPK fertilizers has increased crop production considerably. At the same time, however, higher amounts of magnesium and sulphur and of the so-called micro-nutrients are also removed from the fields and need to be replaced in order to avoid possible yield limitations.

K+S is therefore constantly improving its production of fertilizers containing both magnesium and sulphur. The annual supplies of these special fertilizers to agriculture already surpass 1.5 million tons.



K+S fertilizers, products of nature...!

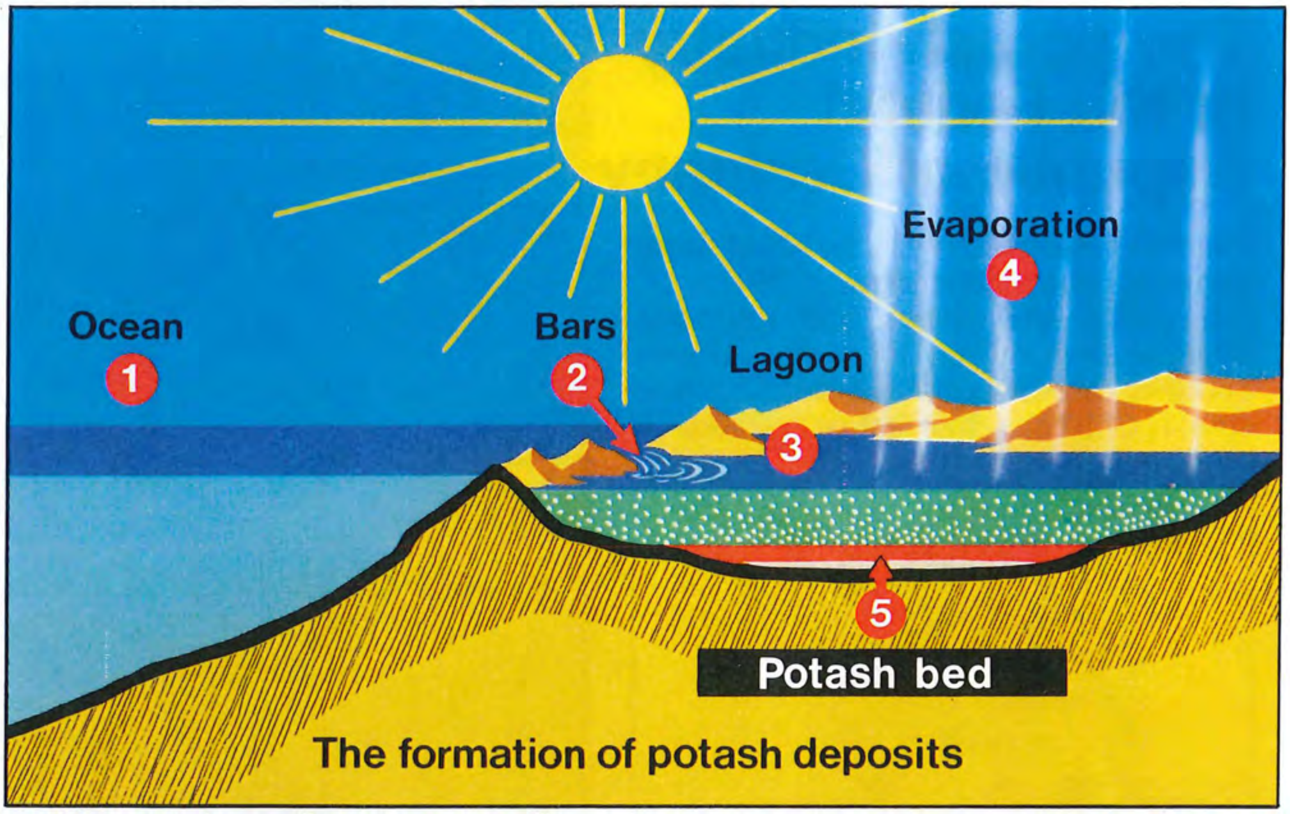
The deposits in the Federal Republic of Germany

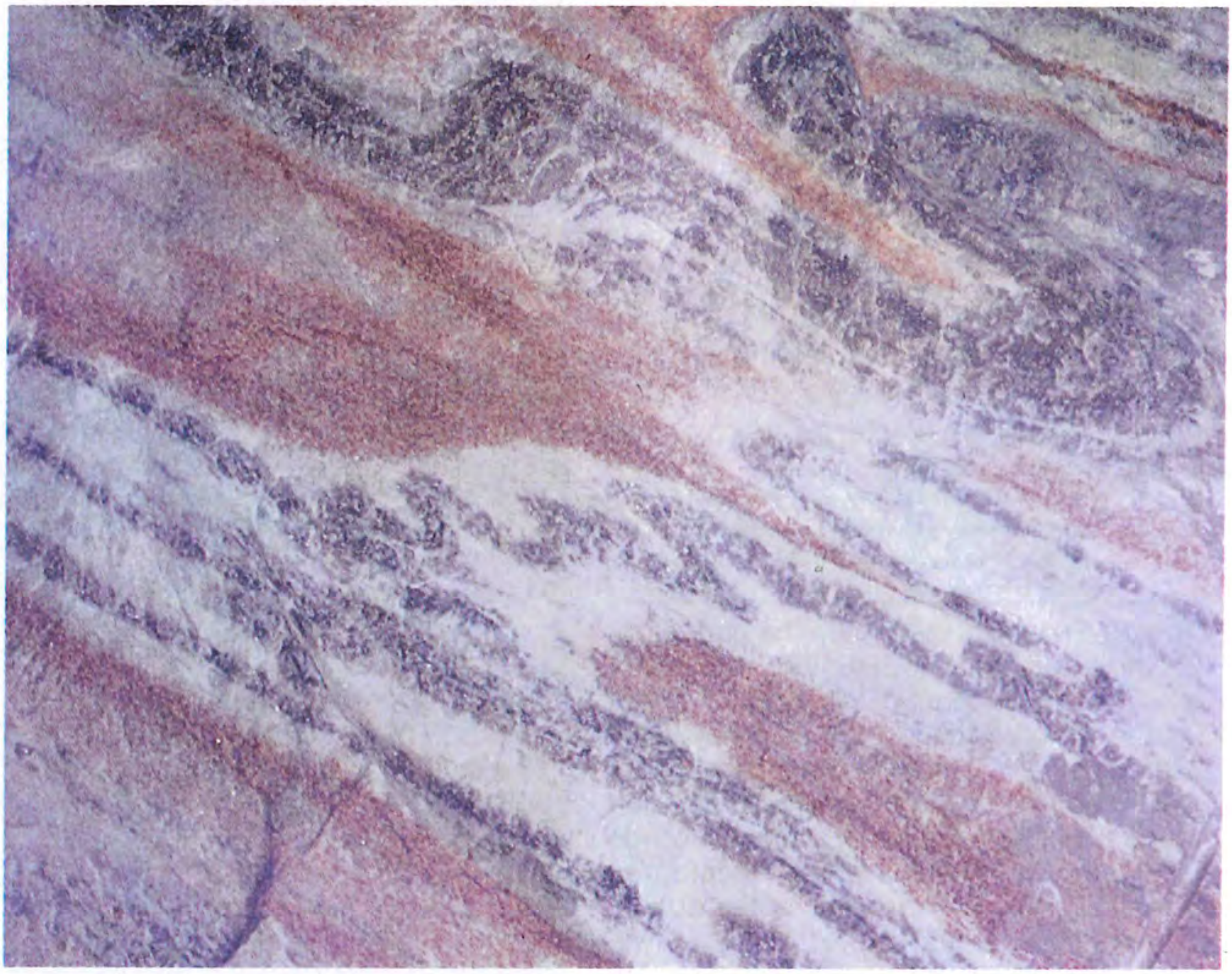
The conditions for the formation of salt deposits, occuring in many geological formations, were most favourable in Germany during the Zechstein period, about 230 million years ago. In the hot and dry climate of that period, sea water contained in large lagoons ③ was cut off from the ocean ① by shallow bars ②. It evaporated ④ and the salts crystallized ⑤. The deposits started with clay sediments (salt clay). With progressive evaporation carbonates (limestone and dolomite) and sulphates (gypsum and anhydrite) were separated first, followed by rock salt and finally potassium and magnesium salts. This process recurred several times through sea-water inflow of varying intensity, thus leading to the formation of various mineable salt deposits.

The materials manufactured by K+S are, therefore, products of nature. There is no difference between the potassium and magnesium contained in mineral fertilizers and that in organic matter.

The deposits were later covered by thick layers of clay and sand which protected them from weathering, erosion and other losses in the course of millions of years.

The known potash reserves in the Federal Republic of Germany are sufficient to cover the steadily increasing fertilizer demands of agriculture for centuries. Unlike most of the deposits in other countries they contain little or no clay but appreciable amounts of magnesium and sulphates as secondary constituents, i.e. two other important plant nutrients.





Strongly folded seams of sylvinite (KCl), halite ($NaCl$), kieserite ($MgSO_4 \cdot H_2O$) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) as found in some potash mines

The potash industry in the Federal Republic of Germany

The first potash factory in the world came into production in Germany in 1857. Today, the K+S mines and refineries produce 7–8 million tons of fertilizers annually. About half of the production is sold in Germany, the rest is exported to more than 50 countries.

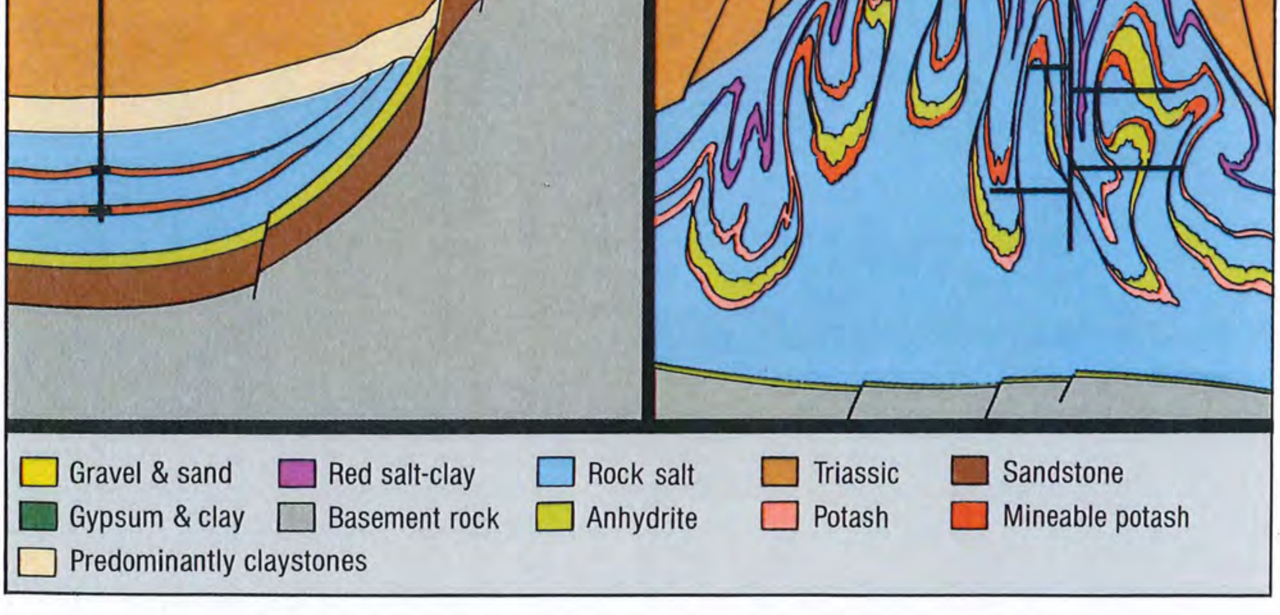
A modern potash refinery. The multistory building (on the left) houses the electrostatic separation units. The typical headframe for ore lifting of the past has been replaced by a more efficient sturdy construction (center). The largest hoisting capacity is up to 30,000 tons of crude salt per day. The tall smoke-stacks (on the right) help to prevent air pollution. They belong to the power stations. The energy consumption of each potash plant corresponds to that of a modern town of about 50,000–80,000 inhabitants.

Potash mining

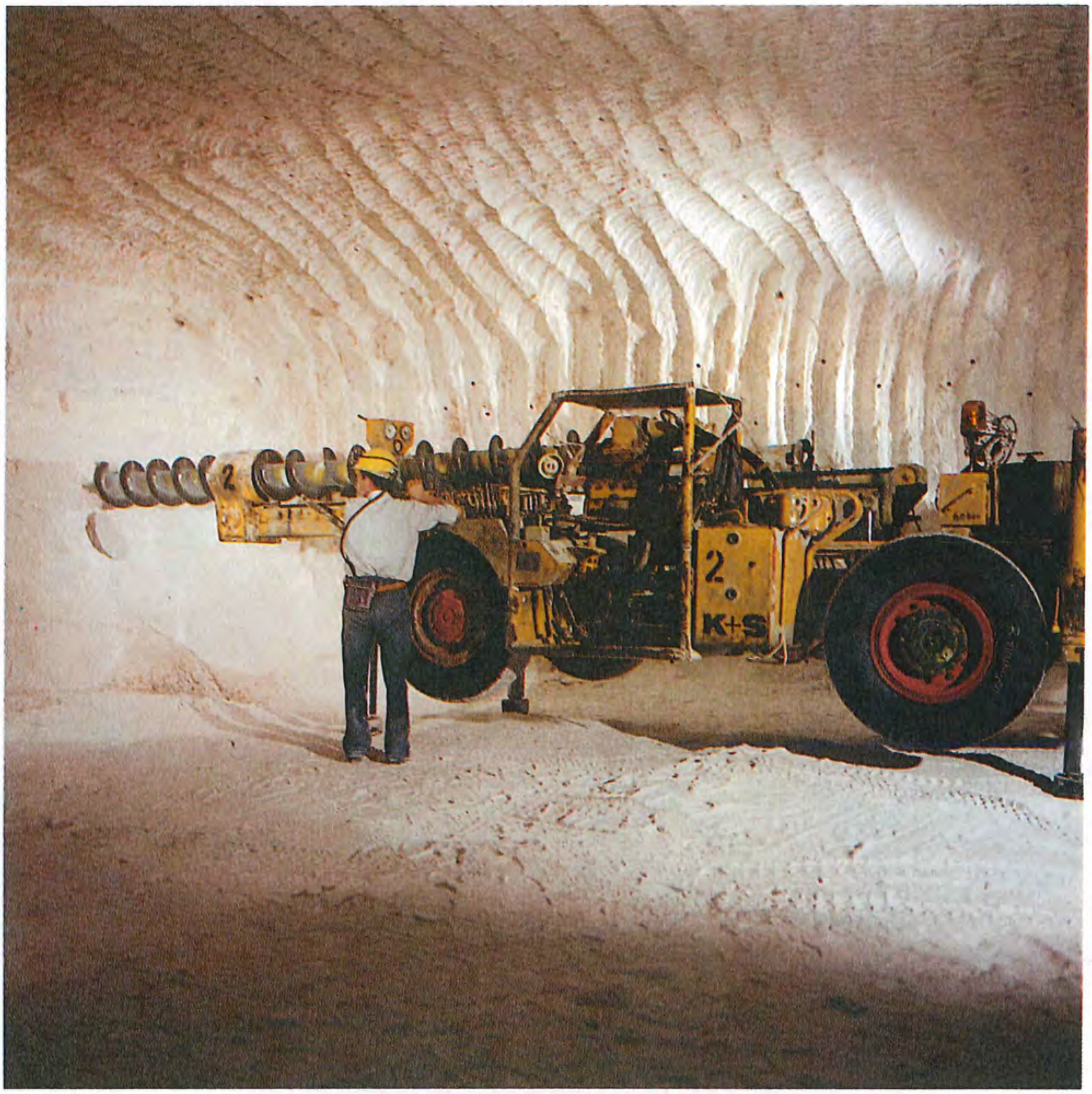
The salt deposits in Germany vary in their character. A large basin is located below the rivers Werra and Fulda. Here the flat beds of evaporites, 200 to 300 m thick, contain two potash layers which are mined at an average thickness of two to four meters by the "room-and-pillar" technique. 35 to 45 per cent of the mineable ore has to be left underground to support the roof. With this method no refilling is necessary.

A second important potash area is located near Hannover. Here, the evaporites, normally found at depths of 2,000 to 4,000 m have been lifted up in weak zones of the overlying strata by tectonic forces, forming the so-called "Salt Domes". Their tops are often situated only 100 m below the surface. To avoid any water seepage which would inevitably flood the mine, exploitation only begins at 350 m depth and goes down as far as 1,400 m beyond which high temperatures pose technical problems.

In the "Domes" the potash bearing beds, 5 to 20 m thick, are steeply inclined or



In steep deposits, the ore is extracted by bench mining. The blasted raw ore is collected from below and dropped into funnels for transport to the main hauling points.



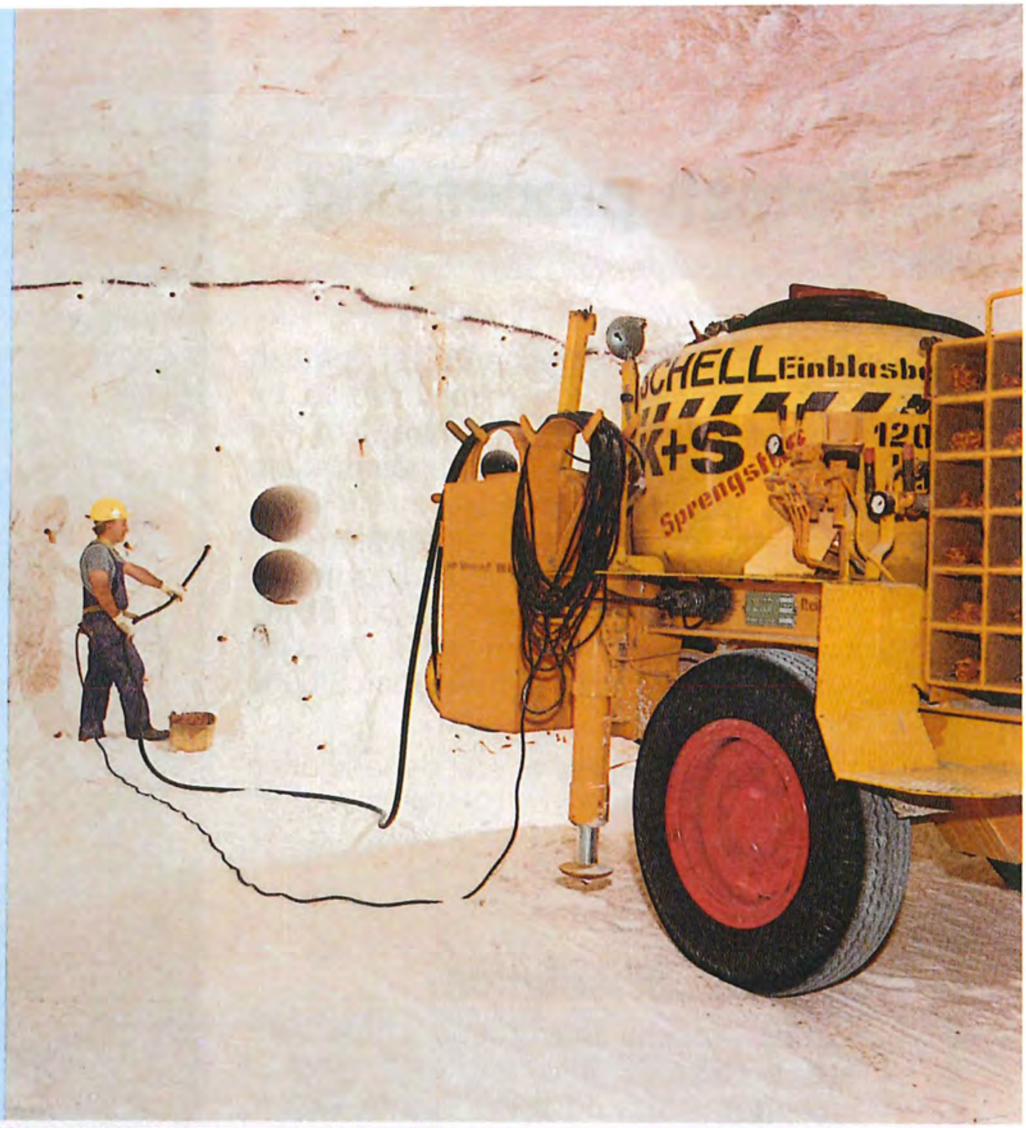
At the entries, box-hole-jumbos drill holes 7 m in lenght and 50 cm in diameter. Subsequently, many smaller blasting holes are drilled around them with automatic parallel setting to attain maximum efficiency of the explosives.

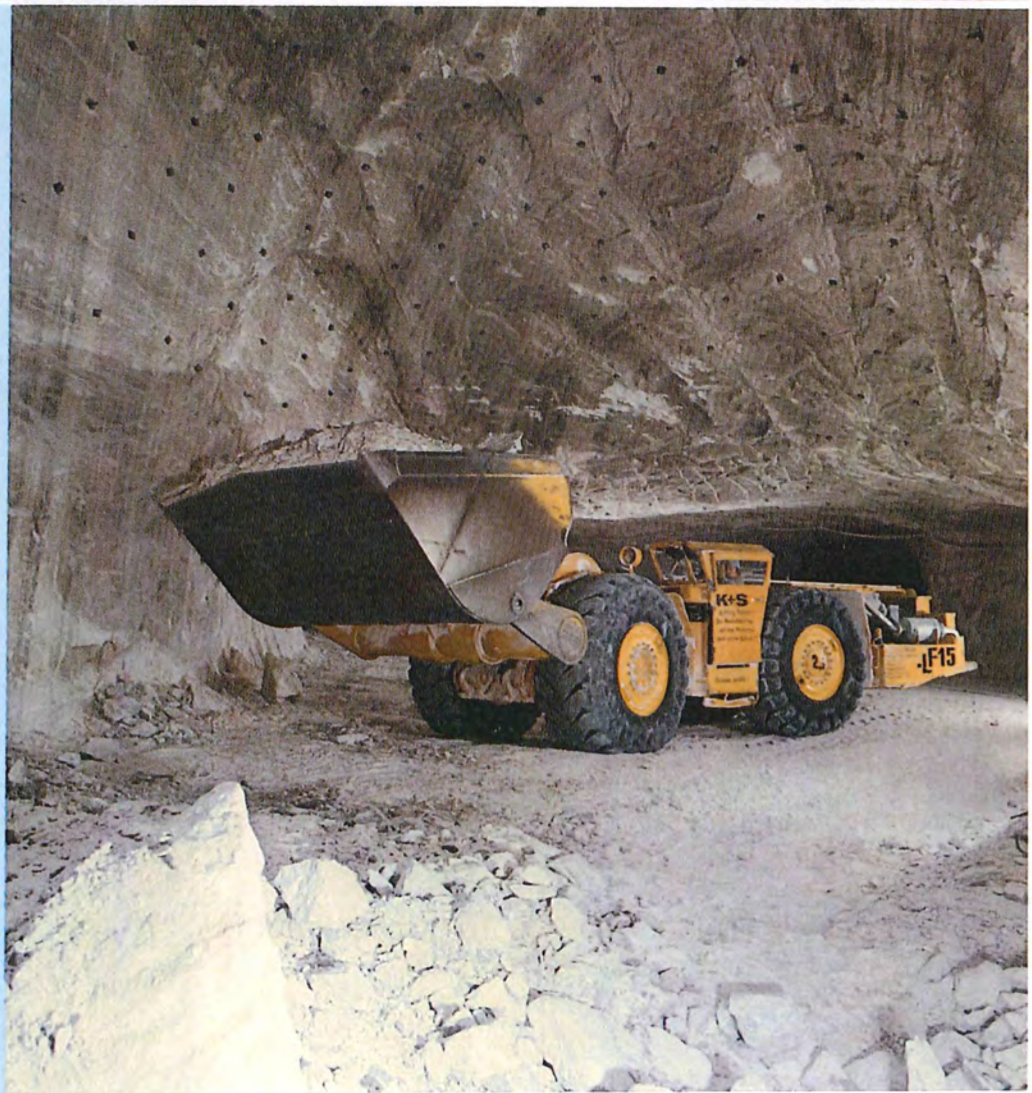
The total length of the blast holes drilled in one year is more than twice the diameter of the globe.

vertical and separated by large deposits of impure rock salt and other sediments.

Extraction is carried out by the bench mining method. Starting from below, horizontal tunnels about 100 m long are opened at vertical intervals of 20 m in the potash layer. The "benches" between the tunnels are then blasted. The raw ore falls into the funnels below, where it is crushed, fed to an underground hauling system for transport to the pit bottom, and hoisted to the refinery. With this method, huge caverns are formed which, for safety reasons, are refilled with residues from the refinery.

The blast holes are filled with explosives pneumatically





A front-end loader with air-conditioned operator cabin. The bucket capacity varies between 5 and 15 tons.

Potash processing

The different components of potash crude salts from the mine have to be separated to produce fertilizers of the required composition and concentration. This is accomplished in large refineries. Different techniques of separation and upgrading are applied depending on the nature of the raw material. Most of the K+S processing plants have a daily through-put capacity of more than 25,000 tons of crude ore.

The three principles of salt beneficiation used in Germany are briefly described as follows:

Thermal dissolution

In this process the ground crude salts are introduced into an NaCl (sodium chloride) saturated brine and heated to about 95°C. The KCl (potassium chloride) dissolves in this solution, whereas the NaCl and other constituents remain undissolved. The hot KCl rich brine is passed into vacuum coolers where the potassium chloride crystallizes. The so-called "mother liquor" is removed by filtration and centrifugation and recycled. For finishing, the potassium chloride slurry must be dried in rotary kilns.

Flotation

This process operates at normal temperature. The raw ore needs to be ground extremely fine in order to separate the KCl and NaCl crystals. These are then added to a salt-saturated solution which does not serve as solvent but as carrier liquid. A flotation agent (usually a few grams of amides per ton of crude salt) introduced into the brine forms a thin

Crystallization unit for the production of large, high-grade KCl crystals

In their natural state the crude potash bearing salts may display a variety of colours. These are caused by minute impurities, such as iron oxide or clay, which do not influence the effectiveness of potash and magnesium fertilizers in plant growth.

film on the KCl crystals. Bubbles of air injected at the bottom of the flotation cells stick to the film and lift the KCl crystals to the surface. There the KCl rich froth is skimmed off and dried in the same way as in the dissolution process.

Electrostatic beneficiation

This process has been developed and patented by the Production Technology Research Institute of K+S in Hannover.

It is a dry process in which the crude ore is neither dissolved nor suspended in a brine. It needs less energy and minimizes environmental problems. Various components of the finely ground raw minerals are separated by selective electric charging after being subjected to a specific conditioning. The negatively charged KCl and kieserite are deflected from the other positively charged components in a free-fall separator operating at a field strength of 4–5 kV/cm.

In a similar second step, yielding highly concentrated products, kieserite ($MgSO_4 \cdot H_2O$) is separated from potassium chloride (KCl).

K+S produces approx. 900,000 tons of potassium sulphate per year, about 30 % of the total world production, by using kieserite and potassium chloride:

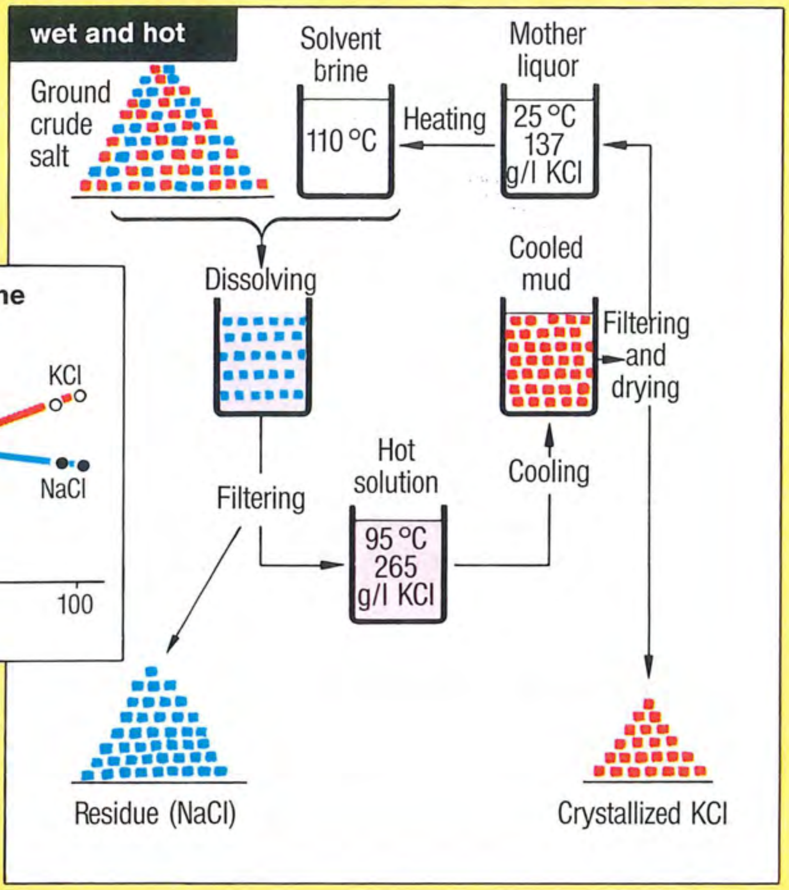
$$2\,MgSO_4 + 2\,KCl \rightarrow \boxed{K_2SO_4 \cdot MgSO_4} + MgCl_2$$

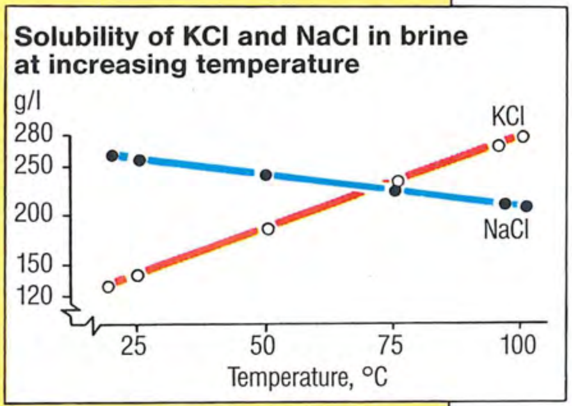
$$\boxed{K_2SO_4 \cdot MgSO_4} + 2\,KCl \rightarrow \boxed{2\,K_2SO_4} + MgCl_2$$

The final product compares favourably with the "converted" potassium sulphate obtained by reaction of KCl with sulphuric acid.

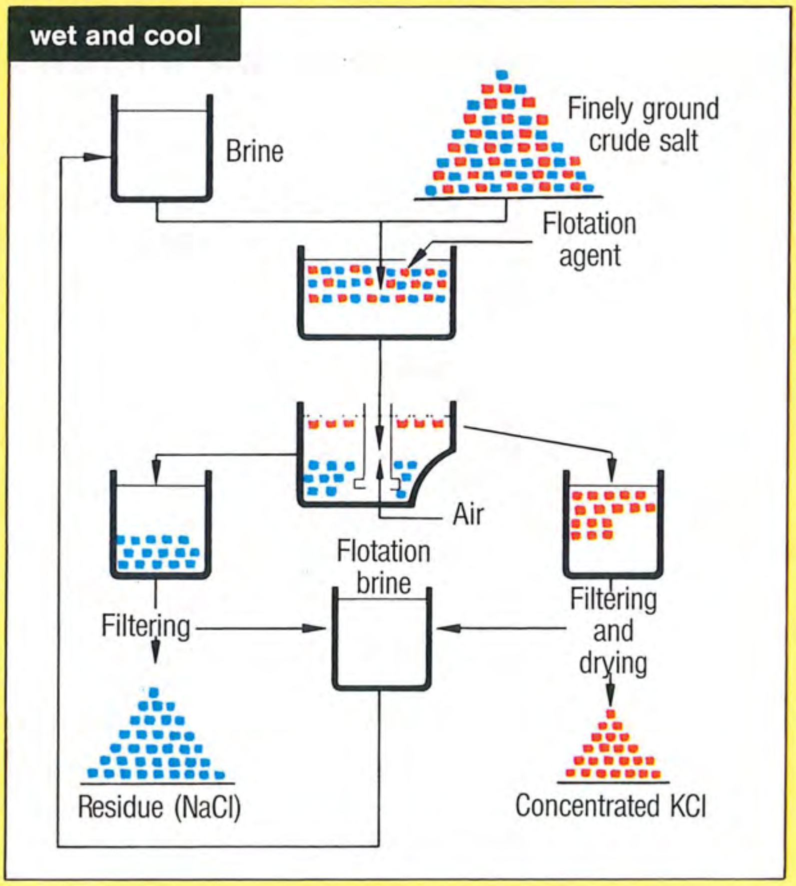
Principles of Potash Beneficiation

Dissolution

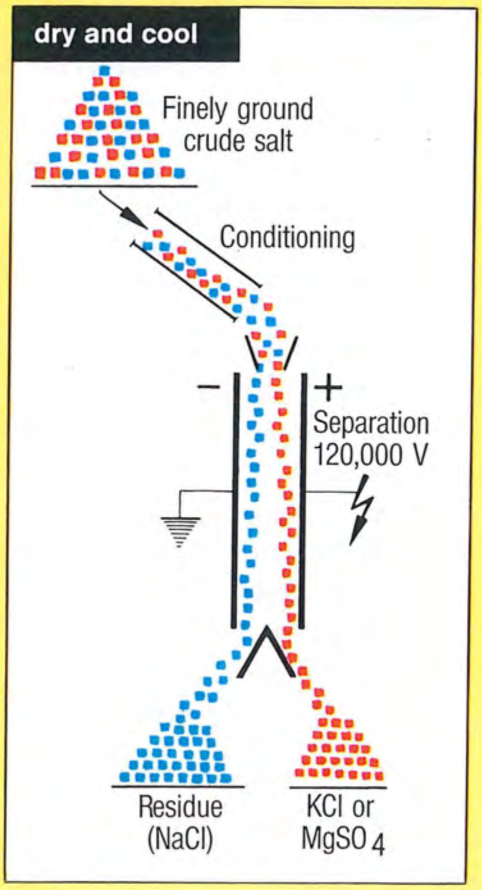




Flotation



Electrostatic



K+S Fertilizers

Potassium chloride

(muriate of potash), the potash fertilizer for almost all crops and soils. This product is available in different grades, with an average content of 40, 50 and 60 % K_2O. The 40 % grade, which contains 10–18 % Na_2O in addition to 40 % K_2O, is particularly recommended to cover the sodium requirements of sugar beet and other halophile plants, such as coconut palms.

Korn-Kali with magnesium

a potassium chloride with 40 % K_2O + 8 % Na_2O and a guaranteed content of 5 % MgO, which meets the high magnesium requirements of sugar and fodder beet, maize and other field crops receiving large amounts of N, P and K fertilizers.

Magnesia kainite

(12 % K_2O + 6 % MgO + 24 % Na_2O) for the specific needs of grazing animals. This fertilizer increases the magnesium and sodium content in the sward, improving the palatability of the herbage (higher forage intake reduces the need for concentrated feedstuffs).

K+S fertilizers containing sulphur should be the choice whenever and wherever:

- Soil sulphur is low
- Sulphur requirements of crops are high
- Chloride-sensitive crops are grown
- Very high rates of fertilizers are used
- Soil salinity is a problem
- Crop quality is a first consideration

Sulphate of potash

(potassium sulphate) with 50 % K_2O (+ 18 % S), for special crops, such as tobacco (see page 90), first-choice grapes, citrus, avocado and mango, as well as for fruits and vegetables for the canning industry (e.g. pineapples or peas).

Sulphate of potash magnesia (granulated)

(Patentkali) contains 30 % K_2O and 10 % MgO, both in form of sulphates (22 % S). This fertilizer is used mainly for crops sensitive to chloride and with high magnesium requirements, such as seed and starch potatoes, fruit, hops, first-grade vegetables, and for forest fertilization (coniferous trees).

Kieserite

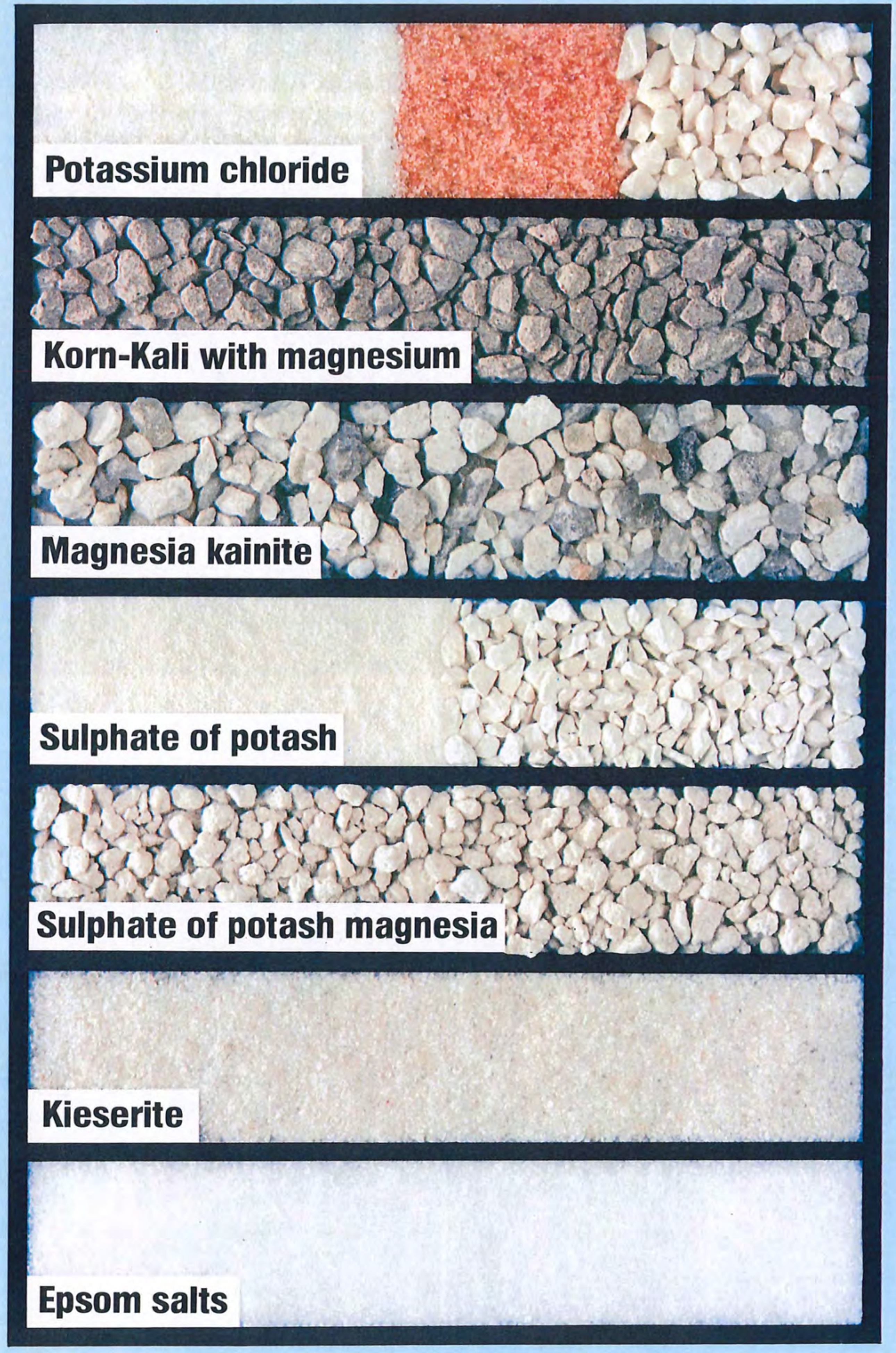
containing 82 % magnesium sulphate (equivalent to 27 % MgO and 22 % S), is a water-soluble magnesium fertilizer which is used both on intensively cropped soils in temperate zones and for some tropical crops, e.g. oil palm and rubber.

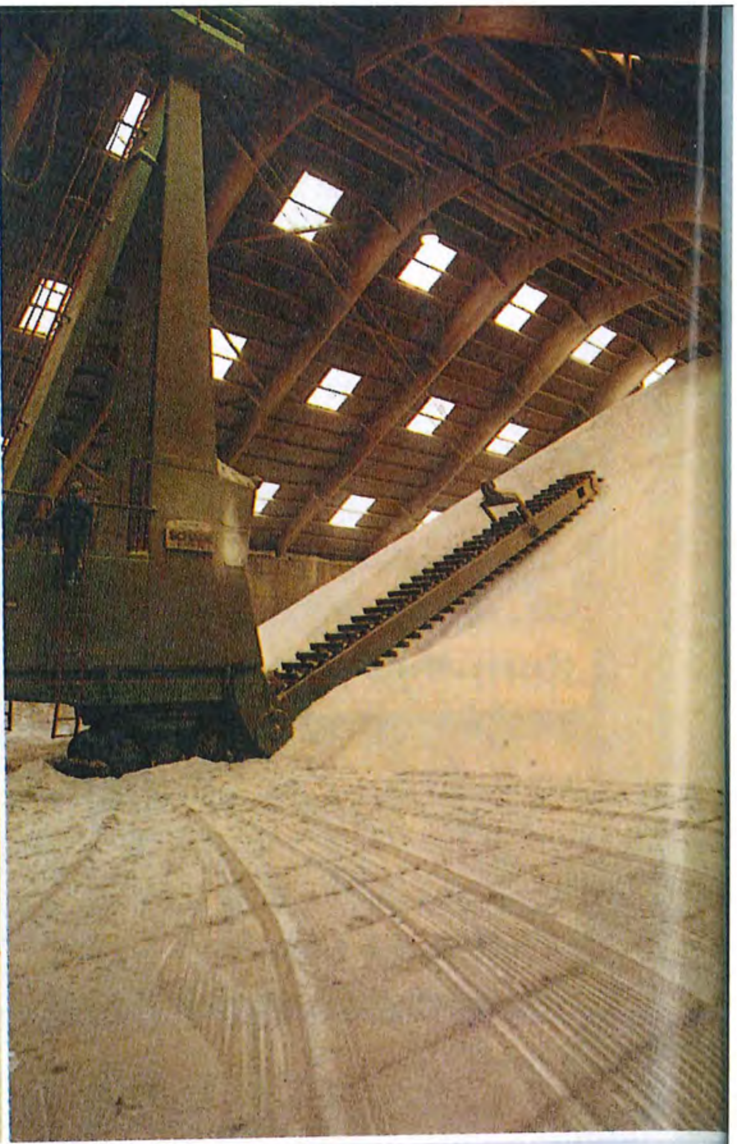
Epsom salts

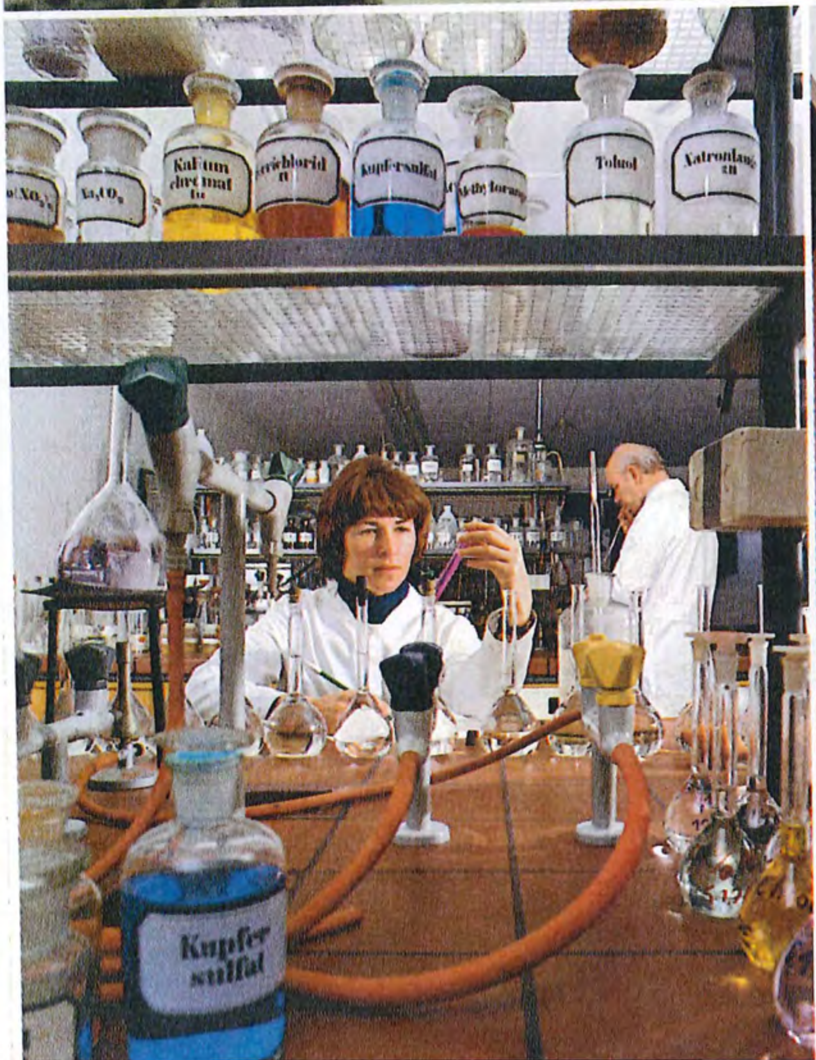
containing 16 % MgO + 13 % S, is immediately soluble in cold water and the product most widely used to correct Mg deficiencies by foliar sprays.

Magnesium sulphate anhydrous

(Calcined kieserite) containing 98 % $MgSO_4$, equivalent to 33 % MgO + 26.5 % S. This concentrated magnesium fertilizer is mainly used in the production of compound fertilizers and may offer savings in transportation costs.


Potassium chloride
Korn-Kali with magnesium
Magnesia kainite
Sulphate of potash
Sulphate of potash magnesia
Kieserite
Epsom salts




Kupfersulfat
Toluol
Kupfer-
sulfat

K+S owns modern fertilizer dock facilities at the port of Hamburg to ensure quick delivery to overseas customers, at a rate of up to 10,000 tons per day

Quality control, storage and shipping

The pictures on the opposite page show:

Upper left: All operations of a potash refinery are automatically monitored from a central control room. The potash content is checked by measuring the naturally occuring isotope ^{40}K.

Lower left: Each fertilizer consignment leaving a German potash refinery is officially checked by independent certified samplers who carry out more than 280,000 analyses per year. Each sample is kept for at least 6 months as a warranty for the guaranteed nutrient content and the physical properties of each shipment.

Upper right: Each refinery specializes in the production of only a few grades of fertilizers, and due to the large storage facilities, K+S can easily meet the varying demands for all grades of potash and magnesium products required by the manufacturers of mixed and compound fertilizers, as well as farmers who need straight material for direct application. In order to ensure quick delivery during peak demand in autumn and spring with special consideration given to export orders, the warehouses can hold up to 100,000 tons of product.

Lower right: More than 150,000 railway cars leave the K+S potash mines and refineries per year. The relatively close network of Central European waterways helps to reduce transport costs. K+S mines are connected to or have nearby bargeloading installations.

K+S Headquarters in Kassel and facilities in Hannover

Kali und Salz AG has its head office in Kassel, one of the principal towns in Hessen and close to the geographic center of the Federal Republic of Germany. The company is functionally structured. There are various divisions, each under the responsibility of a board member. Three divisions are of particular interest in this context: Mining, production and marketing. Mining and production have departments for geology, technology, planning and construction, research and development. Feasibility studies on new potash deposits around the world are offered by the Kali und Salz Consulting GmbH/Kassel. The marketing division has sales departments for each product group: potash fertilizers, rock salt (table, trade, industrial and deicing salts) and chemicals (including magnesium sulphate, magnesium chloride and bromine). The agricultural extension service for the Federal Republic of Germany and Europe is also attached to the marketing division as are the staff groups for planning, market research and advertising. There are 11 branch offices of the agricultural extension service in the Federal Republic of Germany (see map, p. 8).

Kali und Salz AG **K+S**

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In the home market, K+S fertilizers are sold direct to dealers, cooperatives and complex fertilizer manufacturers. In the European Economic Community deliveries are made to importers in the respective countries. All magnesium fertilizers, salts and chemicals are sold from Kassel, whereas most of the overseas exports of potash fertilizers are handled by:

Kali-Export Gesellschaft mbH Wien
Potash-Export Company · Vienna
Linke Wienzeile 236 · P.O. Box 8
A-1153 Wien/Austria
Phone: 8316360 · Telex: 136141 a POTA A
Cables: Potassium Wien

While commercial market research is done at the head office in Kassel, technological and agricultural research is concentrated in Hannover.

Production Technology Research Institute

Besides research and development laboratories at individual mines, the potash industry of the Federal Republic of Germany maintains a research institute for production technology in Hannover.

Among other projects, research scientists at the institute are engaged in continuous efforts to improve the technical quality of all of its products and to develop new methods for more effective and economic production of fertilizers.

Büntehof Agricultural Research Station

The German potash industry has a long tradition of agricultural research. It started around the turn of the century when a department of Agricultural Chemistry was established which later grew into the experiment station Berlin-Lichterfelde. After World War II research activities were resumed in 1956 with the inauguration of the Büntehof Research Station in the outskirts of Hannover. The Büntehof and its team of scientists have established their own reputation. There is hardly another institute in the world where all the aspects of potassium availability in the soil and the role of potassium in plant physiology and yield formation are studied in such detail. The work is not confined to potassium, it includes magnesium, sulphur, sodium, chlorine and their interactions with other plant nutrients.

The Büntehof is an institute where basic research in several agricultural disciplines, sponsored by K+S – a private enterprise –, is carried out to obtain better insight into plant nutrition for the benefit of agriculture all over the world. A per-

manent staff of 50, including 20 scientists, belong to the Büntehof research team. They specialize in soil science, agricultural chemistry, plant physiology, biochemistry, microbiology, tropical agriculture and documentation. Several of them are visiting scientists from foreign countries.

All the results of Büntehof research are made available freely through papers at scientific congresses and by publication in leading scientific and agricultural journals. Summaries are obtainable in the form of the "Büntehof Abstracts", a biennial publication.

In addition numerous results of Büntehof research as well as other scientific and practical findings in fertilizer use obtained elsewhere are regularly published in English, French, German and Spanish and widely distributed over all continents by the

International Potash Institute (IPI),
P. O. Box 121, CH-3048 Worblaufen-Bern, Switzerland.

As an IPI member, K+S is involved in agricultural missions which the Institute maintains in a number of important countries, such as Brazil, Japan, the Republic of Korea, Singapore (for the South East Asian region), the Republic of South Africa and countries of the Mediterranean area. The first four jointly with the Potash & Phosphate Institute, Atlanta-GA, USA.

The "Büntehof", a research institute of K+S

1. Plant physiology
2. Microbiology
3. Isotope laboratory
4. Open air mini plots
5. Soil science
6. Plant nutrition
7. Glasshouses
8. Workshop

Electro-ultrafiltration (EUF)
A visiting scientist from China studying a new method of soil analysis

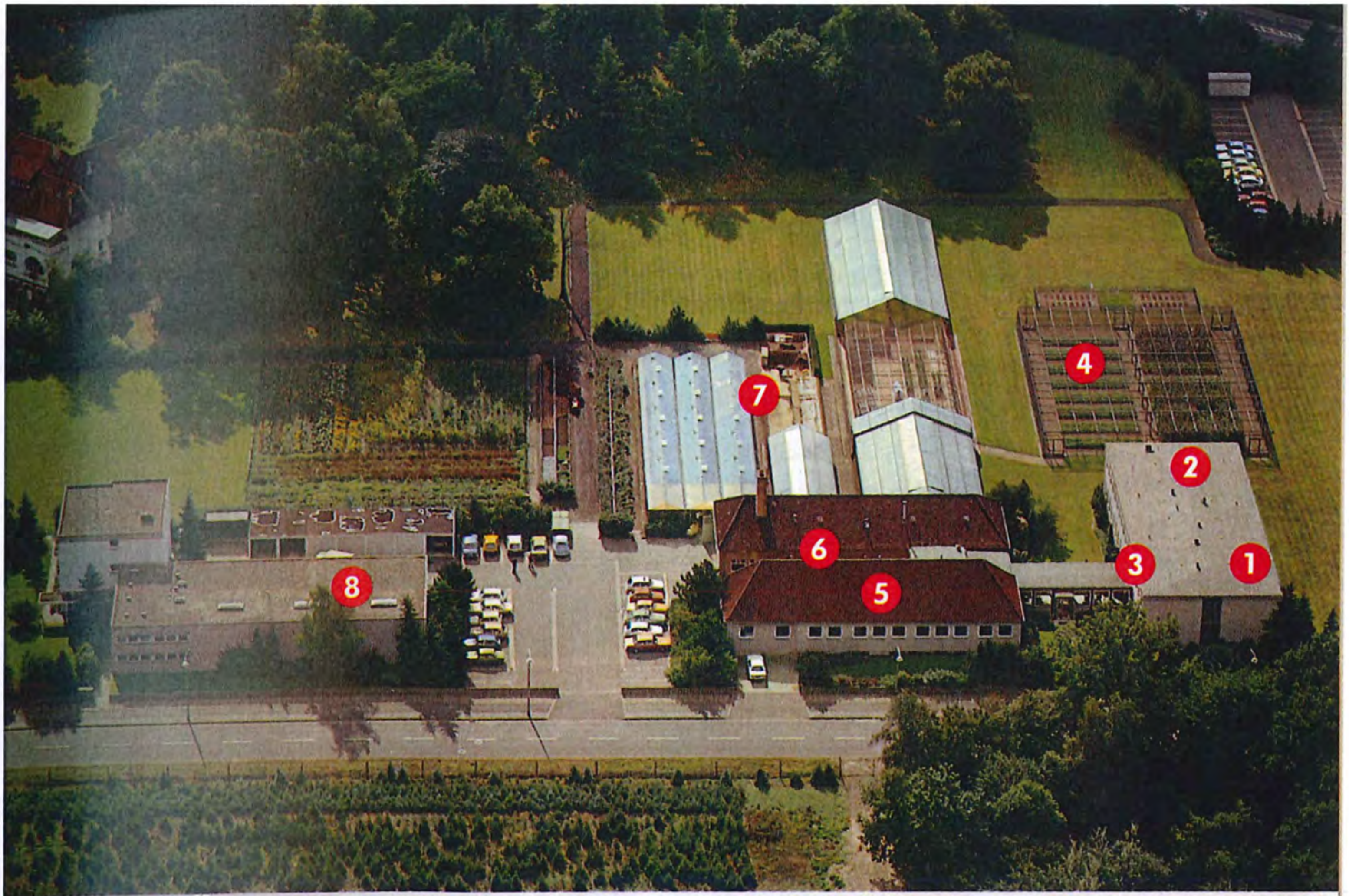
Glasshouse pot experiments
Plant nutrition specialists from Japan, Egypt and Turkey inspecting sugar beet experiments

Atomic absorption spectrophotometer (AAS)
Nutrient elements in soil and plant samples are quickly determined

High pressure liquid chromatograph (HPLC)
All kinds of sugars, amino acids and proteins can be accurately measured

Open air mini plots
Sweet sorghum, a promising bioenergy resource. Note retarded panicle development caused by "hidden" potash deficiency in the plants on the left side of the picture.

^{15}N analyser
Potash exerts a strong and positive effect on the nitrogen metabolism in plants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2
3
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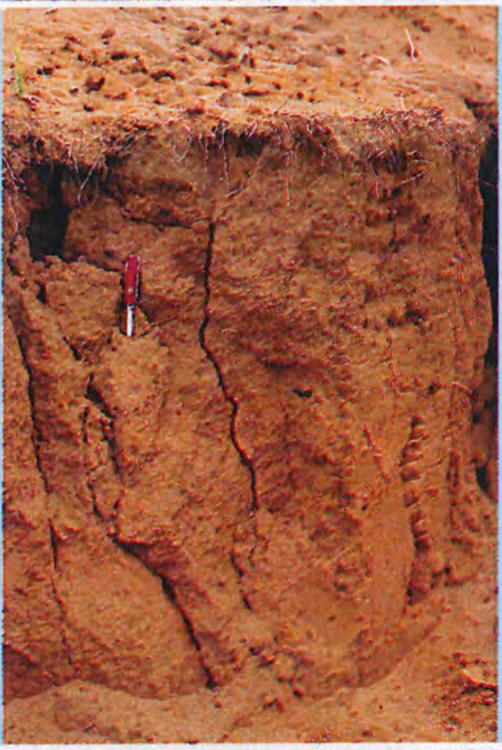
8

Luvisol/Alfisol
Loess
GERMANY
Temperate humid climate, illitic clay and fertilization ensure high yields
Soil-K-Reserves and K-Availability: High

Podsol/ Spodosol
Pleistocene san
GERMANY
Not cultivable without organic and mineral fertilization
Soil-K-Reserves
Low
K-Availability:
Low

Arenosol/ Entisol
Holocene sand
INDIA
Lack of organic matter causes frequent sulphur deficiency
Soil-K-Reserves:
Low
K-Availability:
Low
(under Irrigation: Medium)



Acrisol/ Ultisol
Tertiary sediments
NIGERIA
A tropical rainforest soil without nutrient reserves due to kaolinitic clay minerals
Soil-K-Reserves
Very low
K-Availability:
Low

Acrisol/Ultisol
Weathered granite
PHILIPPINES
Tropical rainfall makes good perennial crops possible with adequate fertilizers.
Soil-K-Reserves:
Very low
K-Availability:
Very low

Ferralsol/ Oxisol
Weathered bas
BRASIL
A well structure "Terra rossa", high in clay, but low in nutrient reserves, sensitive to mechanisation
Soli-K-Reserves
Low
K-Availability:
Low

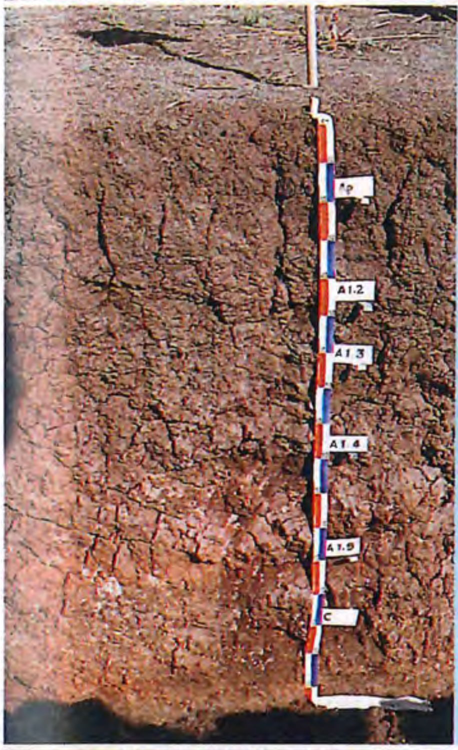
Chernozem / Mollisol

Loess

USSR

Highest potential fertility, a "black earth" (sometimes limited by climatic conditions)

Soil-K-Reserves: Very high
K-Availability: High



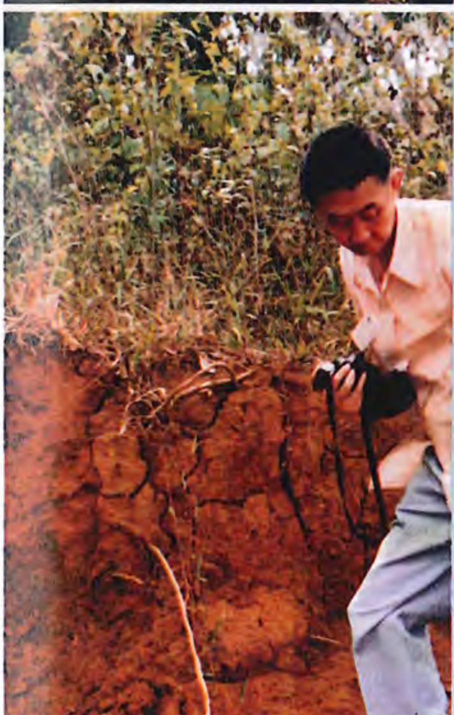
Vertisol

Weathered basalt

INDIA

Smectitic clay allows high nutrient content, but semiarid conditions limit availability

Soil-K-Reserves: Very high
K-Availability: Medium



Ferralsol / Oxisol

Weathered sandstone

MALAYSIA

Acid and poor. Al-toxicity. Not usable without P, N, K and Mg nutrition

Soil-K-Reserves: Very low
K-Availability: Very low

A short summary of the results of recent studies carried out at the Büntehof Research Station is given on the following pages.

Availability of potassium in the soil

Optimum plant growth can only be assured if all the essential nutrients are available to the plant in the course of the vegetation period. The availability of potassium (K) which is needed in large amounts depends on various factors. Some of them are discussed on the following pages.

In the soil, four fractions of potassium are usually distinguished:

① K as component of soil minerals
② Fixed (or non-exchangeable) K
③ Exchangeable K (mainly the fraction extracted with ammonium acetate)
④ K in the soil solution (water soluble K)

Fractions ③ and ④ are often called "available" K as they provide an easily accessible source of potassium for the plant root. However, only 1 to 4 % of total soil K is present in exchangeable form, and the amount of soil solution potassium again is only small relative to the exchangeable K fraction. Yet the soil solution is the medium from which the potassium is taken up by the plant roots [35].

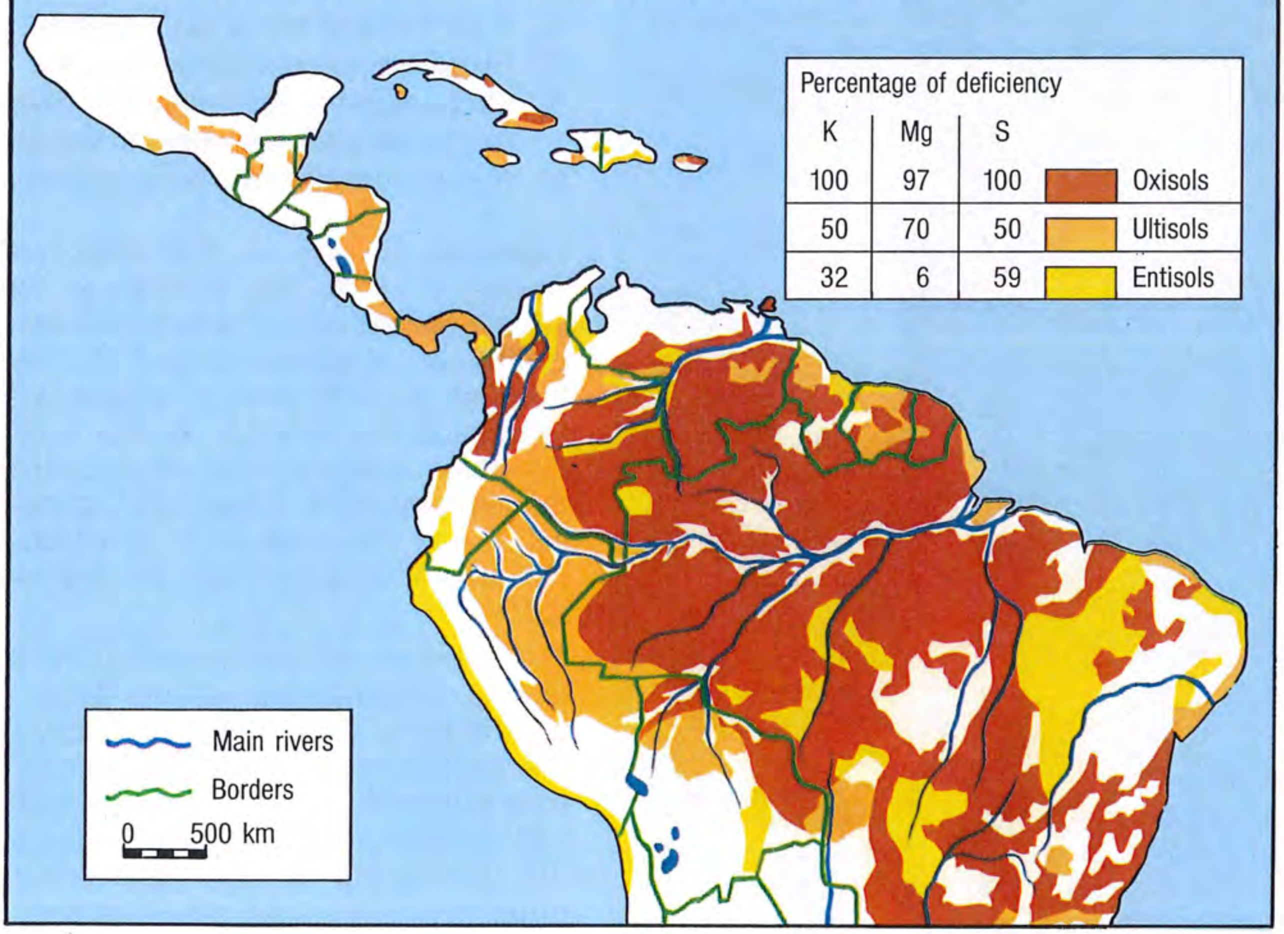
The fixed or non-exchangeable K, fraction ②, constitutes a reserve which can contribute to the nutrition of plants after the exchangeable fraction is exhausted to a minimum level. Potassium of fraction ① will become available only after the weathering of the respective minerals, normally a very slow process.

K availability as related to climate and soil type

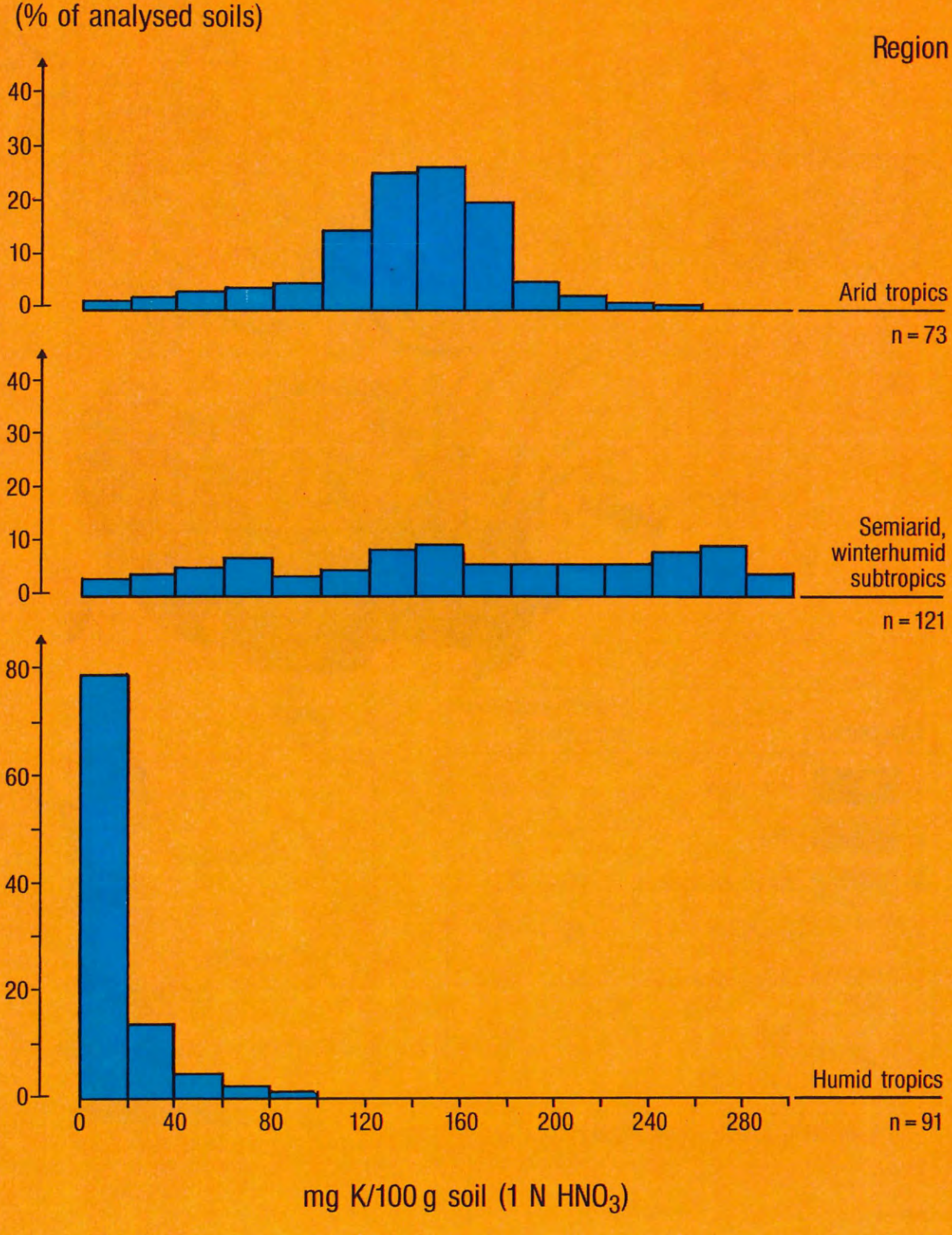
In the tropics more soils are poor in plant available potassium than in temperate regions, notably in the humid tropics in consequence of intensive leaching of nutrients, see figure [95].
For tropical Latin America the proportion of K deficient soils is estimated to be 53 % [113].

Many of these soils are also deficient in magnesium and sulphur, as can be seen on the map. The situation is similar in the humid and subhumid tropics of Africa and Asia. In China the soils with very low and low natural K supply extend across the Southern (tropical) zones of the country, see map page 30. [61].

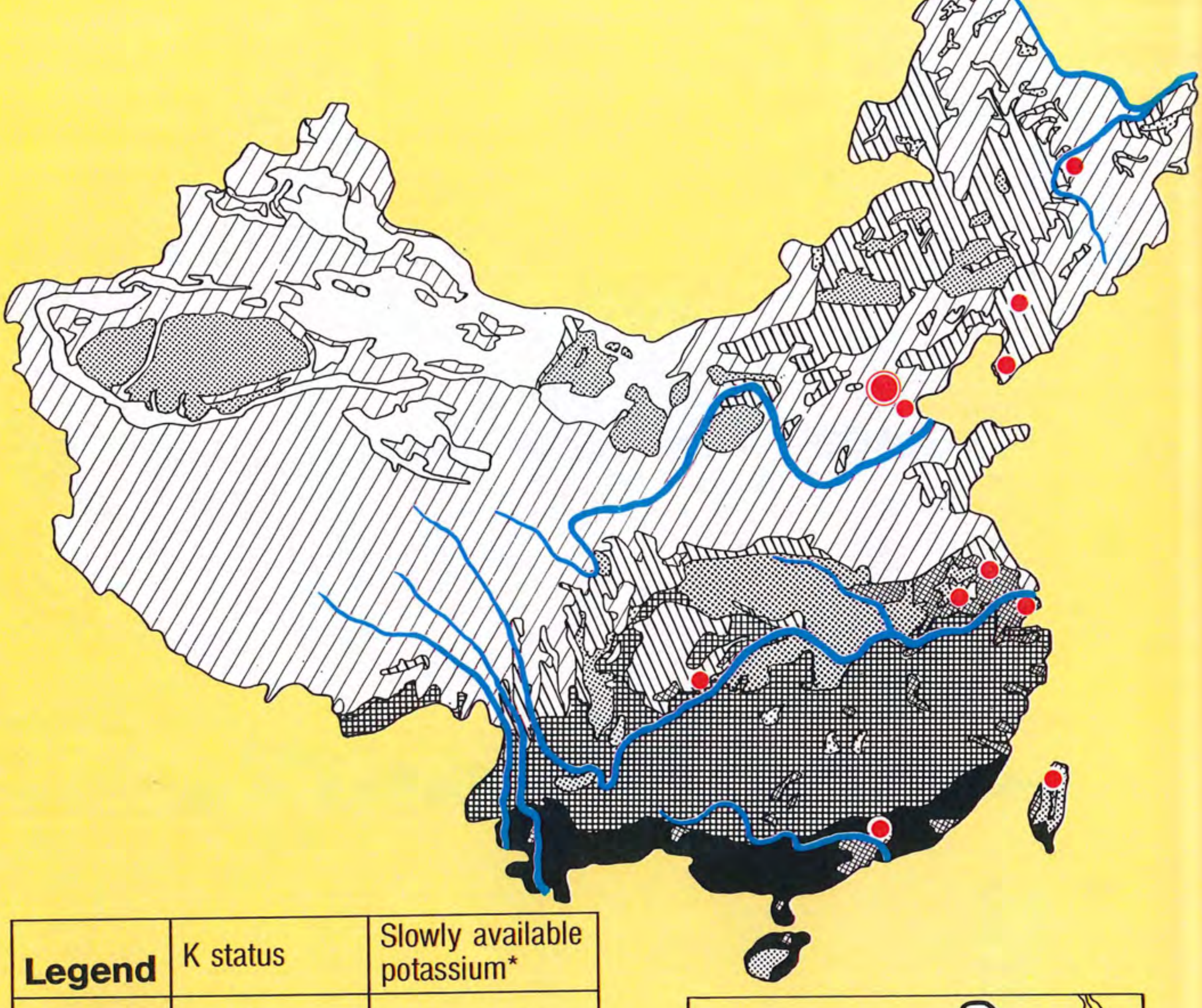
Areas of K, Mg and S deficiencies in tropical America



The average content of non-exchangeable K in tropical and subtropical soils as influenced by climate (rainfall)

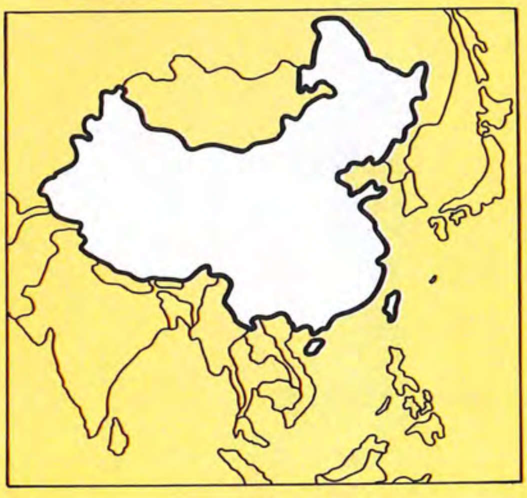


Potassium supply status of the soils of China



Legend	K status	Slowly available potassium*
1 (black)	very low	< 8
2 (grid)	low	8 – 20
3 (cross-hatched)	medium-low	20 – 40
4 (dotted)	medium	40 – 60
5 (backslash hatched)	medium-high	60 – 90
6 (slash hatched)	high	90 – 140
7 (white)	very high	>140

* mg K_2O/100 g, soluble in boiling N HNO_3



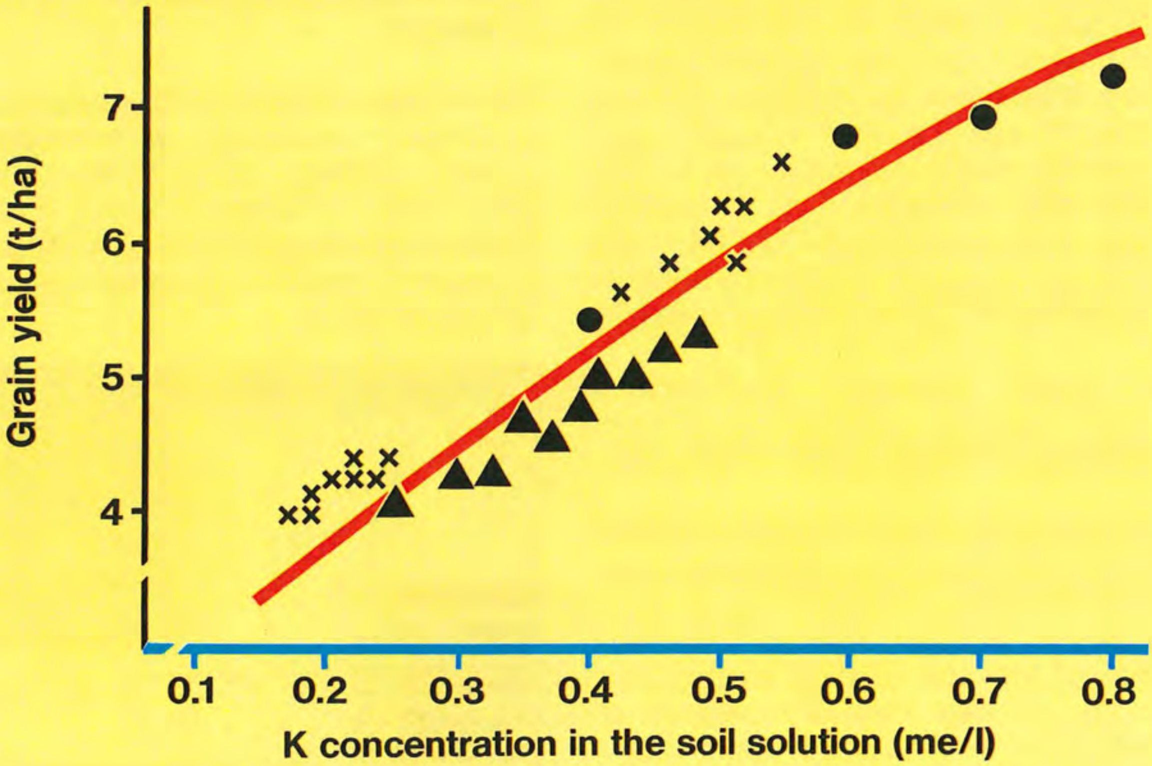
K availability as related to soil texture and clay mineral composition

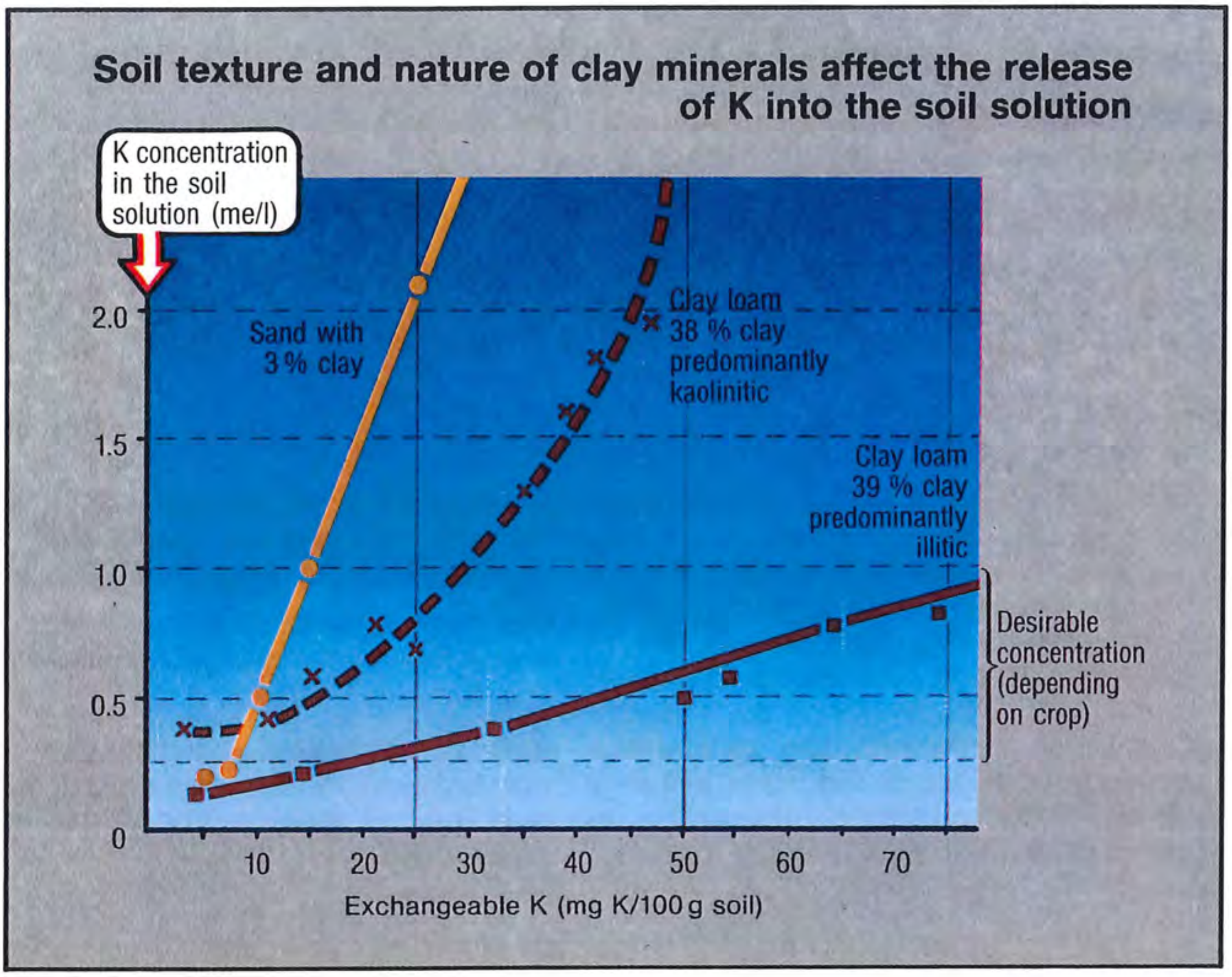
Soil test values (such as of exchangeable K) often do not correlate well with yields or with results of fertilizer experiments. This may be due to many reasons, e. g. different clay contents or different clay minerals in the respective soils. Since nutrients are taken up from the soil solution through the root, more nutrients can reach the roots within a given time if the concentration of the soil solution is high. The relation between wheat yield and K concentration in the soil solution, found in a sample survey of German farms, is shown in the figure (89).

Soil solution concentration is not simply a function of exchangeable potassium. Usually:

a) At the same level of exchangeable K, clay soils show low concentrations of K in the soil solution, sandy soils high concentrations.

Wheat yield and K concentration in the soil solution
(Results of field trials on different loess soils)



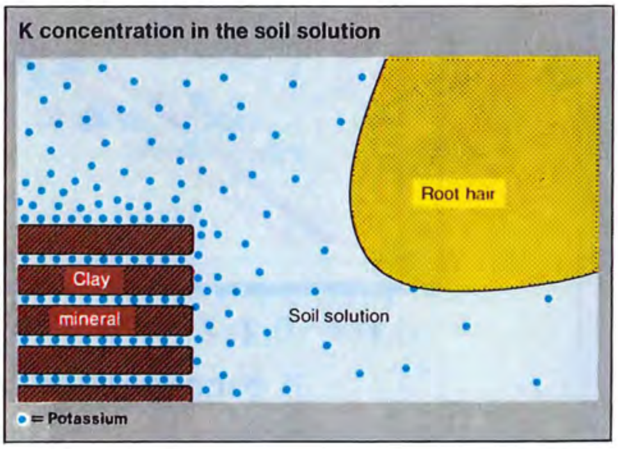


b) At same clay content the soil solution concentration will depend on the type of clay. Illitic clay minerals and particularly vermiculite adsorb K selectively, resulting in a lower soil solution concentration. Kaolinitic clay minerals, as found in Oxisols, and soil organic matter have no specific binding sites for K. In soils where they dominate, the K concentration of the soil solution will be higher but not as high as in sandy soils because of their higher water holding capacity.

The graph illustrates the change of soil solution concentration with increasing exchangeable K in three soils.

When applying equal amounts of fertilizer, (e.g. to raise the levels of exchangeable K from 10 to 15 mg/100 g) the sandy soil shows a steep rise in K concentration of the soil solution as the small amounts of clay minerals present are quickly saturated. In the heavy soil with 39 % clay the soil solution concentration of K may be scarcely changed at all because of its high content of illitic clay minerals, which readily adsorb the added potassium.

The soil with predominantly kaolinitic clay, an Oxisol, represents an intermediate position. Despite being a "heavy" soil (38 % clay), it releases K into the soil solution almost as readily as a sandy soil because of the low K holding capacity of its clay minerals.



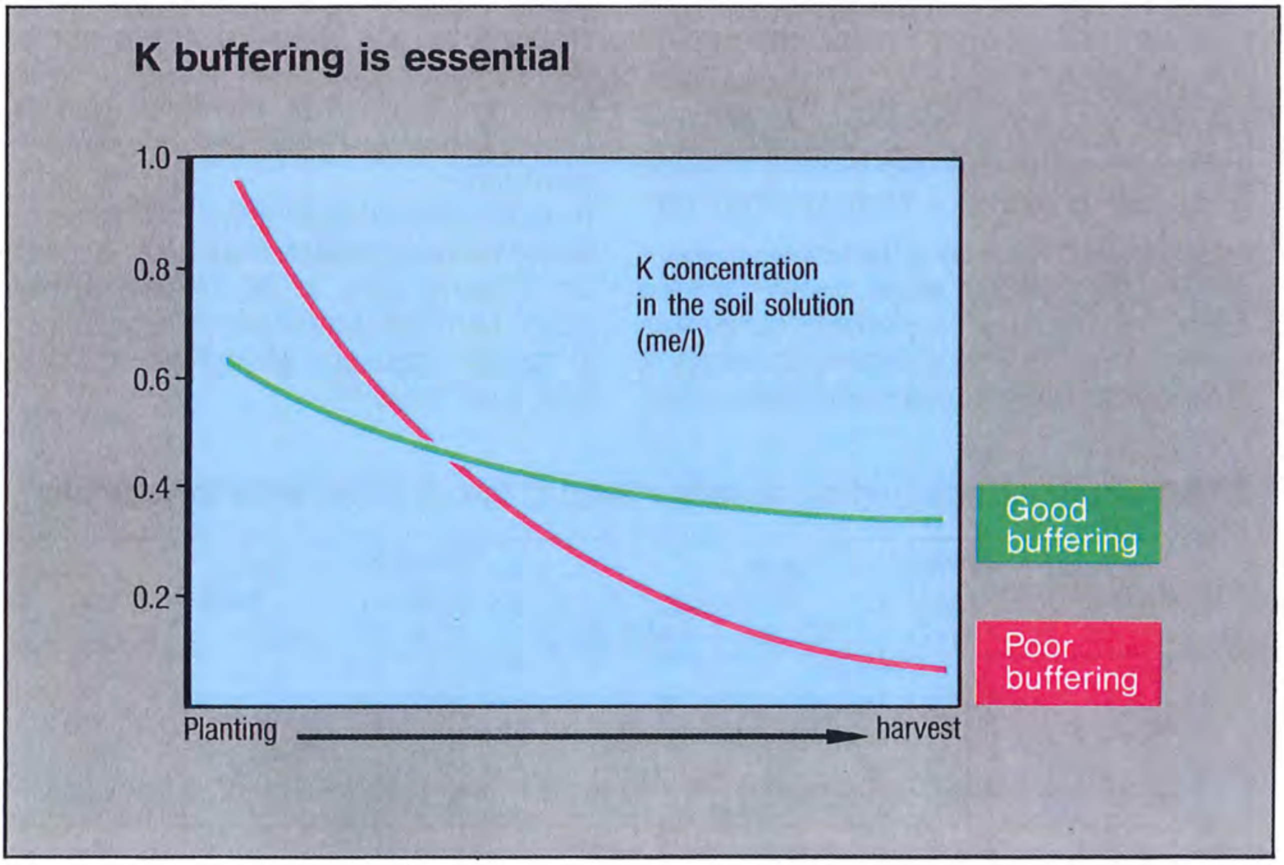
K buffering, release of non-exchangeable K and K fixation

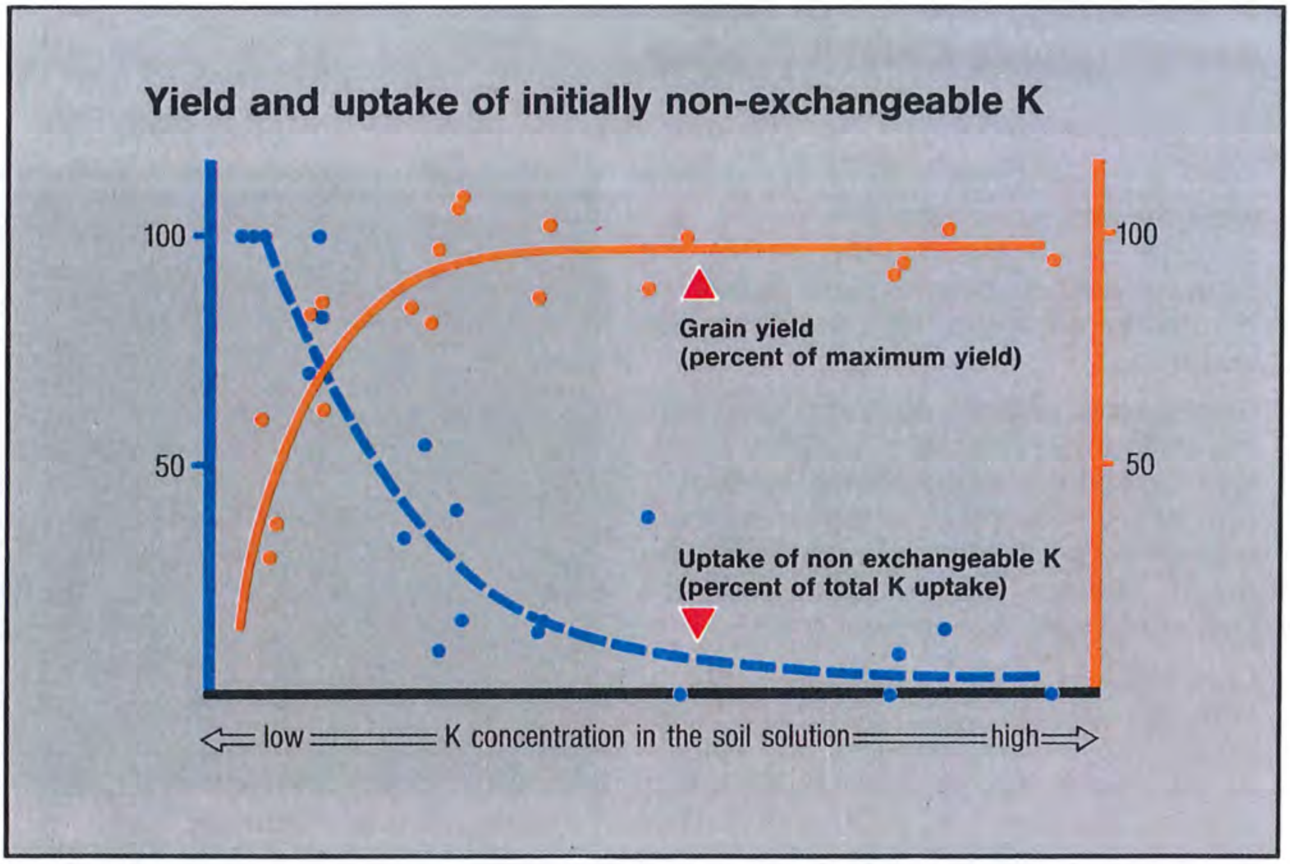
For crop production it is of importance whether the concentration of the soil solution decreases rapidly during the growing season due to plant uptake or is maintained at a fair level = well buffered.

Sandy soils, organic soils and soils with kaolinitic clay minerals show poor potassium buffering and may need repeated K fertilizer dressings or a higher initial K concentration in order to ensure an adequate nutrient supply throughout the period of vegetative growth.

Clay soils containing vermiculite, illite or smectite possess a high potassium buffer power. They can maintain the soil solution concentration at a similar level for a long time as illustrated in the figure [11]. The soil solution potassium may be replenished from exchangeable and non-exchangeable K sources. At the time of fast vegetative growth when the trans-

Close-up of an expanded clay mineral with high K-fixing capacity in its interlayers (approx. magnification × 10,000)





port rate from the adjacent soil is not sufficient to meet the uptake requirements of the plant, non-exchangeable K from the soil in the immediate vicinity of the root can be a source of potassium [36].

In most cases, however, the rate at which K is set free from the reserves of non-exchangeable K into the soil solution is too low to sustain a high-yielding crop.

Experiments with 18 different soils have shown that yields were lowest where plants had to rely on non-exchangeable reserves for their K nutrition [37]. When K fertilization is insufficient and plants must rely on the release of non-exchangeable potassium, K is removed from the interior of the clay minerals (the interlattice positions). Such K-depleted minerals are strong sinks for soluble potassium. Thus, subsequent potash fertilizer dressings first of all replenish the clay minerals and are only partly available to plant roots.

To overcome such fixation of fertilizer K, heavy rates of potash may be necessary. On K-fixing soils in Southern Germany maize showed significant yield responses to potash dressings as high as 900 kg/ha K_2O. See Table [15].

Effect of potash application on maize yield at two K-fixing sites in Germany

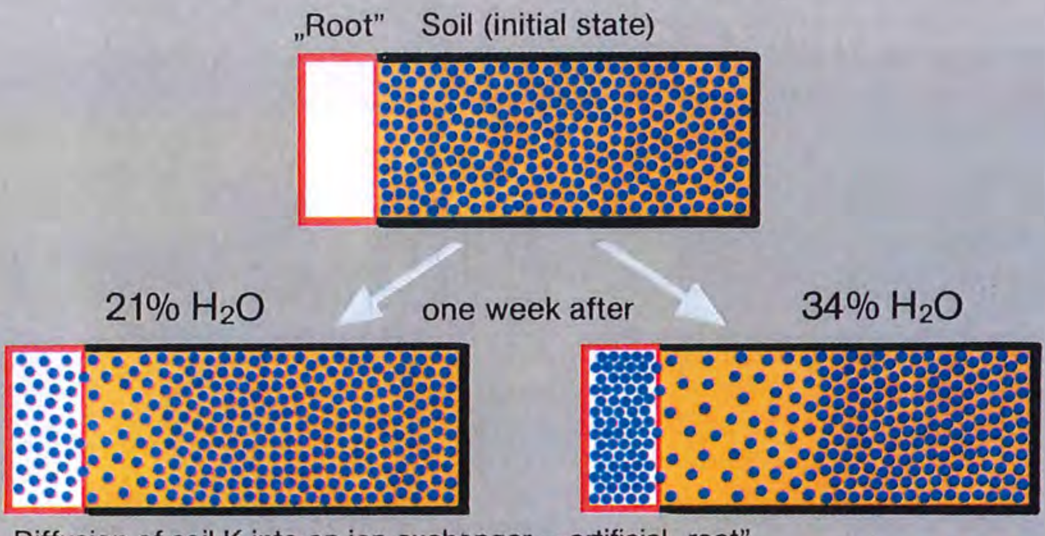
kg K_2O/ha	Dornwag* Yield t/ha	1973 Response to K kg/ha	Response to K kg/kg K_2O	Weng** Yield t/ha	1972 Response to K kg/ha	Response to K kg/kg K_2O
0	2.48	—	—	5.34	—	—
300	3.88	1,400	4.7	5.63	290	1.0
600	5.04	2,560	4.3	8.66	3,320	5.5
900	5.48	3,000	3.3	9.37	4,030	4.5

*,** 4 and 7.7 mg exch. K/100 g soil, respectively

K availability as related to soil moisture

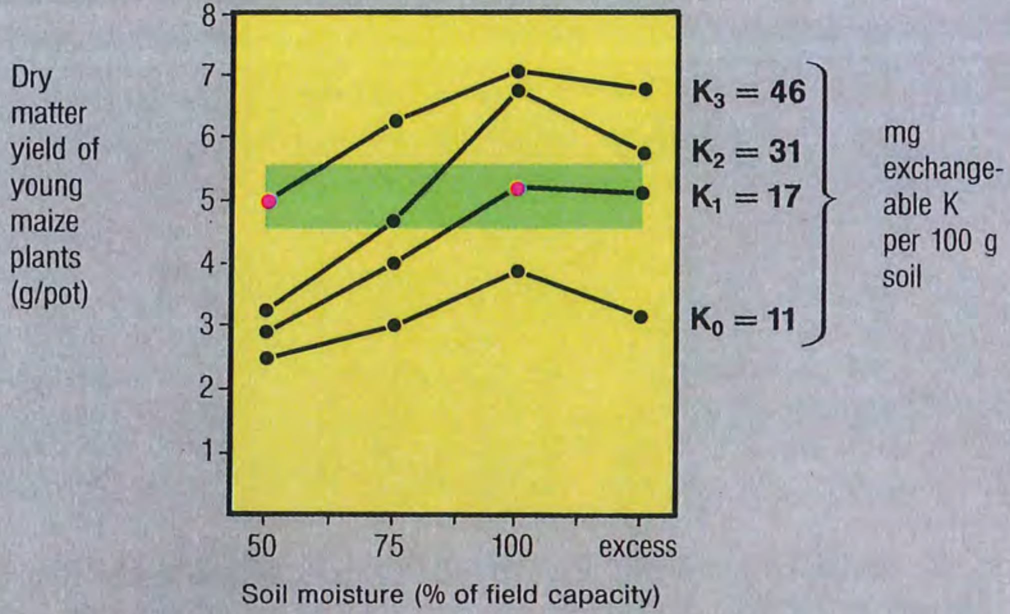
Most ot the potassium needed by the plant is transported to the roots in the soil solution. This transport occurs by mass flow (with the water moving to the plant root) and by diffusion along a concentration gradient caused by the absorbing root. Diffusion is strongly influenced by soil moisture, as confirmed in laboratory experiments at the Büntehof where K diffusion took place from the soil into an ion exchanger (= artificial root). In moist soils, the diffusion rate and potassium depletion were higher and the distance of potassium movement longer than in drier soils [35]. At an equal level of exchangeable K, therefore, the effective availability of potassium is higher at optimum soil moisture.

Good soil moisture · High diffusion rate · Increased availability



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

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

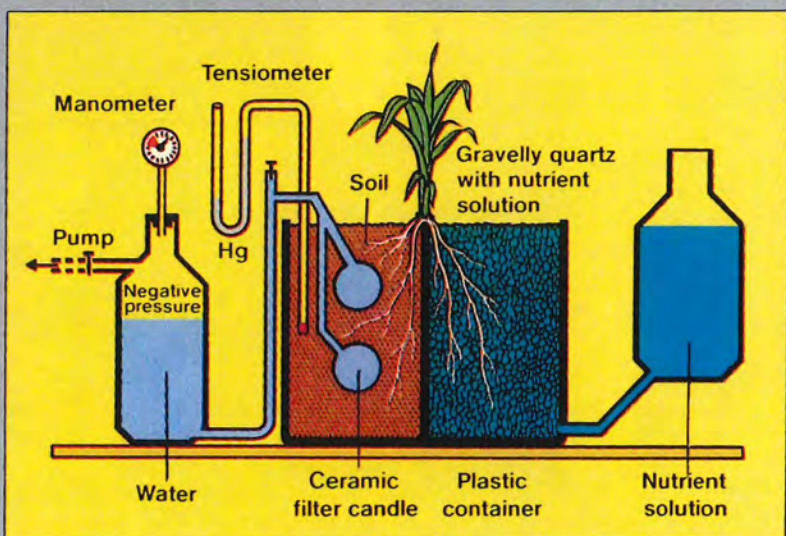


Restricted nutrient availability due to unfavourable soil moisture conditions can be compensated to a certain extent by improving the K status of the soil, e.g. by fertilizer application. This was confirmed in growth chamber studies with split root technique [11a] and in long-term field experiments.

An ample supply of potassium is of particular importance in dry periods of short duration when nutrient transport in the soil is reduced while plants do not yet suffer from water shortage [82].

In a wet soil, additional potassium helps to counterbalance the diminished capacity of the roots for active nutrient uptake, caused by poor aeration, and to reduce unfavourable reduction processes in the soil.

Experimental design of the "split root" technique



K in plant physiology and yield formation

It has been long known that potassium is needed by the plant in large quantities for the production of high yields and improved crop quality. But the essential functions of K in the complicated physiological processes in plant metabolism are difficult to unravel in detail.

In contrast to many other essential elements, K is not a firm constituent of organic compounds. It is present in all plant organs and cells, where it is of utmost importance for the osmotic and turgor pressure and accordingly the size of the cell. Potassium is very mobile in the plant. This high mobility and the participation of K in the activation of numerous important enzyme reactions are significant properties of this element.

K promotes photosynthesis

Potassium is important in photosynthesis, the basic process in plant production by which the energy from sunlight is converted to organic matter (chemical energy). Leaves with a high potassium content (4–5 %) show about a 50–70 % higher energy yield as compared to leaves with a low potassium content (1–2 %). Büntehof investigations were concerned with the synthesis of adenosine triphosphate (ATP), the major compound involved in the energy transfer [102].

Influence of potassium on ATP synthesis in chloroplasts

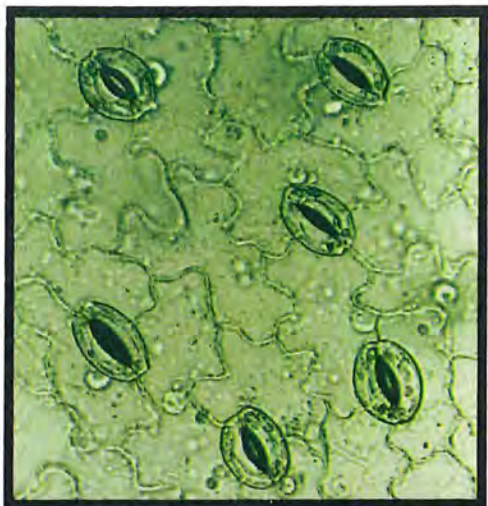
Plant species	% K in dry matter	µmoles ATP per mg chlorophyll/hour
Broad bean *(Vicia faba* L.*)*	3.70 1.00	216 143
Spinach *(Spinacea oleracea* L.*)*	5.53 1.14	295 185
Sunflower *(Helianthus annuus* L.*)*	4.70 1.60	102 68

K controls stomatal opening

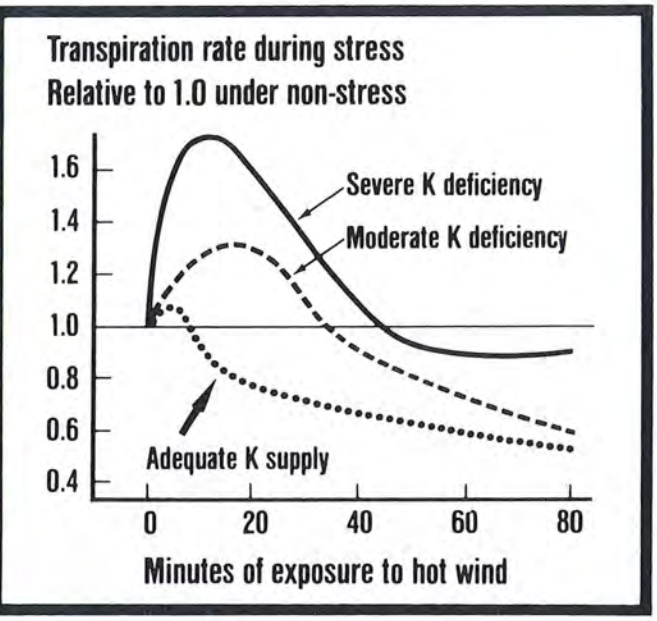
The carbon dioxide (CO_2) needed for photosynthesis is mainly taken up through the stomata, tiny pores on the lower side of the leaves. They open in daylight and close at night. The opening of the stomata is due to the swelling of so-called guard cells. Their high turgor is brought about by accumulation of potassium. Electron probe analysis has shown that the K concentration in the guard cells of open stomata is very high as compared to guard cells with stomata closed [49].

The beneficial effect of K is not restricted to the control of the stomatal mechanism. Abundant K supply also leads to an increase in the number of stomata per leaf surface [9]. A greater number of stomata results in higher gas exchange, increased uptake of carbon dioxide and ultimately in a higher photosynthetic activity of the plant.

Potassium strengthens plants against drought



Stomata (plant leaf pores)
natural size 0.055 mm

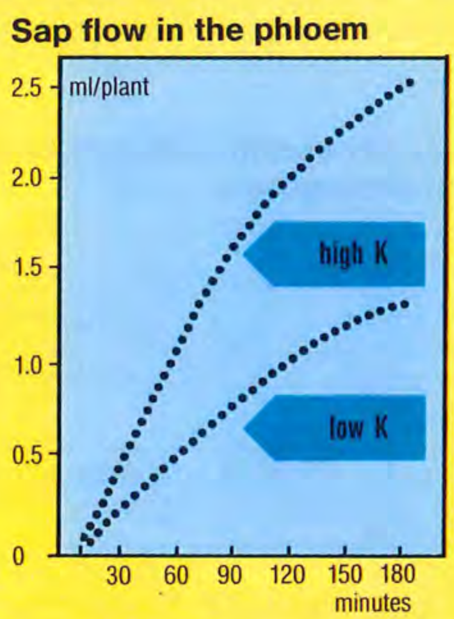


Experiments carried out at the Montana State University/USA have revealed that barley leaves deficient in K lose their ability to respond to rapidly changing transpiration conditions. When subjected to hot and dry winds, plants with adequate K content closed their stomata within a few minutes. With severe K deficiency the transpiration rate increased greatly, and it took more than forty minutes before it declined below the normal level. These results explain the serious consequences of K deficiency on plant development in areas where warm and dry winds are common during the growing season (120a).

K speeds up the flow of assimilates

A high rate of CO_2 assimilation can only be maintained when the assimilates are translocated from the leaves to other plant organs, particularly storage tissues such as fruits and tubers. This process is as important as photosynthesis itself.

The flow of assimilates in the phloem vessels where the transport takes place is faster when plants are well supplied with K. This finding is the result of Büntehof studies with castor oil plants. Over a 3 hour period plants with higher K supply produced almost twice as much of phloem sap as plants less well fed with K (84).

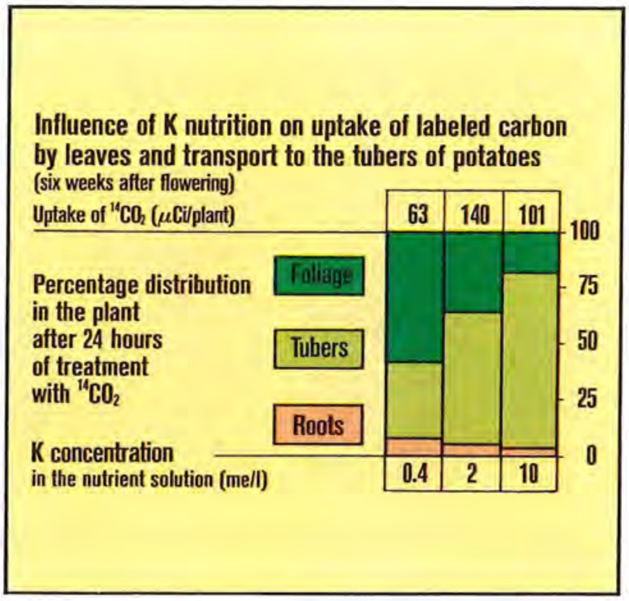


K promotes storage of assimilates

Better delivery of assimilates improves the filling of storage organs. In nutrient culture experiments potatoes were exposed for 24 hours to air containing a certain amount of carbon dioxide labeled with ^{14}C. In high-K plants, nearly 80 % of the ^{14}C was translocated to the tubers within 2 hours. In plants grown at low K concentration, more than 50 % remained in the leaves and probably exerted a feed-back inhibition on photosynthesis (42).

In this connection the form of K fertilizer plays an important role. Potassium sulphate, the K fertilizer recommended in potato cultivation, promoted movement of ^{14}C to the tubers while potassium chloride retarded the translocation of photosynthates from the stem to the tubers (43).

Among the three yield components of grain crops: number of ears per unit area ①, grain number per ear ② and grain weight ③, two and three are markedly improved by potassium nutrition. Usually we find that K has little effect on the number of ears per plant ①, however a temporary interruption of the K supply at tillering can have a detrimental effect on yield, reducing the number of ears and grain weight (81). The influence of K on the number of grains per ear ② and grain weight ③ of winter wheat was again confirmed in Büntehof pot experiments with K-fixing soil. The results showed that favourable K supply advanced flowering and delayed ripening so that the grain filling period was extended which resulted in a considerable increase in the number and weight of grains (44).

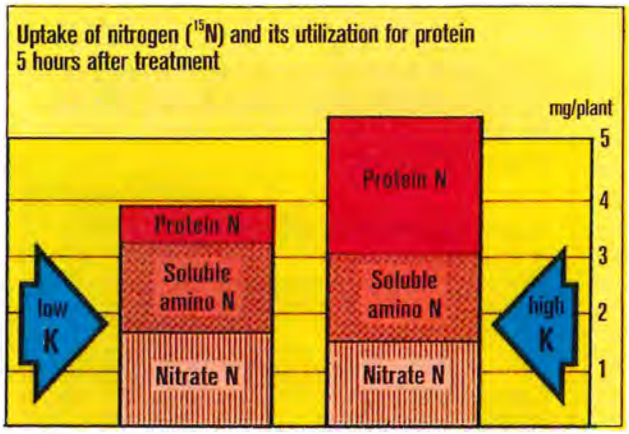


Effect of K on yield components in wheat

Treatment (mg K/100 g soil)	K_0	K_1	K_2	LSD, 5 %
	0	60	120	-
Days from flowering to ripening	46	68	75	-
Ear number per pot	58.8	65.2	61.3	5.9
Grain number per ear	36.3	37.6	42.6	3.8
Single grain weight (mg)	17.4	33.0	34.4	4.8
Grain yield (g per pot)	37.2	81.0	89.9	7.5

K favours protein formation

Nitrogen (N) is the most important plant nutrient. Application of fertilizer nitrogen results in a significant increase of plant growth. Uptake and utilization of N are promoted by K. In experiments with the nitrogen isotope ^{15}N Büntehof scientists have shown that plants well supplied with K were able to take up more N and to convert the nitrogen more rapidly into protein [66]. In low-K plants protein formation is inhibited.

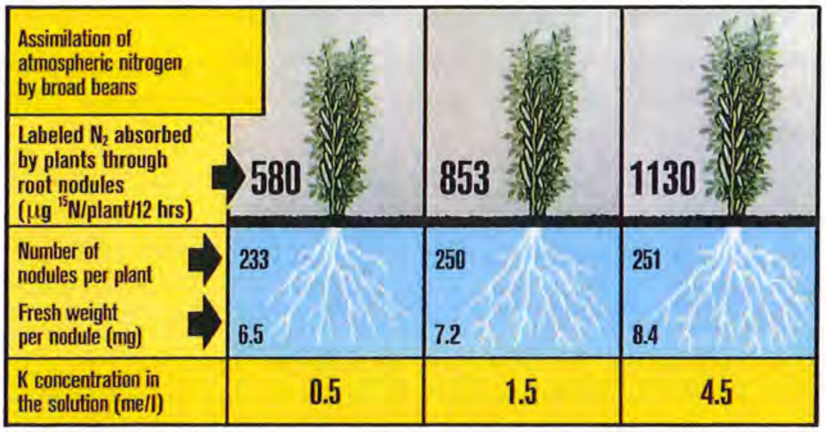


It is therefore understandable that high rates of nitrogen can be utilized by the plant and transformed into maximum yield only in the presence of correspondingly high K levels. An example of this strong positive N/K interaction is illustrated in the table which shows the results of a nutrient culture experiment with sugar beet [65].

Effect of varying N and K supply on the yield of sugar beet (av. yield, g/pot)

	N_1		N_2		N_3	
	Root	Top	Root	Top	Root	Top
K_1	640	99	960	214	1153	348
K_2	547	75	1091	254	1308	472

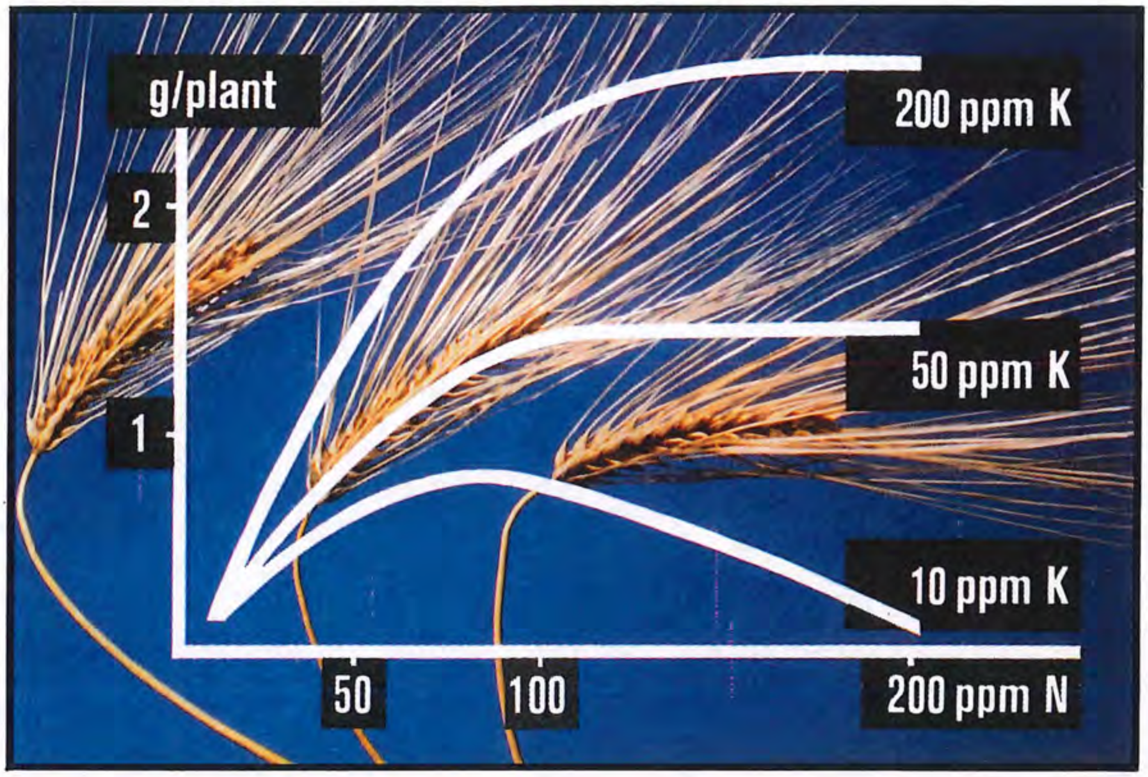
Potassium enhances nitrogen fixation



The influence of potassium on nitrogen metabolism has also been confirmed for the process of N_2 fixation by microorganisms. Leguminous plants, for example, are able to utilize nitrogen from the air, fixed by *Rhizobium* bacteria living in symbiosis with the plants in the root nodules. Many studies are under way to develop more efficient *Rhizobium* strains for inoculation. However it is not generally known that the N fixing activity of bacteria can be greatly enhanced if the leguminous plants receive ample potassium. Büntehof experiments with broad beans have shown that the root nodules of the plants were larger at higher K levels. Tests with ^{15}N revealed increased activity in these nodules. They fixed about twice as much atmospheric nitrogen as the nodules of low-K plants [45].

These results of greenhouse studies help to explain why leguminous cover crops or forage crops, such as clovers and alfalfa, show better growth and nitrogen uptake when properly supplied with potash fertilizers.

Potassium improves the effect of nitrogen



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

Fertilizer nitrogen will display its full effect on plant production only at optimum supply levels of the other plant nutrients, notably potassium. This has a great impact on the profitability of fertilizer use.

Basic research experiments on nutrient interaction were carried out in Canada with barley, c.v. Herta, grown in solution culture. At a low K level (10 ppm) there was a moderate response to nitrogen up to 50 ppm N. With higher N supply the grain yield was markedly depressed, mainly due to a strong decrease of the 1,000 grain weight.

At medium K concentration (50 ppm) the response to nitrogen was improved, but it levelled off at 100 ppm N.

Only at the highest K level (200 ppm) an increase of the nitrogen concentration up to 200 ppm led to an additional yield increase. With the nutrient supply combination $N_{200}K_{200}$ (ppm) the grain yield was about twice as high as with $N_{200}K_{50}$.

K improves water-use efficiency

It is well established that plants abundantly supplied with K can utilize the soil moisture more efficiently than K-deficient plants. Thus high-K plants need less water to produce a given yield than plants undersupplied with K. This was demonstrated in a nutrient culture experiment with **sugar beet.** While the root weight increased with increasing K concentration in the nutrient solution, water consumption per beet remained constant (83).

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

What is the mechanism of the effect of K? Potassium is a dominant ion in the plant. As a consequence of the active uptake of K and its accumulation in the cell, water moves in and increases the turgor pressure in the cell. In the fast growing tissues of young plants K is indispensable for obtaining optimum cell turgor which in turn is required for cell enlargement (85). In fact, the involvement of potassium in "osmoregulation", i.e. adjustment of cells to environmental conditions, seems to be its most important biophysical role (7, 68). Thus it is understandable that potassium improves plant tolerance to stress conditions, such as drought, low temperature or salinity.

K and plant tolerance to salinity

Soil salinity and alkalinity pose severe problems to food production in many countries. Under these conditions the selection of salt tolerant plants or, within a crop species, of relatively more tolerant varieties is important. One of the characteristics for salt tolerance is the ability of the plant to take up sufficient potassium and to avoid the accumulation of too much sodium, as can be seen in the table which shows pot experiments with tolerant and sensitive varieties of wheat at increasing exchangeable sodium percentage (ESP) in the soil (55). In the normal soil with a low ESP level, both varieties showed a very low Na/K ratio and produced similar grain yields. With rising ESP, reduced K uptake and increased Na accumulation led to a higher Na/K ratio and a decrease of grain yield. But the two varieties reacted very differently. At the highest ESP level, only the tolerant one (Kharchia) survived and produced grain. The yield of the sensitive variety (HD 4530) was already strongly depressed at an exchangeable sodium percentage of 43 % where Kharchia still produced 67 % of the normal yield.

In Büntehof experiments with barley it was found that salt stress caused by NaCl could be reduced by an increase of the K supply (46). It is therefore assumed that the application of potash fertilizer to the level needed by the crop and preferably in the form of the less "saline" K_2SO_4 will improve plant tolerance to salinity.

Influence of exchangeable sodium percentage (ESP) of the soil on Na/K ratio in shoots at tillering and on grain yield (g/plant) of two wheat varieties

Wheat variety	Treatment (ESP)	Na/K ratio	Grain yield, t/ha
Kharchia (tolerant)	7	0.04	3.68
	29	0.25	2.95
	43	0.43	2.48
	51	0.92	1.78
HD 4530 (sensitive)	7	0.12	3.43
	29	0.79	2.26
	43	2.59	0.75
	51	4.78	–

K and soil microorganisms

Microorganisms, which live in the root zone (rhizosphere), exert an influence on the nutrient dynamics in the soil. On the other hand, rhizosphere organisms are influenced by the nutrient supply to the plant. In Büntehof trials a larger number of bacteria was found in the rooting medium of plants when the nitrogen supply was increased but a lower number with increasing potassium supply [126]. Roots of high-N and low-K plants excrete compounds which can very easily be utilized by bacteria. In high-K plants these readily soluble compounds are converted to more complex carbohydrates and proteins so that less food is available for microorganisms [128].

Soil microbes compete with plant roots for soil air. Consequently, the oxygen content decreases more rapidly causing anaerobic conditions in compacted soils when a larger number of bacteria are present, i.e. in the rhizosphere of high-N and low-K plants.
Anaerobic processes resulting from microbial activity are characteristic of submerged rice soils. Due to the oxidizing power of their roots, rice plants are adjusted to the reducing conditions prevailing in paddy soils. In many rice soils reduced iron accumulates. But it is not harmful to the rice plants because the iron is oxidized and precipitated as a reddish brown coating on the roots.

Roots of K-deficient rice plants. Note the high percentage of dead roots covered with black iron sulphide.

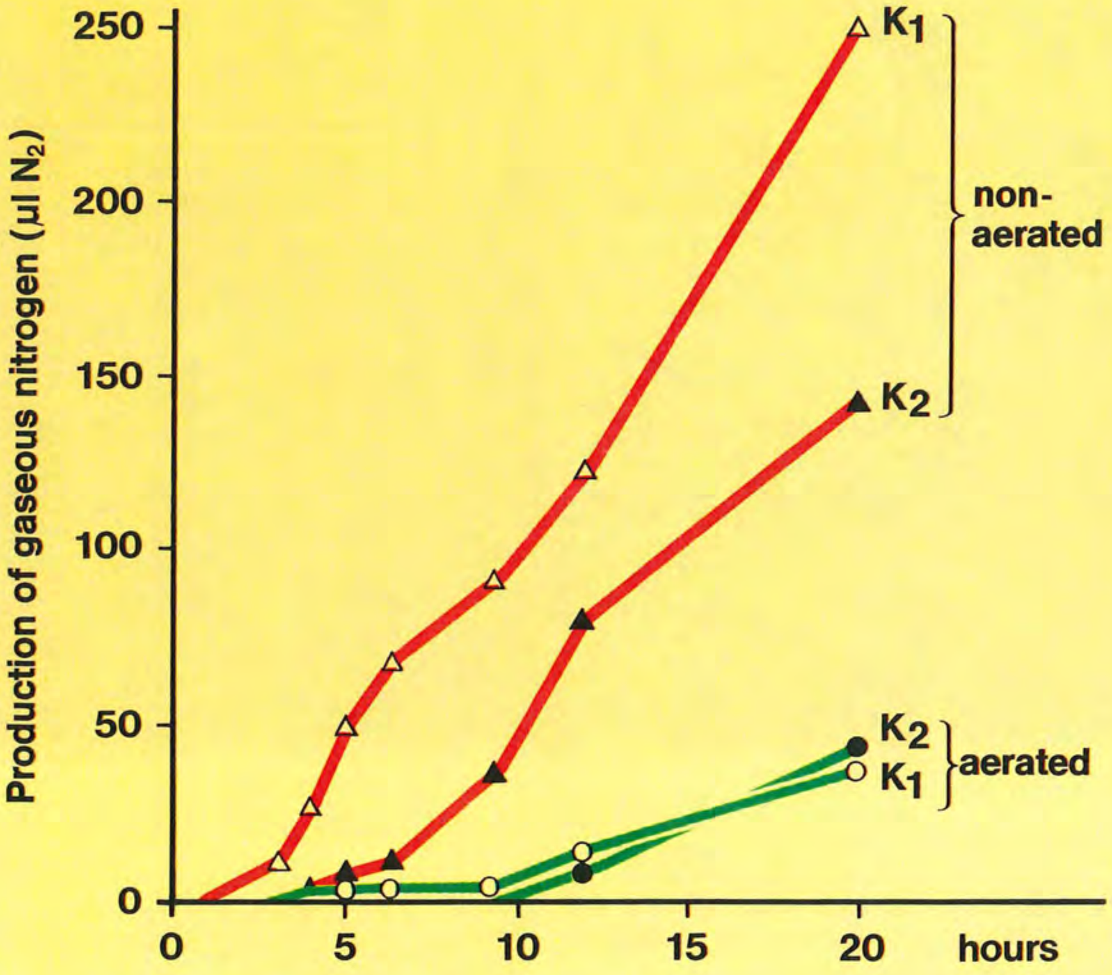
Healthy rice roots covered with reddish-brown iron oxide grown on plots with adequate K supply

K deficiency reduces the iron excluding power of rice roots. In that case the oxygen is consumed by the larger number of microorganisms present and iron is not precipitated. (122). The consequence is a high uptake of iron, resulting in iron toxicity, a serious problem in many paddy soils of Asia and Latin America.

The results of Büntehof research have confirmed the beneficial effect of applying potash to overcome iron toxicity. Similarly, the oxidizing power of rice roots well supplied with K turns the rhizosphere into a favourable environment for free living nitrogen fixing bacteria (129).

Reducing conditions are not confined to submerged rice soils. They can occur in ordinary field soils also notably after incorporation of organic manure and at high soil moisture. They favour the development of anaerobic microorganisms including those which convert nitrate nitrogen to atmospheric nitrogen and thus bring about losses of N through "denitrification". In Büntehof experiments with wheat plants, grown in water culture, abundant K supply reduced the number of denitrifying bacteria and, consequently, the losses of N through denitrification (127). Losses were highest in the low K treatment in those pots where the nutrient solution was not aerated.

Denitrification in the rhizosphere as influenced by the potassium nutrition and aeration of the nutrient solution



K, Na and Mg in human and animal health

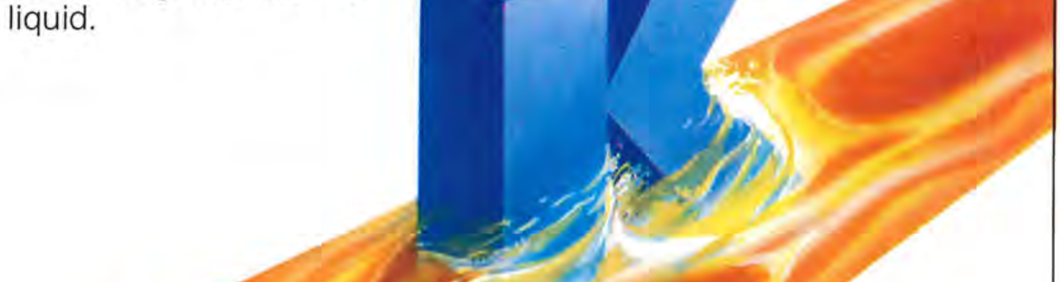
Everybody knows that salt (NaCl) is essential for the life of man and animals. Since immemorial times salt has been a precious commodity. As agricultural crops usually do not contain sufficient sodium (Na^+) to cover the requirements of the organisms, salt is added to human food and to animal feed.

It may not be generally known that potassium (K^+) is as essential as sodium (Na^+) for normal growth and health of man and animals.

In the human body the major part of sodium is contained in the fluids, such as the blood serum, circulating outside the cells, whereas potassium is accumulated inside the cells. Sodium and potassium are essential for the maintenance of the osmotic equilibrium. By the movement of K^+ through the membrane to the outside medium and of Na^+ into the cell, and the subsequent reestablishment of the initial status, both ions, Na^+ and K^+ participate in vital processes such as nerve impulses, muscle activity, heart beat. Another role of these cations is the activation of enzymes which regulate the functioning of the metabolism [138].

The daily requirements of potassium have generally been met by the natural K content of the food, while the shortage of sodium had to be overcome by the intake of salt. Nowadays people in many countries consume too much salt. Excessive intake of NaCl has been asso-

Persons suffering oedema or dropsy (excessive accumulation of sodium in the body) are prescribed special diuretics which prevent the excretion of K while enhancing the loss of superfluous liquid.



Potassium fertilization and potassium content of food.

The K content of several agricultural products for human consumption can be raised by adequate fertilizer application.

Crop	K content, % in dry matter	
	Fertilizer treatment	
	without K	with K
Spinach	1	6
Carrots	1	4
Tomatoes	1.5	3.5
Potatoes	1	2

On the other hand, fertilizer application does not lead to substantial increases in the K content of grains (rice, wheat, maize or coffee beans) nor is the K content of meat and milk significantly affected by the K content of the fodder.

ciated with high blood pressure and other related disturbances [58, 80]. The potassium balance, on the other hand, may become negative if K excretion is higher than K intake as has been observed in persons subjected to stress or under treatment with certain medicaments such as diuretics, purgatives or corticoids [138]. In such cases it is necessary to compensate the deficit by the additional intake of K. Products rich in potassium are fruits, juices, wine, vegetables etc. But it should be borne in mind that much of the K supplied by vegetables and fruit in the daily diet may be lost in their preparation, especially when liquid is drained off after boiling or processing.

Similar considerations refer to magnesium (Mg) which, after potassium, is the second most abundant mineral cation in most of the cells in the human and animal body. Mg plays an essential role in the vital processes of energy, carbohydrate and protein metabolism, in the transfer of impulses from nerves to muscles. Too low a magnesium supply may lead to tetany, brain disturbances, heart diseases [47, 48, 87] and malformations of babies.

In animal nutrition the cations K^+, Na^+, Mg^{++} play an eminent role as well. While the K supply through the forage is usually abundant, shortages of Na and Mg can occur. In ruminants, such as cattle or sheep, various disturbances have been observed as a result of sodium or magnesium deficiency. It is the actual shortage of these minerals rather than an oversupply of potassium which brings about these disorders. Cattle can consume and excrete K in rates considerably higher than the daily requirement without adverse effects on magnesium and sodium content in the blood serum, the overall health status as well as milk and meat production provided the animal is receiving sufficient Mg, Na and water [41, 64, 137].

Potassium levels* in some feedstuffs for cattle and sheep

Feed	% Potassium
Urea	none
Maize grain	0.4
Milo grain	0.4
Barley grain	0.5
Maize silage, well eared	1.0
Cottonseed meal	1.4
Sorghum silage	1.5
Alfalfa hay, mid-bloom	1.8
Soybean meal	2.1
Molasses	4.0

* Dry matter basis

Mg contents in grass-clover forage (g/kg dry matter) as influenced by Mg application

Fertilizer treatment	Year of experiment		
	1st	2nd	3rd
Without Mg	1.69	1.79	1.82
With Mg	1.86	2.08	2.03

K+S Fertilizers to cover Mg and S needs

The importance of magnesium*

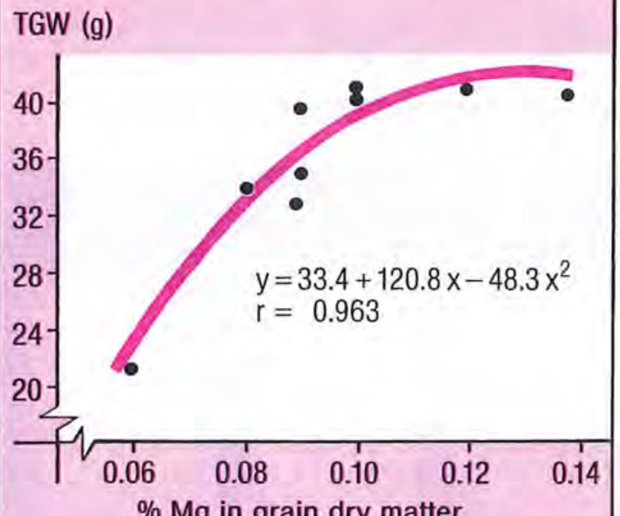
Magnesium is an important constituent of chlorophyll, the essential pigment of the chloroplasts in which photosynthesis takes place, but other functions of Mg are also of eminent physiological importance. Magnesium particularly activates the processes of phosphorylation which are essential steps not only in photosynthesis and the formation of high-molecular substances but also in glycolysis and respiration (85).

As shown in the graph, an adequate supply of magnesium markedly increases the grain size of cereals (8).

Magnesium deficiency, which is widespread on acid soils, can often be observed in crops such as fruit trees, vegetables, legumes, oil and coconut palms, root crops, etc. The typical symptom is the interveinal chlorosis of older leaves. The veins remain green while the area between the veins appears yellowish.

Mg deficiency has been occuring more frequently in recent years. With increasing NPK fertilization and the resulting rise in crop yields higher amounts of magnesium, sulphur and other plant nutrients are removed from the soil.

Relationship between the Mg content in the grain of barley and grain size (thousand grain weight)



* More detailed information on magnesium and sulphur as plant nutrients is contained in the K+S brochure "Kieserite, $MgSO_4$ for better crops"

In order to maintain high yields, application of adequate rates of Mg containing fertilizers such as kieserite (magnesium sulphate) becomes important. In some countries, the domestic Mg source is dolomitic limestone (calcium magnesium carbonate). However the Mg in carbonate is less readily available than in sulphate. Furthermore, the transport costs of bulky limestone material can be high, and its use is not recommended on soils with pH values higher than 6. In any case, for the control of magnesium deficiency the application of the water soluble Mg fertilizers produced by K+S is preferable.

Optimum Mg availability to plant roots is found in soils with a pH of about 5. At high soil pH the competition of calcium (Ca) ions is responsible for restricted Mg uptake. At lower pH, the uptake of Mg is reduced due to the increased concentration of aluminium (Al) ions in the soil solution, and Al toxicity becomes a major problem for plant growth. Büntehof research has shown that in very acid soils, as found in many parts of the tropics, the addition of Mg fertilizers exerts a similar effect to that of lime by reducing Al toxicity and simultaneously controlling Mg deficiency (38). (See also page 82).

The range of fertilizers containing Mg produced by K+S comprises:

"Korn-Kali" (granular potash) with MgO	5 % MgO
Magnesia Kainite	6 % MgO
Sulphate of Potash Magnesia (Patentkali)	10 % MgO
Epsom Salts, for foliar sprays:	16 % MgO
Kieserite	27 % MgO
and, as a high-grade magnesium source: **$MgSO_4$ anhydrous**	33 % MgO

Sulphur needs of crops

Part of the potash applied to agricultural crops has always been in the form of potassium sulphate. In most cases the reason for the use of K_2SO_4 has not been the fact that this fertilizer contains sulphur, but that it does not contain chloride, which may exert unfavourable effects on special crops and under certain soil and climatic conditions.

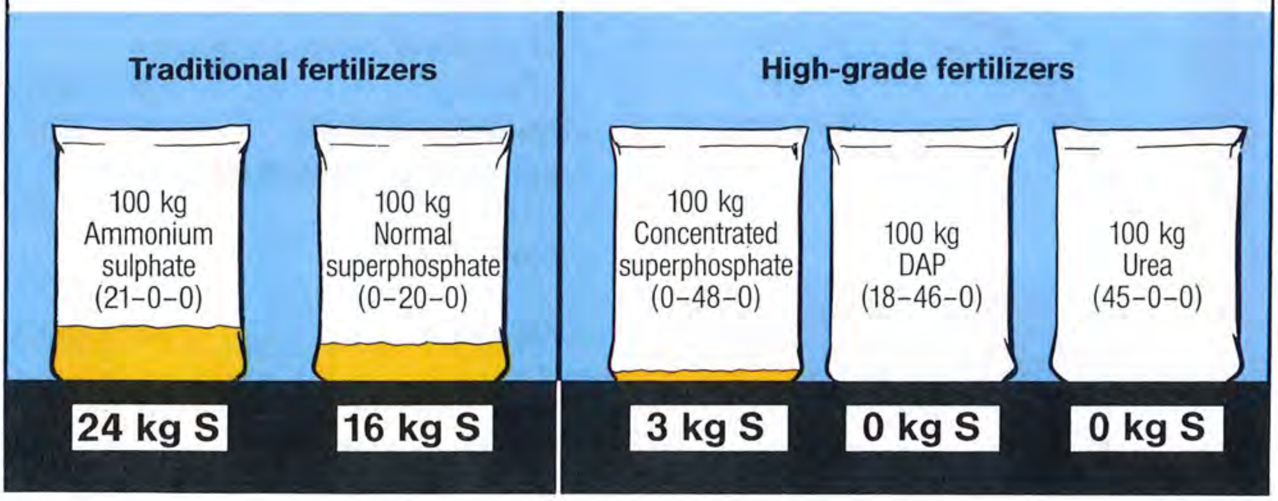
In the past little attention has been paid to sulphur as a plant nutrient in potash fertilizers. But with the switch over from ammonium sulphate (24 % S) and single superphosphate (12–16 % S) to high-analysis N and P fertilizers, more or less free of sulphur, and in view of the measures undertaken by governments to control air pollution (which will restrict the supply of S via industrial waste gases and smoke) potash fertilizers containing S will gain in importance.

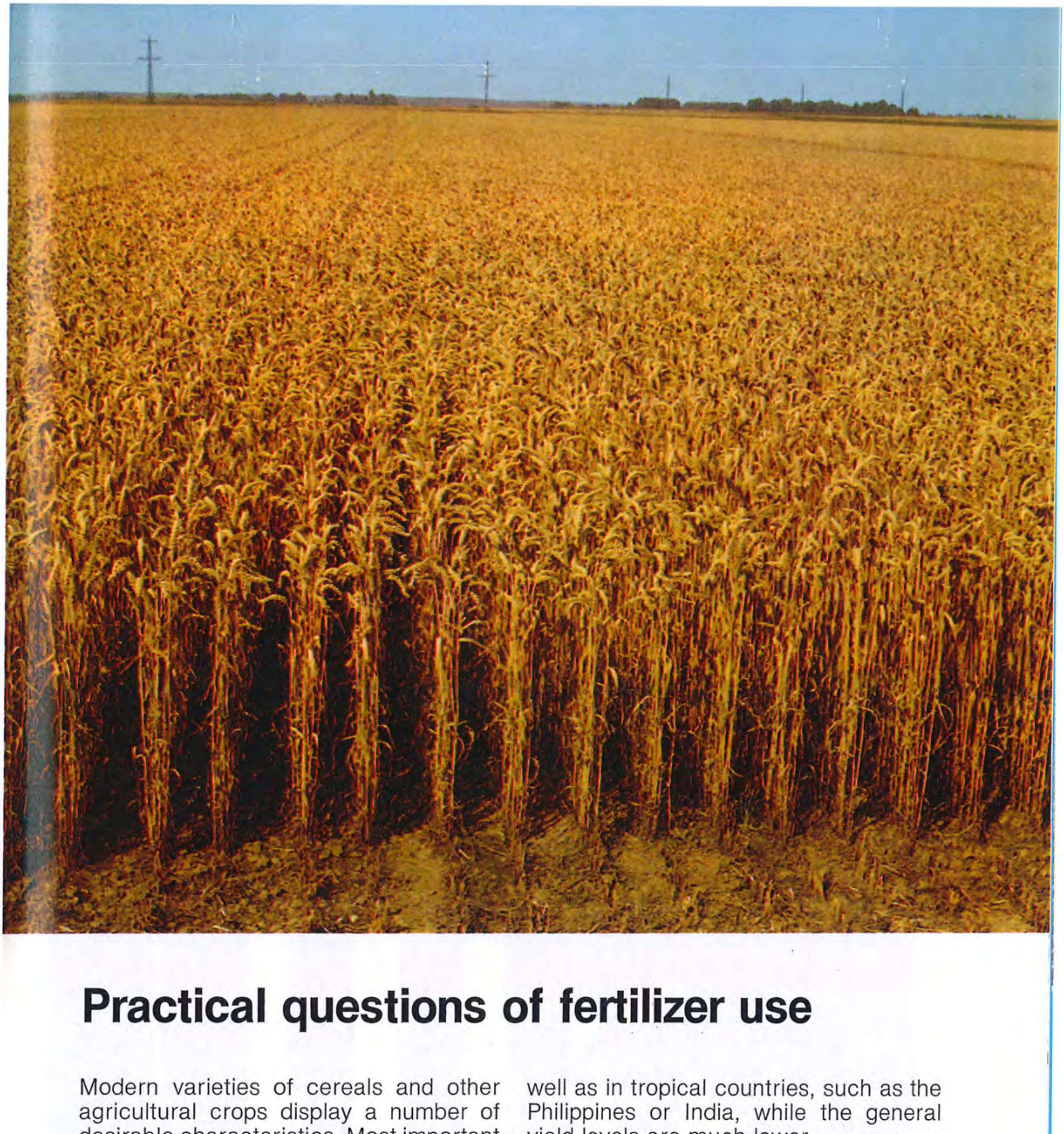
In countries with arid or semi-arid districts, where soils tend to have a high salt content in the surface layer, it is imperative to apply fertilizers with a low salt index. The same holds true for the intensive cultivation of flowers and vegetables in glasshouses. Under these conditions potassium sulphate is preferable to potassium chloride because the salt index of the sulphate is less than half as large as that of the chloride.

The K+S fertilizers containing sulphur:

Epsom salts ($MgSO_4 \cdot 7H_2O$)	13 % S
Sulphate of potash magnesia (Patentkali)	16–22 % S
Potassium sulphate (K_2SO_4)	18 % S
Kieserite ($MgSO_4 \cdot H_2O$)	22 % S
Magnesium sulphate anhydrous ($MgSO_4$)	26.5 % S

Sulphur content in nitrogen and phosphate fertilizers





Practical questions of fertilizer use

Modern varieties of cereals and other agricultural crops display a number of desirable characteristics. Most important is their genetic potential for high yields. Of the various growth factors – such as sunlight, temperature, water, plant nutrients – the supply of nutrients and, in certain cases, of water can at least be influenced by the farmer. The prevailing climatic conditions are by no means fully utilized for plant production. Yields of 10 t of rice and 20 t of maize grain per hectare and harvest have been obtained in North America, Europe and Japan as well as in tropical countries, such as the Philippines or India, while the general yield levels are much lower.

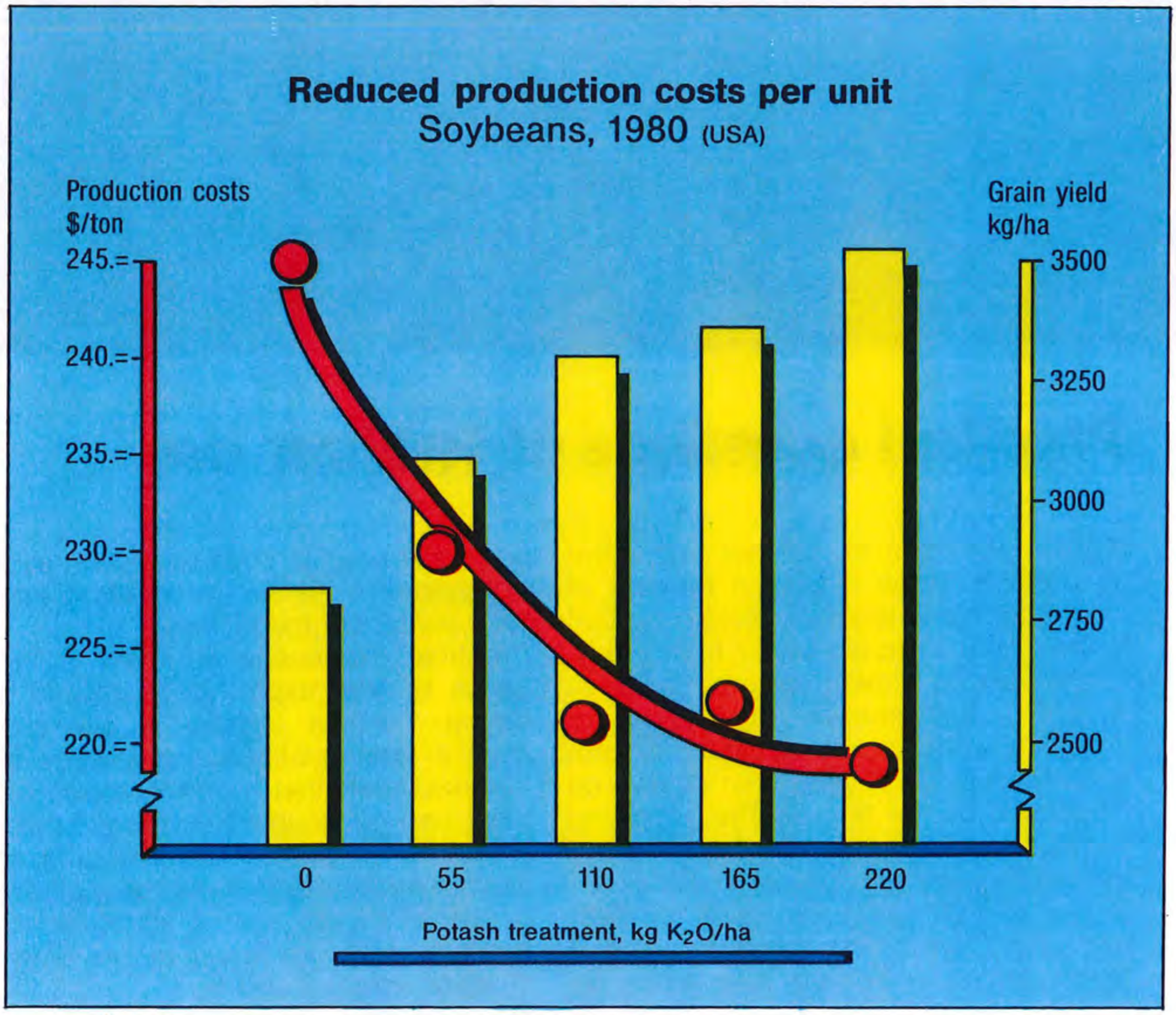
Practical experience obtained in thousands of field experiments carried out during the last decade in almost all tropical and subtropical countries has demonstrated that in many cases crop yield can be doubled by proper use of balanced fertilizers. Summarizing the experimental results it can be stated, as a rule of thumb, that 1 kg of fertilizer nutrients NPK will increase the yield by 10 kg of cereal grain (100).

Reduced production costs per unit

Assuming stable prices for agricultural products, the profitability of farming is determined by the yield level. The following graph shows how the production costs per ton of grain decrease with increasing yield in the USA. In other countries the figures may be different, but the tendency will be the same.

As a rule, the higher the yield per hectare, the lower the production costs per unit of marketable product.

Yield differences between two farmers who grow the same variety under identical soil and climatic conditions indicate that one of them employs superior cultivation techniques including a better supply of plant nutrients. These differences in yield may be due to "hidden hunger" of the crop grown by the less efficient farmer. The term "hidden hunger" means that visible nutrient deficiencies, which occur only under conditions of extreme malnutrition, have not shown up so far. The amount of fertilizer applied in this case, large though it may have been, was not sufficient to ensure an adequate nutrient supply to the crop for exploiting its genetic potential and producing top yields.



Potash, a low cost input

Generally three economic measures are used to indicate the profitability of fertilizer use:

① **The crop price/fertilizer price ratio,** which indicates how much grain or vegetable or fruit etc. is required to purchase 1 kg of fertilizer nutrient.

② **The net return,** the money value of the yield increase due to fertilizer **minus** the cost of the fertilizer used.

③ **The value/cost ratio (VCR),** calculated by **dividing** the value of the yield increase due to fertilizer by the cost of the fertilizer used.

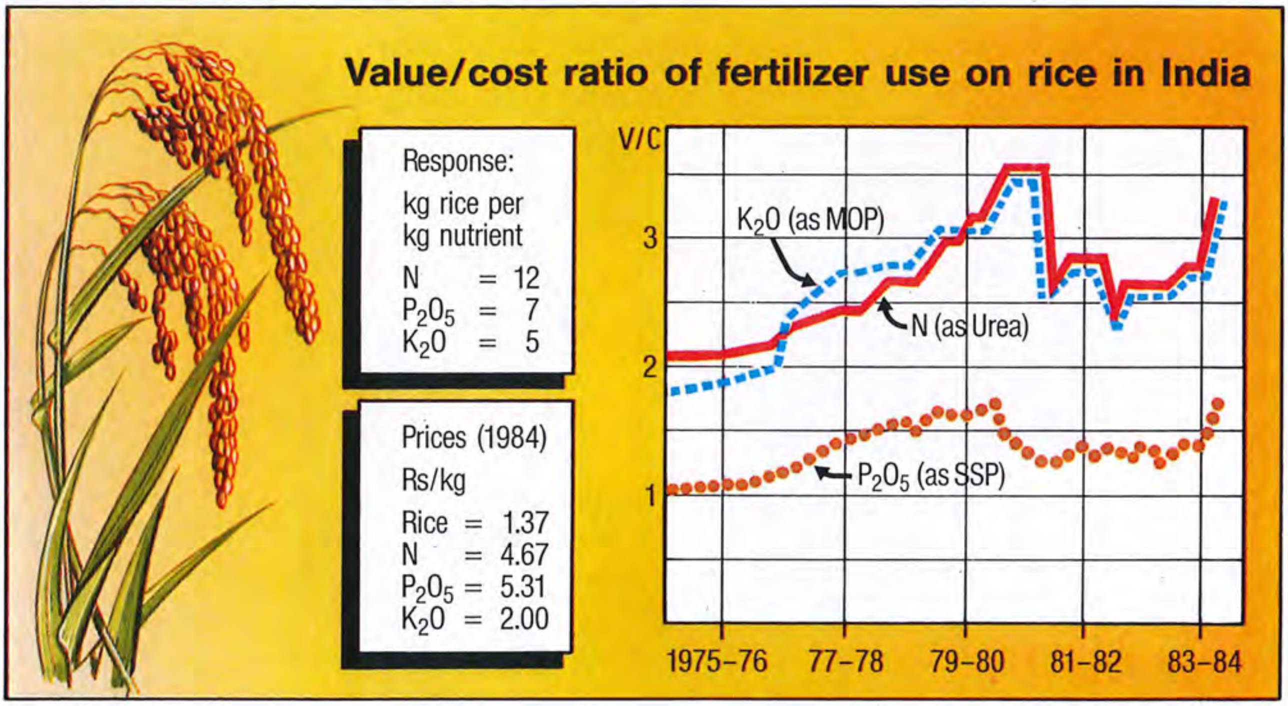
A VCR of more than 1.0 indicates that fertilizer application is profitable, a ratio of 2.0 is equivalent to a 100 per cent net return on the money spent on fertilizer. Net return and VCR depend on the crop response per kg plant nutrient in the fertilizer applied and on the crop price/fertilizer price ratio.

For India, where prices of fertilizers and procurement prices of rice, wheat and other food grains are fixed by the government, as in many other countries, these relationships for the rice crop are summarized in the graph [26].

Accordingly the VCR for nitrogen and potash in the case of rice was above 3, for phosphate almost 2 in 1984. In other words, for every rupee invested in N or K fertilizer the farmer can expect a gross financial return of more than three rupees. Based on thousands of experiments, the yield increase in kg rice or wheat due to fertilizer application amounts to about 12 per kg N, 7 per kg P_2O_5 and 5 per kg K_2O.

Though the crop response per kg nutrient is smaller for K than for N, as a result of the differences in fertilizer nutrient prices the application of potash is as profitable as the application of nitrogen.

Potash as profitable as nitrogen



Optimum nutrient supply

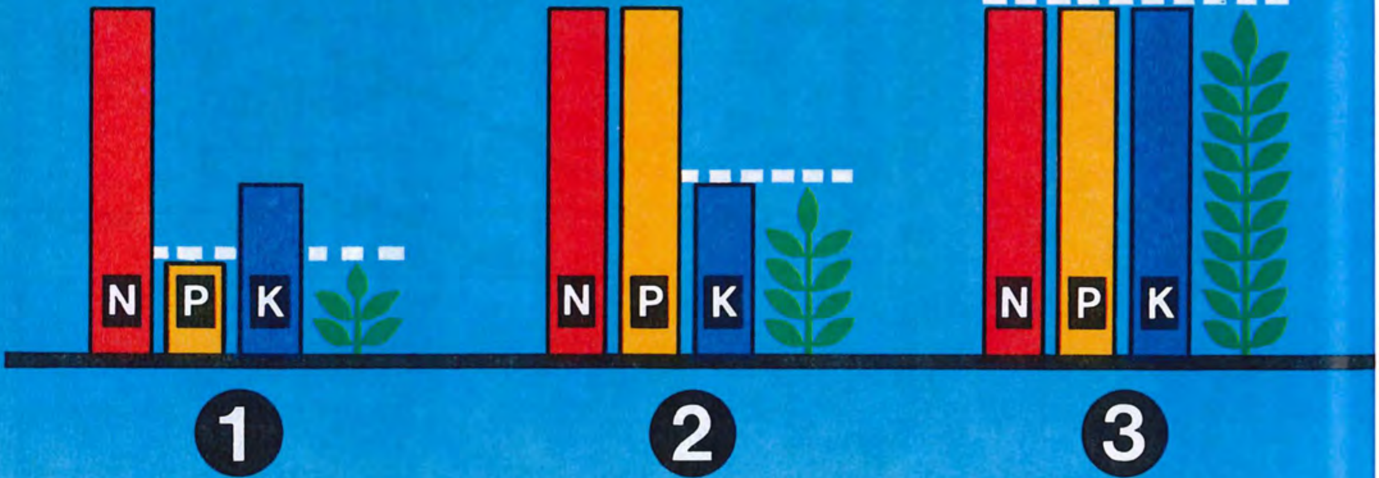
We know that plant production cannot increase further if there is one factor limiting the positive influence of all the other growth factors. How this "Law of Limiting Factors" works in the case of the plant nutrients N, P and K is illustrated in the diagram below.

Case ❶: N is available in sufficient quantity due to nitrogen fertilizer application, but it cannot produce its full effect because of the small quantity of available P limiting the development of the plant.

Case ❷: After increasing the P supply to match the quantity of available N the nutrient K becomes the yield-limiting factor. Case ❸: The three nutrients NPK will produce their full effect only when the supply of the third, K, corresponds to the level of available N and P.

Case ❹: The application of higher amounts of NPK in order to exploit the genetic potential of new crop varieties will not lead to the desired yield increase if other nutrients, such as Mg and S, be-

The Law of Minimum (simplified)



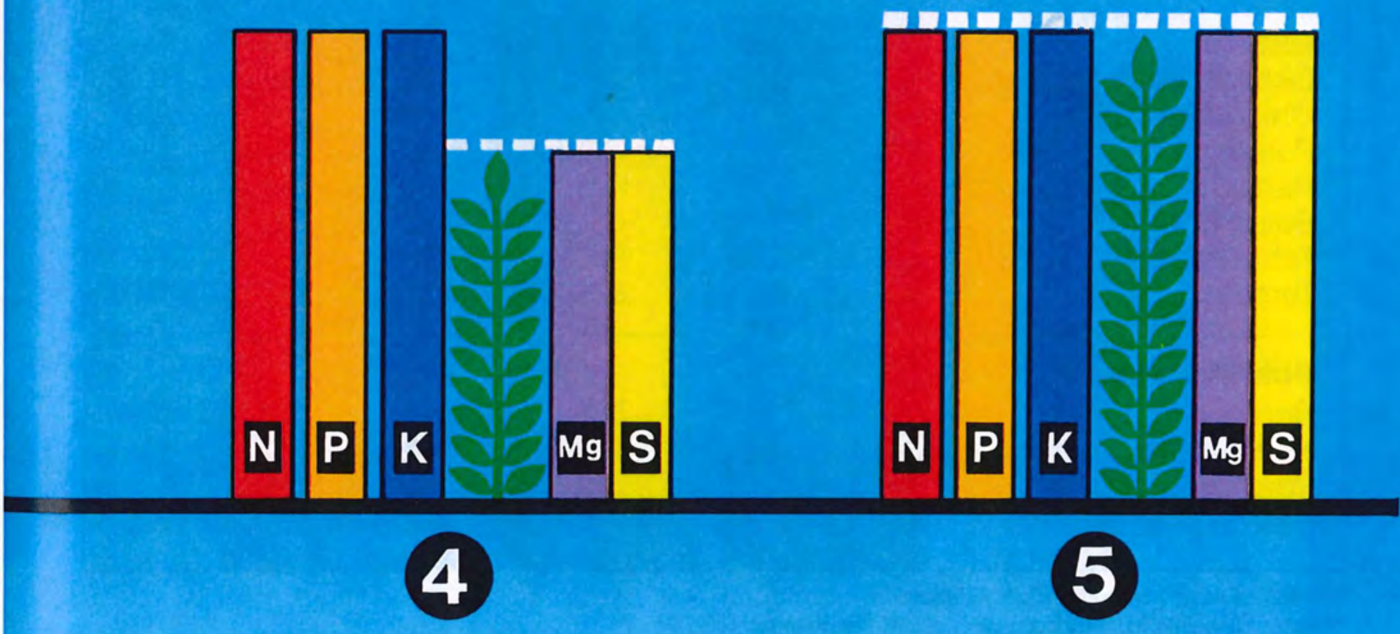
come minimum factors. Case ❺: Only when the supply of all plant nutrients is adequate for the plant's requirements, does optimum plant production become possible.

What are "the plant's requirements"?

They differ from crop to crop, even from variety to variety, and depend on the quantity harvested. At high yield levels, crops not only remove substantial amounts of nitrogen, phosphorus and potassium but also of calcium, magnesium and sulphur from the soil. Furthermore, they may respond to the application of various "micro-nutrients", in many cases zinc, in others boron, copper, molybdenum, etc.

Nutrient uptake by crops

The figures on the following pages of the uptake of nutrients are average values which refer to normal conditions of soil,



climate and cultivation. They are calculated for the whole plant on the basis of the yield stated.
These uptake figures cannot be fully equated to the quantities of fertilizers required. The nutrients supplied by the soil have to be taken into consideration. On the other hand, part of the fertilizer nutrients will not be readily available to plant roots due to fixation or losses by volatilization, denitrification or, sometimes, leaching.

Crop	Yield	Nutrient removal, kg/ha ≈ lb/ac *				
	t/ha	N	P_2O_5	K_2O	MgO	S
Cereals						
Barley	5	150	55	150	25	20
Maize	6	120	50	120	40	25
Oat	4	130	45	160	15	20
Rice (paddy)	6	100	50	160	20	10
Sorghum	4	120	40	100	30	15
Wheat	6	170	75	175	30	30
Root and tuber crops						
Cassava or tapioca	40	150	70	350	40	20
Potato	40	175	80	310	40	20
Sugar beet	45	200	90	300	90	35
Sweet potato	40	190	75	340	65	–
Yams	35	140	40	190	20	–
Vegetables						
Asparagus	5	120	60	150	20	–
Beans (green)	15	130**	40	160	30	–
Cabbage	70	370	85	480	60	80
Carrot	30	125	55	200	30	–
Cauliflower	50	250	100	350	30	–
Celery (roots)	30	200	80	300	25	–
Cucumber	40	70	50	120	60	–
Eggplant	60	175	40	300	30	10
Leek	35	120	45	280	25	–
Lettuce	30	90	35	160	15	–
Okra or lady's fingers	20	60	25	90	35	10
Onion and garlic	35	120	50	160	15	20
Pumpkin	50	90	70	160	40	–
Radish	20	120	60	120	30	–
Spinach	25	120	45	200	35	–
Table beet	30	150	50	220	50	–
Tomato	50	140	65	190	25	30
Pulses (dry grain)						
Bean	2.4	155**	50	120	20	25
Horse bean	2.4	160**	45	120	20	–
Pea	2.0	125**	35	80	15	–
Pigeon pea	1.5	70**	10	55	10	5

* Average values taken from various sources
** Leguminous plants can obtain most of their nitrogen from the air

Crop	Yield t/ha	N	P_2O_5	K_2O	MgO	S
		Nutrient removal, kg/ha ≈ lb/ac *				
Fruits						
Apple	25	100	45	180	40	–
Avocado	15	40	25	80	10	–
Banana	40	250	60	1000	140	15
Citrus	30	270	60	350	40	30
Grape	20	170	60	220	60	30
Mango	15	100	25	110	75	–
Papaya	50	90	25	130	15	10
Passionfruit	15	60	15	75	10	5
Pineapple	50	185	55	350	110	20
Oil crops						
Castor bean	2	80	20	35	10	–
Coconut (10,000 nuts)	–	130	60	200	50	15
Groundnut or peanut	2	170**	30	110	20	15
Oil palm (fresh fruit bunches)	25	190	60	300	100	30
Sesame seed	1	50	10	45	10	5
Rapeseed	3	165	70	220	30	65
Soybean	3	220**	40	170	40	20
Sunflower	3	120	60	240	55	15
Stimulants and spices						
Black pepper (dry fruit spikes)	7	240	40	210	30	–
Cocoa (dry beans)	1	40	15	90	10	–
Chillies (dry)	5	220	45	340	–	–
Coffee (clean beans)	1.5	120	30	130	30	20
Tea (made tea)	2.5	160	50	90	15	–
Tobacco (dry leaf)	2	130	40	240	25	10
Fibre crops						
Cotton (lint)	1	120	45	90	40	20
Jute (dry fibre)	2	65	30	160	35	–
Sisal (dry fibre)	1.5	50	10	120	45	5
Rubber (dry latex)	2.5	60	30	65	10	–
Sugar cane	100	130	90	340	80	60
Forage crops						
Alfalfa or lucerne (hay)	9	240**	65	170	40	25
Coastal Bermuda (hay)	20	500	140	420	70	40
Grass/clover (hay)	12	300**	90	360	60	35
Green maize (silage)	70	210	80	250	50	25
Red clover (hay)	7	175**	45	140	50	20
Stylosanthes (hay, 7 cuts/y)	20	570**	140	530	105	60

How much fertilizer?

The question remains as to what quantities of fertilizers should be applied in the actual case in order to obtain the most profitable yield under the prevailing local conditions.

Knowledge of the plant food requirements of the particular crop is one yardstick, detailed information about the soil is another important factor. The farmer (or his adviser) should know what quantity of additional plant nutrients the soil needs to attain the adequate fertility status to meet the requirements at any growth stage of his crop. If the soil fixes fertilizer nutrients so that they do not become available to the plant roots, fixation has to be overcome by placement, repeated applications or very high fertilizer rates. If the soil is sufficiently supplied with available nutrients, only a maintenance application of fertilizer will be needed to replace the quantities removed by the crops and keep soil fertility at the desirable level.

In the long run it is possible to obtain high yields on a sustained basis only when the nutrient balance is positive, i.e. when the input is larger than the removal.

In many cases, notably in tropical countries, potash application is still so low that plants have to rely on the potassium released from the soil. Thus farmers are not building up soil fertility: On the contrary, they are mining their soil with the consequence that sooner or later severe K deficiency will reduce the effect of other fertilizer materials and eventually diminish the yields. To avoid such development, farmers should keep track of the soil K status by means of soil tests.

Soil analysis is a very useful tool, especially if it includes determination of the non-exchangeable, exchangeable and water-soluble form of K. But we are expecting too much of soil analysis if we use it as **the** basis for fertilizer recommendations. The chemical soil test carried out in the laboratory cannot reproduce exactly the biological factors involved in plant growth in the field.

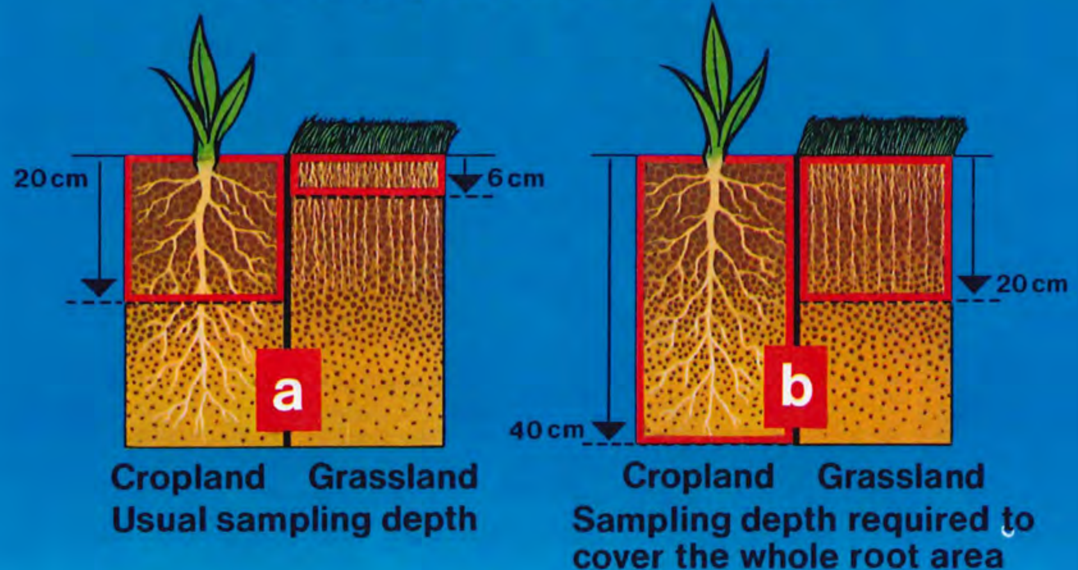
There are numerous cases where experiments revealed significant and economical yield responses to the application of K on soils which were supposed to be rich in "available" potassium according to soil analysis (see also 'K availability', p. 27).

Leaf analysis, although successfully utilized in the fertilizer programming of plantation crops, has severe limitations in the case of annual field crops.

Fertilizer trials, therefore, appear to be indispensable for determining the optimum quantities of fertilizers to be applied. They should be performed on a long-term basis since experiments limited to a period of one year often fail to produce reliable results.

Some results of recent field experiments on the effect of potassium are presented on the following pages.

Sampling depth for soil tests



Results obtained in the field

K and cereals

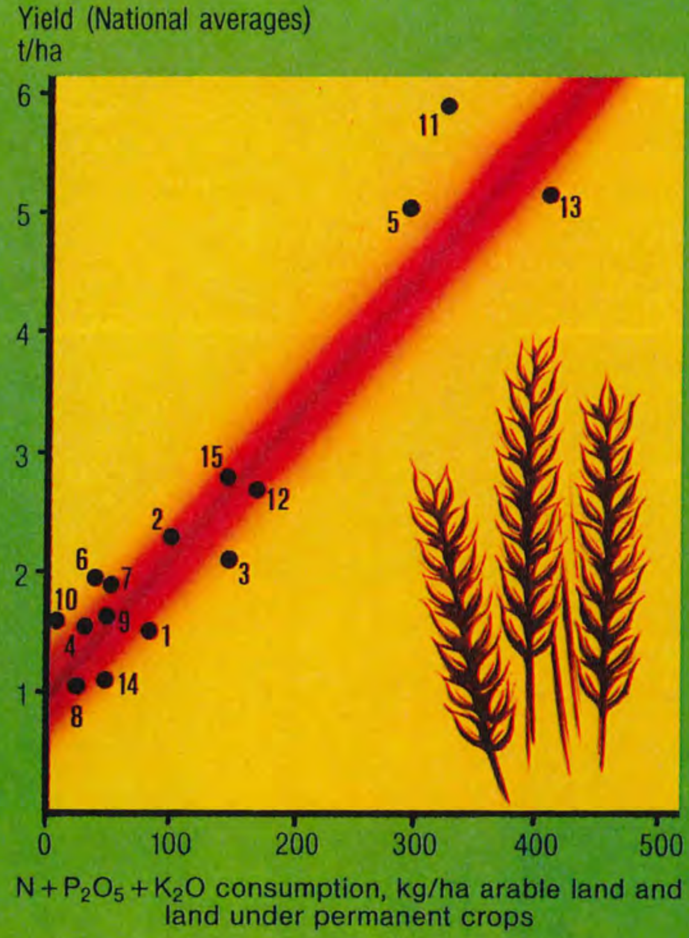
Wheat

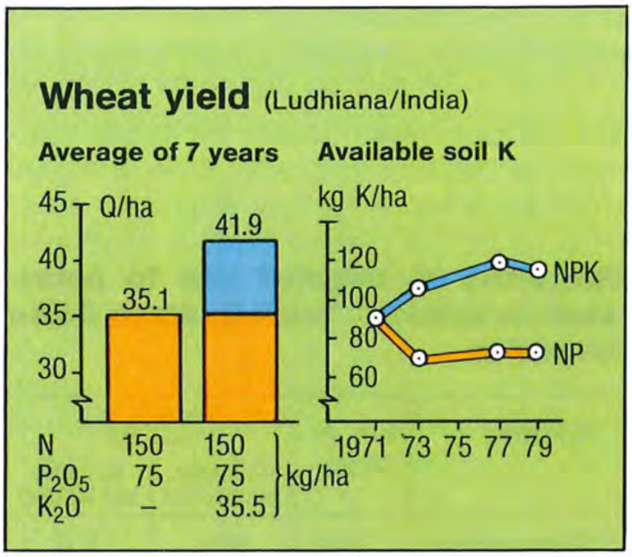
Wheat occupies the largest area of all the cereals in the world. Between 1970 and 1980 wheat production grew by 35 %, from 328 to 444 million tons (3 yr. av.). The increase was due to higher yields rather than to the expansion of the wheat acreage which amounted to 10 % only. There is a close connection between yield level and fertilizer use as seen in the figure which relates average wheat yields to NPK consumption per hectare in the 15 countries with the largest wheat production in 1981.

Nitrogen can be used on the wheat crop at 100 to 200 kg N/ha to produce top yields under suitable growing conditions, provided the other plant nutrients, particularly K, are available in optimum quantity. As mentioned under the heading 'K in plant physiology and yield formation' (page 37) potassium plays a major role in improving the components of grain yield, notably the number of grains per ear and the grain weight. The results of field experiments presented here are from India and France, the countries with the 4th and 5th largest production of wheat in 1981.

1981 wheat yields (3 yr. av.) related to 1981 NPK consumption in major wheat producing countries (FAO)

Country	Production (Million tons)
1 USSR	88.4
2 USA	72.4
3 China	59.3
4 India	35.3
5 France	24.0
6 Canada	23.9
7 Turkey	17.1
8 Australia	11.9
9 Pakistan	11.2
10 Argentina	10.1
11 UK	9.1
12 Italy	9.0
13 Germany FR	8.4
14 Iran	6.3
15 Romania	6.1





In India where wheat production has increased almost twice as fast as in the rest of the world during the seventies, long-term experiments of the Indian Council of Agricultural Research have confirmed the superiority of balanced fertilizer application (32). At the Punjab Agric. Univ., Ludhiana, the application of K in addition to N and P raised wheat yields considerably and built up soil fertility as shown in the figure.

The combined effect of the fertilizer nutrients N and K is demonstrated in the 1978 results of a fertilizer experiment in Chesnoy/France (22). On a soil with 12% clay and 10 mg exch. K/100 g soil the highest yield of 6.6 t grain/ha was obtained at the highest rates of both the nutrients (150 kg N and 180 kg K_2O/ha).

Slightly lower, but still above 6 t/ha were the yields on the treatments $N_{150}K_{120}$ and $N_{120}K_{180}$ as shown in the table.

Response of wheat to nitrogen and potassium. Grain yield in t/ha. (France)

Potash kg K_2O/ha	K_0	K_{60}	K_{120}	K_{180}	Mean (effect of N)
Nitrogen kg N/ha					
N_{60}	4.24	4.58	5.26	4.95	4.76
N_{90}	5.42	5.18	5.43	5.63	5.41
N_{120}	5.15	5.63	5.64	6.26	5.67
N_{150}	5.95	5.92	6.53	6.64	6.26
Mean (effect of K)	5.19	5.33	5.71	5.87	

Premature yellowing of the flag leaves during the grain filling period, due to potash deficiency, seriously reduces the grain yield of wheat.

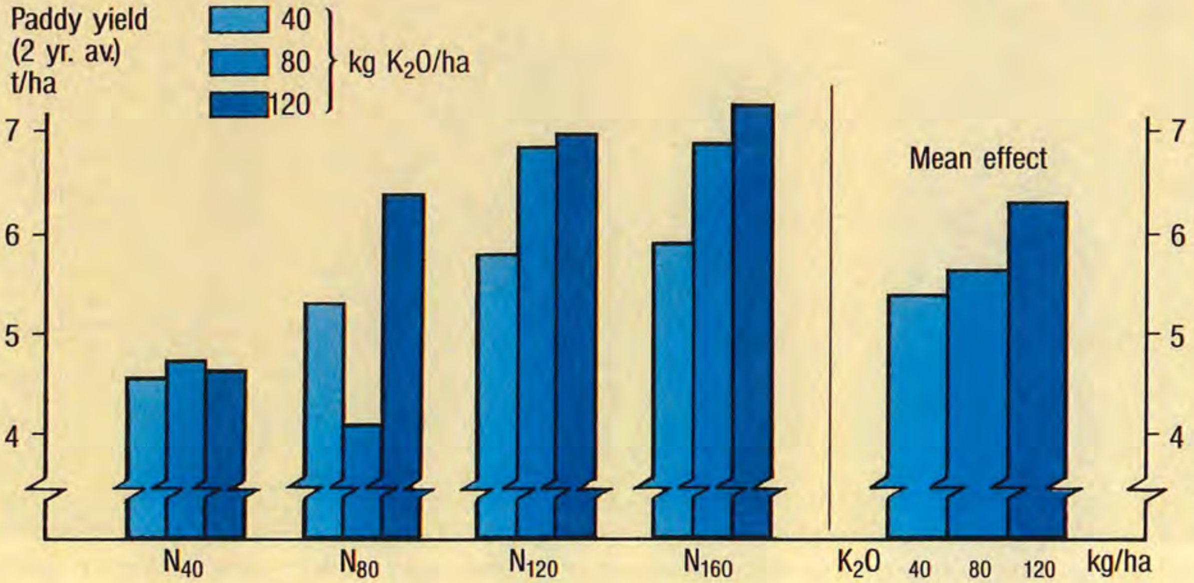
About 90 % of the world rice supply is produced in Asian countries. China and India together produce more than half of the total, which amounted to 396 million tons of paddy in 1980 (3 yr. av.). As there is little chance of major expansion of the rice acreage, efforts are concentrated on increasing yields per unit area in order to feed the growing population. Controlled irrigation, the introduction of modern or hybrid varieties and the use of fertilizers are particularly effective. In Indonesia, for example, farmers have succeeded in raising paddy yields from 2.3 t/ha in 1970 to 3.4 t/ha in 1980. At the same time, fertilizer use for rice increased from about 10 kg to 100 kg $(N + P_2O_5 + K_2O)$/ha (50, 60). If we compare the increases in yield and in fertilizer use for the ten years, we find a fertilizer efficiency of 10 kg paddy for each kg $(N + P_2O_5 + K_2O)$ applied to rice. Usually the response ratio is assumed to be as follows: 12 kg grain/kg N, 7 kg grain/kg P_2O_5, 5 kg grain/kg K_2O (26). While the response to potash is smaller than the response to nitrogen, the application of K is often as profitable as the application of N and P, because K is the cheapest of the three major plant nutri-

Response of irrigated rice to potassium in farmers' fields in some Asian countries

Country	No. of trials	Response to K over NP	
		kg paddy per hectare	kg paddy per kg K_2O
Bangladesh	800	356	7.6
China*	1361		9.3
India Kharif	1573	279	4.6
India Rabi	1573	493	8.2
Pakistan	540		4.6
Philippines	3225	139	4.6

* Red soil region

Response of rice to increasing rates of potash at varying levels of nitrogen (India)



ents. The table summarizes the results of thousands of fertilizer trials on the response of rice to potash (60, 63, 73).

As a result of more intensive cropping, coupled with the application of high rates of N, the lack of K is increasingly becoming a yield limiting factor on soils previously considered not responsive to K. An example of the nitrogen/potassium interaction is illustrated in the figure which presents data from West Bengal/India. At the low rate of nitrogen (40 kg N/ha) there is practically no yield response to increasing rates of potash application. At the highest N level (160 kg N/ha) however, the application of 120 kg/ha K_2O instead of only 40 kg/ha increases the yield by 1.4 t/ha paddy or by 17.5 kg grain/kg K_2O (86).

Rice leaves with typical symptoms of potash deficiency. The tips of the lower leaves turn yellowish-brown and rusty brown spots appear on the leaf blades.

1/3 more Azolla = 1/3 more N fixation

China (Yunnan Province)

Azolla pinnata

Azolla growth in 15 days

Fertilizer treatment kg/ha N — P_2O_5 — K_2O	Yield t/ha fresh weight
0 — 54 — 90	15.00
0 — 54 — 0	11.25
Effect of potash →	+ 3.75

Among the N fixing green manure crops the tiny water fern azolla is of special interest in East Asia. Due to symbiosis with blue-green algae the plants are able to utilize atmospheric nitrogen. Azolla is cultivated in Vietnam, parts of China and other countries. Under favourable conditions it can multiply rapidly and supply up to 100 kg N/ha to the rice field in several successive crops of azolla.

While self-sufficient in nitrogen, azolla needs the supply of other nutrients particularly phosphate for optimal growth. But it also responds to potash, as shown in experimental results obtained in Yunnan/ PR China (71). 90 kg of K_2O/ha, applied in addition to 54 kg P_2O_5/ha, increased the fresh weight of azolla by one third from 11.25 to 15 t/ha within 15 days.

K improves resistance to stalk breakage

It is a well known fact that an ample supply of potash increases the development of strong cell walls in the stems of plants. Thus resistance to lodging in cereals is enhanced and stalk breakage in maize is reduced.

In Tennessee/USA, for example, lodging was reduced from 80 % to 5 % in maize receiving 168 kg N and 90 kg P_2O_5/ha by the addition of 202 kg/ha fertilizer potash (34a).

This effect was corroborated once again by results obtained in fertilizer trials at the "Cerrado" Research Center in Planaltina/Brazil on a red-yellow latosol (108). Where 150 kg N and 175 kg P/ha was used without any potash, almost all maize stalks were broken prematurely by occasional winds. The grain yield hardly reached 1 t/ha. When potash at 150 kg K_2O/ha was also applied, no breakage occured, the stalks remained erect and the leaves green for a longer period, the photosynthetic activity was prolonged and the grain yield increased by 1776 kg/ha, i. e. 12 kg grain per kg K_2O. The extra grain yield was reportedly worth nine times the cost of the potash fertilizer added.

Only long-term trials give reliable information

Maize

In tropical Africa with moderate rainfall (1400–1600 mm) cereals grown under shifting cultivation traditionally received no fertilizers. With the change to continuous cropping and a general improvement in farm management it is possible to increase production but unless steps are taken to maintain soil K at a satisfactory level, potash supply to the crop can become a limiting factor within a few years. Results obtained with maize in the Ivory Coast – as an example among many other cases – clearly stressed the importance of long-term potash fertilizer trials to obtain more reliable information on how much fertilizer to apply [16]. During the first year, high rates of N, P and K were applied together with Mg and S in order to prevent any possible nutrient deficiency. Afterwards, each crop received (in kg/ha) 100 N, 60 P_2O_5, 0 or 100 K_2O together with 25 CaO, 25 MgO and 15 S. These quantities were considered sufficient to produce 5 t/ha maize grain (var. CJB). The analysis of the data obtained is given in the following table:

Maize grain yield of long-term field experiments (Ivory Coast)

Year	1969	1971 I*	1971 II*	1972
Control (t/ha)	2.13	1.75	1.19	1.35
NP	5.17	3.25	2.35	3.07
NPK	4.78	3.45	3.30	4.41
Response to K (kg/ha)	negative	200	950	1340
kg grain/kg K_2O	–	2	9.5	13.4
Soil test K on NP plots (me K/100 g)	0.40	0.14		0.07

* 1st and 2nd crop

Except for the year 1969, omission of K from the fertilizer dressing reduced yield, the reduction increasing with time until, in 1972, it was more than 30 %. In that year the response to K was 1340 kg/ha or 13.4 kg grain/kg K_2O. The progressive exhaustion of soil potassium in the NP plots is reflected in the soil test results.

Sorghum

Due to their rapid growth and relatively low moisture requirements, many varieties of sorghum and millet are the major source of food for the population in the semiarid regions of Africa and Asia. In other areas, sorghum is also grown as an important stock feed or as a raw material for ethanol production. When rainfall is sufficient or irrigation available, high grain yields can be harvested by applying large amounts of fertilizers, as reported from Georgia/USA. Three grain sorghum hybrids were grown for three years on a sandy loam low in available magnesium. The experimental sites received 1680 kg calcium carbonate/ha the year before planting, to avoid calcium becoming a limiting factor, and annual fertilizer rates of 0, 172, 345, 516 and 690 kg Epsom salts

Response of 3 grain sorghum hybrids to NPKMgS (USA)

Fertilizer treatment, kg/ha					Grain yield (q/ha, 3 year average)				
N	P_2O_5	K_2O	MgO	S	GA-615	FA-64	Savanna	Means	Mg+S effects
135	135	135	–	–	55	46	36	46	–
135	135	135	28	23	63	54	41	53	7
135	135	135	56	46	62	52	44	53	7
135	135	135	85	69	68	57	50	58	12
135	135	135	113	92	67	61	53	60	14
Mean yield of hybrids					63	54	45		

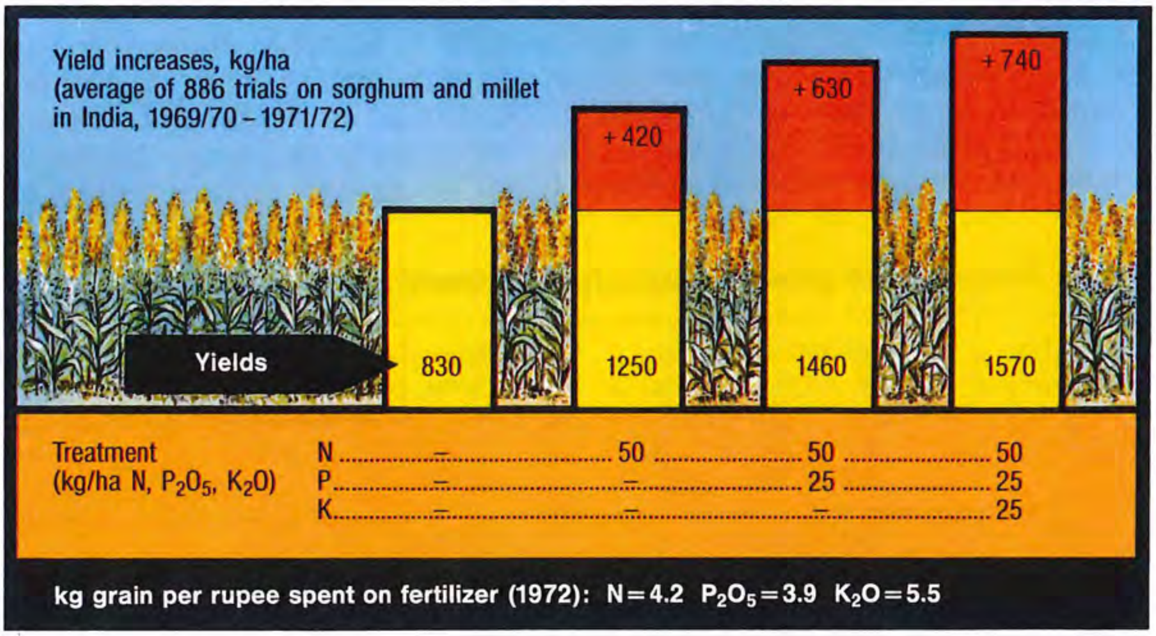
($MgSO_4 \cdot 7H_2O$) together with 67.5 kg N + 135 kg P_2O_5 + 135 kg K_2O per hectare. Each crop received an additional topdressing of 67.5 kg N/ha [28].

The results obtained show that notwithstanding considerable differences in yield potential between the varieties, grain sorghum responded to the application of magnesium sulphate in a remarkable manner. On the average, 690 kg Epsom salts added to uniform dressings of NPK increased the grain yield by 1400 kg/ha, i.e. 12.4 kg grain per kg MgO.

The magnesium content in the leaves increased from 0.06 % on the check plots to 0.22 % with the highest Mg fertilizer rate.

K deficiency in pearl millet *(Pennisetum glaucum* L.)

Yields can be doubled in semi-arid regions



Results from 886 fertilizer trials carried out with 9 varieties of "jowar" (sorghum) and 2 varieties of "bajra" (pearl millet) under dryland conditions in 14 different districts of India during three years show that the yield (weighted average of all trials) was raised from 830 kg/ha grain to 1570 kg/ha due to the application of 50 kg/ha N with the addition of only 25 kg/ha each of P_2O_5 and K_2O. Potash has proved to be the most profitable fertilizer element. Based on 1983–84 prices for sorghum and fertilizers, the value/cost ratio amounts to 2.2 for N, 2.0 for P and 2.7 for K [74].

K for root and tuber crops

Roots and tubers are an important part of the daily food for people in many countries, such as yams in West Africa, cassava in tropical America and Africa, sweet potatoes in South East Asia, white potatoes in Europe. Their overall production has shown little change in the last ten years. In 1980 (3 yr. av.) it amounted to 555 million tons worldwide. But there were regional differences. While production has decreased in Europe and stagnated in North and South America, it has expanded in Asia and Africa. Root and tuber crops are known for their high potassium requirements.

Potatoes

The potato has lost its role as the staple food in Germany, but it has gained importance in a number of less industrialized countries. In Africa potato production has nearly doubled between 1970 and 1980. Numerous trials and demonstrations have been carried out in Kenya under the FAO Fertilizer Programme. Data on the response of potatoes to potash were reported at the

Table 1. Response of potatoes to potash in farmers' fields (Kenya)

No. of demonstrations	Treatment, kg/ha N – P_2O_5 – K_2O	Yield t/ha	Response to potash	
			t/ha	kg tubers/kg K_2O
18	67 – 67 – 0 67 – 67 – 67	11.08 12.41	– 1.33	– 20
68	60 – 60 – 0 60 – 60 – 60	11.40 13.37	– 1.97	– 33
116	60 – 60 – 0 60 – 60 – 60	15.62 17.75	– 2.13	– 36


without potash with potash

10th Colloquium of the International Potash Institute (79). They are summarized in the table.

The response of 33 to 36 kg tubers per kg K_2O is in line with the figure of 32 kg/kg K_2O which was calculated as average response ratio based on 769 results from various countries with appli-

Table 2.
Effect of increasing rates of potash on tuber yield and black spot damage. Three year average. (United Kingdom)

Treatment, kg K_2O/ha	0	200	400	600
Yield, t/ha	24.0	30.9	32.8	34.1
Response, t/ha	–	6.9	8.8	10.1
Response, kg/kg K_2O	–	34.5	22.0	16.8
Percentage of tubers showing internal black spot	32.3 %	23.7 %	19.5 %	15.4 %

cation rates of up to 100 kg K_2O/ha [99]. Similar data about the effect of potash on potato yield and quality were published in a recent paper from the Norfolk Agric. Stat., United Kingdom, one of the countries with the highest potato yields in the world [96]. As shown in the table, tuber yields increased up to very high rates of K application. In addition the incidence of internal black spot was much reduced.

K increases frost resistance

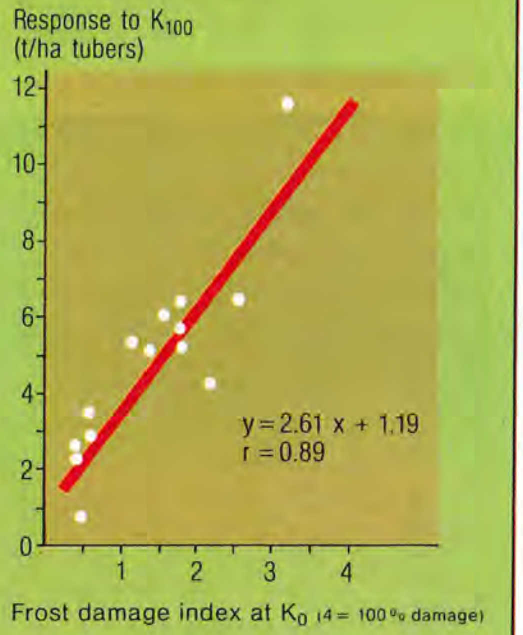
The increased frost resistance of plants well supplied with K is due to the favourable effect on the turgor of plant cells, regulation of osmotic pressure, resistance to dehydration, high sugar and carbohydrate reserves, high soluble protein, high cation content of polymer products and increased lipid content.

In perennial crops, resistance to late frost is sometimes more important than resistance to low temperatures in winter as late frost may occur when plant tissues have already dehardened.

The effect of potassium on the frost resistance of annual crops can be illustrated, for example, by results obtained in the Indian State of Punjab with potatoes.

In field experiments conducted on 14 alluvial soils during two consecutive years frost damage was more severe on soils testing low in available K (below 114 ppm exchangeable K). Application of potash fertilizer reduced the frost damage and increased tuber yields. There was a significant positive correlation between frost damage on K_0 plots and yield response to the application of 100 kg K_2O/ha [33].

Relationship between frost damage in potato and K nutrition (India)



Cassava (Tapioca)

Cassava is often grown on very poor soils. In Colombia, the Centro Internacional de Agricultura Tropical (CIAT) has investigated fertilizer problems in the Eastern plains of the country where soils are deep, rather well textured, but poor in plant nutrients. The results of pot experiments with soil from Carimagua (0.08 me exch. K/100 g soil) showed that potassium was very effective in improving the growth of cassava plants. K_2SO_4 was superior to KCl (Figure I). The superiority of K_2SO_4 over KCl, especially at high fertilizer levels, was due to the additional sulphate. This was confirmed in field experiments at Tranquero (0.05 me K/100 g) where 200 kg K_2O/ha as KCl plus elemental sulphur gave better results than KCl alone and was almost as effective as K_2SO_4 (Figure II). The application of potassium sulphate at 200 kg K_2O/ha almost doubled the root yield (18).

The substitution of sulphate of potash for potassium chloride fertilizer is thus recommended for crops grown on poor soils, not only because the sulphate can supply the needed sulphur but because high rates of chloride may actually exacerbate sulphur deficiency.

Figure I

Total dry matter production of six-month-old cassava plants as related to five levels and two sources of K at Carimagua (Colombia)

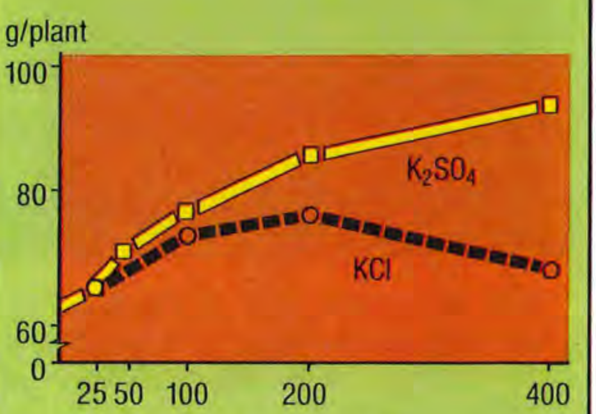
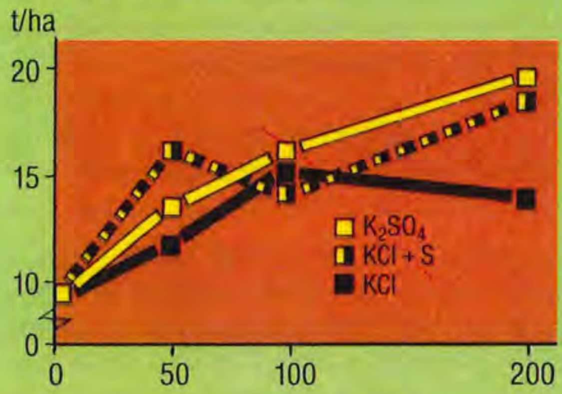


Figure II

Effect of varying levels of three K fertilizer sources on cassava root yields at Tranquero (Colombia)



On a strongly acid Ultisol at Onne/Nigeria the International Institute of Tropical Agriculture (IITA) tested the response of cassava under continuous cropping to potassium and magnesium using uniform levels of 60 kg N and 39 kg P_2O_5 per hectare. The results of the 3rd year, 1981, show high responses to both, K and Mg, applied as muriate of potash and kieserite (53).

Response of cassava roots to K and Mg, average of two cultivars (Nigeria)

Treatment, kg/ha* K	Mg	Yield, t/ha Fresh	Dry	Response (dry matter) kg/ha	kg/kg
					(kg/kg K)
0	40	14.3	5.68	–	–
30	40	15.5	6.32	640	21
60	40	17.8	7.11	1430	24
120	40	18.7	7.38	1700	14
					(kg/kg Mg)
120	0	16.3	6.03	–	–
120	20	18.4	6.67	640	32
120	40	18.7	7.38	1350	34

* 1 kg K = 1.205 kg K_2O, 1 kg Mg = 1.658 kg MgO

The favourable effect of kieserite (40 kg Mg = 228 kg kieserite) on the yield of dry cassava roots is remarkable.

Yams

Yams belong to the genus *Dioscorea.* Six hundred botanical species are known, but only about ten of them are commercially grown for human consumption. In large areas of West Africa, yams constitute a major staple food. Their nutritive value is distinctly superior to cassava, especially with regard to protein and vitamin C.

Like all other root and tuber crops, yams are highly responsive to potash. This was confirmed by results obtained in China at the Taiwan Agricultural Research Institute, Taichung Hsien. The addition of 50 kg/ha of P_2O_5 to 50 kg N, which is considered as a "normal" nitrogen dressing for this crop, gave a tuber yield increase of less than 700 kg/ha. When 50 kg potash was applied in addition, however, tuber yield was raised by more than 1,400 kg/ha.

Doubling the amount of potash lifted the yield by another 1.7 t, that is 31.8 kg more tubers per kilo K_2O (118).

Dioscorea alata L.

Fertilizer treatment kg/ha	Tuberous root yield kg/ha
	6 122
50 N	6 805
50 N + 50 P_2O_5	8 236
50 N + 50 P_2O_5 + 50 K_2O	9 985
50 N + 50 P_2O_5 + 100 K_2O	

kg tubers per kg K_2O → at 50 kg/ha .... 28.6; at 100 kg/ha 31.8

Sweet potatoes, like all other root and tuber crops, are very sensitive to potassium deficiency as shown in this picture of a fertilizer experiment laid out in Southern China. Note the healthy foliage of the treatment with N, P_2O_5, K_2O as against the appearance of the plants in the row without potash. Signs of K deficiency are pale green leaves, yellowish and necrotic leaf tips, followed by discoloration of margins and blades. Tuber yields are affected by a deficiency long before visual symptoms appear. To produce 40 t/ha of tubers, sweet potatoes take up about 190 kg N, 75 kg P_2O_5, 340 kg K_2O and 65 kg MgO. The amounts required may be considerably higher if the foliage is harvested twice for forage.

K and vegetables

In the decade from 1970 to 1980 world vegetable production has increased by nearly 30 per cent. In 1980 (3 yr. av.) it amounted to over 350 million tons. More than half of the total quantity was produced in Asia, of which about 80 mill. t in China and 40 mill. t in India. As can be seen on page 54 the nutrient requirements of most vegetables are very high. A cabbage crop of 70 t/ha may remove (in kg/ha) 370 N, 85 P_2O_5, 480 K_2O, 60 MgO, 80 S. Vegetable growers maintain a high level of soil fertility by the application of compost or manures supplemented by generous quantities of mineral fertilizers.

Chinese cabbage

Though mainly grown in East Asia, Chinese cabbage is gaining popularity in other regions as well, e.g. in Central Europe. In recent fertilizer experiments in Korea with Chinese cabbage (*Brassica pekinensis* Lour.) on a relatively poor red-yellow soil two nitrogen rates were tested in the absence and presence of two potash dressings (150 and 250 kg/ha of each nutrient) at a uniform level of 200 kg P_2O_5/ha. The results, see table, show the favourable influence of potassium on the effect of nitrogen at high N rates. The response to potash application was substantially larger at 250 kg N/ha than at 150 kg N/ha (91).

A field of Chinese cabbage strongly affected by potash deficiency. Note the withering, pale brownish, leaf margins.

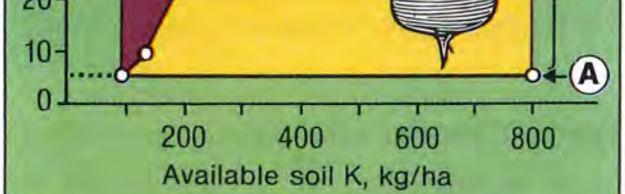
Effect of N × K interaction on the production of Chinese cabbage (Republic of Korea)

Potash treatment	Yield of cabbage, t/ha		Response to potash at two N levels			
			t/ha		kg cabbage/kg K_2O	
	N_{150}	N_{250}	N_{150}	N_{250}	N_{150}	N_{250}
K_0	87.0	103.9	–	–	–	–
K_{150}	93.4	115.2	6.4	11.3	42.6	75.3
K_{250}	96.2	116.4	9.2	12.5	36.8	50.0

Table beet

Vegetable growers often apply heavy rates of fertilizers and thus improve the fertility of their soils. It is therefore of interest to know the effect of the accumulated soil nutrients as compared to the direct effect of additionally applied fertilizer nutrients. In a field study with table beet at the New York State Agric. Experiment Station the response to residual and band-applied P and K was tested (97). The figure shows the results with regard to potassium. A fertility gradient, ranging from below 100 to above 800 kg/ha available soil K, had been established by annual potash applications of 0 to 560 kg K/ha for 9 years. In the 10th year potash treatments of 0 resp. 140 kg K/ha were superimposed to study the direct effect of K application. The response to these 140 kg K was, of course, higher in those treatments which had received little or no K earlier. But even in the plots with the highest residual K, the yield increase due to the additionally applied potash amounted to 9.1 t roots/ha or 20 %. In the treatments which had received 140 kg K/ha annually (200 kg/ha av. soil K), the direct effect (16.4 t/ha) was almost as high as the residual effect (18.7 t/ha). The results of this study confirm that it is advisable to build up soil fertility and to apply fertilizer to crops as required in accordance with the expected yield level.

Response of table beets to residual and band-applied potassium (USA)



(A) Yield without K application

(B) Residual effect of K applied over 9 years at annual rates of 35, 140 and 560 kg/ha

(C) Direct effect of 140 kg/ha, band-applied in the 10th year

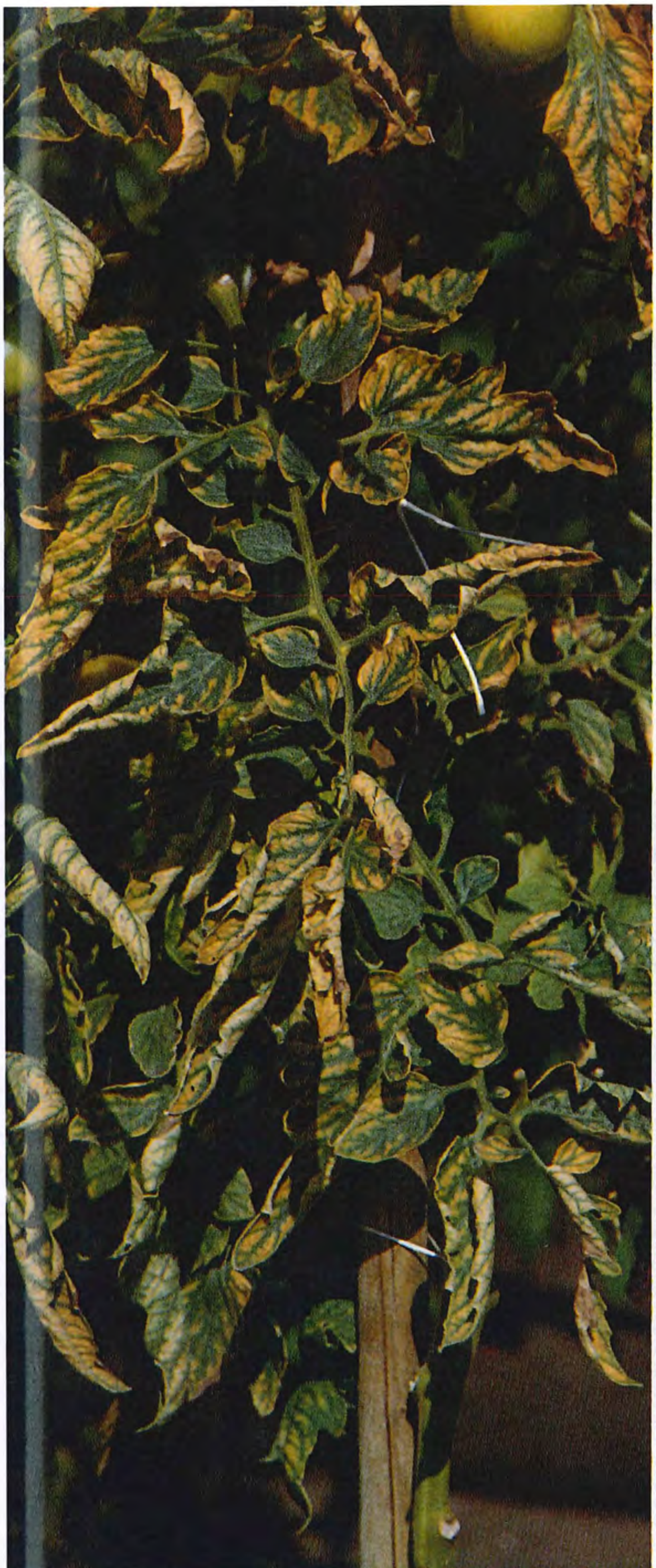
Cabbage cultivated in a field near Cuenca/Ecuador without potash fertilizer

Onions

In Egypt, as a consequence of the Asswan high dam, vegetables can be cultivated the whole year with perfect irrigation control. But the deposition of mud and the corresponding supply of nutrients from flood water has been eliminated. Thus vegetable growers make increasing use of mineral fertilizers. In experiments with onions (*var.* Giza 6), application of potash reduced the infection by white rot disease (*Sclerotium cepivorum* Berk) (119). Highest yields associated with low infection rates were obtained in treatments with the highest NPK levels. The summarized results of the study are shown below.

Effect of fertilizers on infection of onions with white rot and on bulb yield (Arab Republic of Egypt)

Treatment, kg/ha $N - P_2O_5 - K_2O$	Percent infected bulbs 1st yr.	2nd yr.	Yield of healthy bulbs, t/ha 1st yr.	2nd yr.
74– 0– 0	23	23	12.4	15.3
74– 94– 0	20	22	12.9	13.1
74– 0–60	17	18	13.8	16.4
74– 94–60	21	19	14.8	16.7
110–140–90	18	13	16.7	18.3



A tomato plant showing potash starvation. Leaf margins are dry and twisted upwards. Insufficient supply of potassium can lead to premature fruit drop, to cracking of the skin and to development of "greenback".

When tomatoes are Mg deficient, the leaves become brittle and show a tendency to curl from top to bottom. The veins remain green, while the intercostal areas turn yellow and die off.

K and fruit crops

Apples

As potassium is needed in fruit filling, it is translocated from the leaves into the fruits. Under conditions of K deficiency the leaf margins become brown and necrotic, as shown here with the apple var. Boskoop.

Potash reduces biennial bearing

In perennial fruit crops, "alternate" bearing is an undesirable phenomenon. It is a fact that a year with high production is often followed by another of low productivity. This is attributed to the physiological difficulty fruit trees have in replenishing their nutrient reserves within a short time. In certain years, low yields are due to damage by drought or frost or by parasites, etc. unrelated to this phenomenon. However, in some long-term fertilizer experiments carried out over 16 years in French orchards, it was possible to observe five true alternative bearing cycles [22]. How the yield performance in the "lean" years was influenced by the supply of K is shown in the table. Besides the control trees receiving no fertilizers and those receiving only NP, two potash fertilizer levels (150 and 300 kg K_2O/ha) were tested at uniform annual dressings of 75–150 kg N/ha and 75 kg P_2O_5/ha. The average fruit yields harvested during these 10 years are given in the table. Yield reductions for the five "lean" years were over 20 % in the treatments without K but negligible in the treatments with NP + 300 kg K_2O/ha. In similar experiments carried out in France, the importance of deep placement of potash prior to the establishment of the plantation was also investigated. 800 kg K_2O/ha were applied on a slightly K fixing soil. Afterwards the plots received annual dressings of 0, 100, 200 and 300 kg K_2O/ha with uniform rates of 150 kg P_2O_5/ha and nitrogen according to the tree development (up to 160 kg N/ha/yr). The average yield of three varieties obtained in eight harvests due to annual potash dressings (without initial deep placement) amounted to 16.7 t/ha/yr. It was profitably increased to 21.2 t/ha on the plots which received the basal pre-planting potash treatment.

Average apple yields (t/ha) obtained in 10 years of biennial bearing (France)

10 "alternating" harvests	0–0–0	NP	NP + 150 K_2O	NP + 300 K_2O
the 5 "fat" years	113	103	146	157
the 5 "lean" years	41	80	123	153
Yield reduction in "lean" years	- 64 %	- 22 %	- 16 %	- 2.7 %

Grapes

Grapes rank first among all the fruits listed in the FAO production yearbook. In 1980 (3 yr. av.) world production amounted to 66 million tons. Grapes are cultivated in many countries of the temperate as well as the tropical zone. They are used for the production of wine or raisins, or for direct consumption as table grapes. Of the less industrialized countries, India is the one with the highest average grape yield (almost 20 t/ha in 1980). In India the cultivators of table grapes pay special attention to an ample supply of plant nutrients through balanced application of manures and fertilizers. In fertilizer experiments with seedless grapes by the Indian Institute of Horticultural Research in Bangalore, the best results in the 1981 and 1982 harvests were obtained with 500 to 1000 kg K_2O/ha (as potassium sulphate) in the presence of 300 kg N/ha [117a].

Wine growers are very particular about the quality of their products. They know that fertilizers are among the major factors influencing not only grape yields, but also wine quality. In this connection potassium and magnesium are of special importance [104]. On a Mg deficient soil in Germany the application of kieserite improved wine quality noticeably. After treatment of the soil by a meliorative dressing of 357 kg MgO/ha the wine developed more of the flavour typical for the cultivar grown than without magnesium treatment [14].

A vine, var. Müller-Thurgau, showing symptoms of potassium and magnesium deficiency simultaneously, a rather uncommon phenomenon. Whereas the brown and necrotic leaf margins denote the lack of K, interveinal chlorosis is the typical Mg deficiency symptom. The combined deficiency caused premature fruit drop, reducing yield by about 30 per cent.

Citrus

Citrus fruits are major export crops in quite a number of countries. Citrus and citrus products are esteemed not only as delicious fruits but also because of their vitamin content. The abundance of K in the juice of oranges is another valuable quality factor. A diet devoid of common salt (NaCl) is indicated for a number of diseases. With reference to the high K and low Na content of the juices of citrus fruits medical specialists speak of "oral potassium therapy" (see also 'K, Mg and Na in human and animal health', page 45).
Potash fertilizers, therefore, are essential not only for an increase in citrus yields, but also for improvement in the quality of citrus fruits. High levels of K usually increase the size of the fruits and the acidity of their juice. Vitamin C content also increases with K fertilization [19].
The effect of K application on citrus yield was demonstrated in a 5-year experiment carried out with "Marsh" grapefruit trees at the Citrus Exp. Station of the University of Florida/USA where two forms of K fertilizers were tested at increasing rates of K_2O [67].

Except for the first year, doubling the potash rate from 79 to 157 kg/ha K_2O increased the yield by 20–30 %. Preharvest fruit drop was significantly lower with the high-K treatments. There was little difference in yield between potassium chloride and potassium sulphate treatments but there was less fruit drop with the K_2SO_4 treatment.

Potassium deficiency has been observed in a number of citrus plantations in South Africa, even on soils which had so far been considered well supplied with available K. Deficiency symptoms occurred notably after the suspension of farmyard manure application. According to the Nelspruit Citrus and Subtropical Fruit Research Institute it is not possible to correct the deficiency with a single application of K.

Standard recommendations for Valencia oranges are 540 g K_2O/tree, for Navel oranges 270 g K_2O/tree per year in the form of KCl or K_2SO_4. If there is no response, the amount should be increased, but not beyond 4.5 kg KCl per tree [12].

Effect of potash on grapefruit yields in Florida (USA)

Year	Effect of K source (av. of 12 plots)			Effect of K_2O rates (av. of 8 plots)			
	KCl	K_2SO_4	Sig.	79 kg/ha	157 kg/ha	236 kg/ha	Sig.
Yield in boxes/tree							
1968	2.97	2.79	n.s.	2.89	2.87	2.88	n.s.
1969	2.75	2.84	n.s.	2.24	2.81	3.33	**
1970	4.04	4.05	n.s.	3.28	4.33	4.54	*
1971	5.21	4.70	n.s.	4.43	5.24	5.19	n.s.
Fruit drop, boxes/tree							
1969	0.43	0.33	*	0.50	0.33	0.36	n.s.
1970	0.23	0.19	n.s.	0.34	0.17	0.14	*
1971	0.21	0.16	**	0.26	0.16	0.13	**
Weight, g/fruit							
1968	343	352	n.s.	337	350	364	**
1969	372	375	n.s.	349	374	399	**
1970	367	371	n.s.	328	382	398	**
1971	473	468	n.s.	432	481	499	**

n.s. = no significance, * = significant at 5 %, ** = significant at 1 %

Bananas

A banana plant severely affected by premature yellowing caused by potash deficiency. The fruit bunch shows a much reduced number of hands with badly shaped and twisted fingers not suitable for marketing.

Bananas are second only to grapes as regards the quantity produced: 40 million tons in 1980 (3 yr. av.). The banana is an important food crop, especially in the tropics. Most of the production is consumed locally. About 1/6 is exported. Bananas can produce very high amounts of dry matter in a relatively short time. Rapid plant growth under humid tropical conditions is possible only if the nutrient supply is optimal. A banana plantation producing 50 t/ha of fresh fruit per year may extract annually about 1500 kg K/ha from the soil along with 450 kg N, 60 kg P, 215 kg Ca, 140 kg Mg and 17 kg S (69).

In parts of Central America, the most important region for banana export, severe yield decreases have been observed at some banana plantations due to exhaustion of the soil, notably of its potassium reserves. How the production of the cultivar "Grand Nain" recovered after K_2SO_4 application in a plantation in Panama is shown in the table (110).

Potassium deficiency symptoms have been described as "leaf fall", "premature yellowing" and "banana yellows". Banana plants well supplied with K may contain more than 5 % K in the dry matter (3rd leaf). A concentration below 3 % in the lamina or midrib of leaf No. 3 is considered critical (69).

Effect of K on yield and some agronomic characteristics of banana (Panama)

Treatment (kg/ha) N – P* – K	No. of bunches/ha Harvested	Lost	Mean bunch weight kg	Yield t/ha**	Nutrient contents in the lamina (% DM)*** K	Ca	Mg
390–112– 0	2741	100	23.3	70.4	1.46	0.93	0.44
390–112–450	2797	77	28.8	88.6	2.54	0.84	0.39
390–112–900	2932	43	31.2	100.8	2.93	0.79	0.35

* Mean of P treatments ranging from 0 to 225 kg P/ha
** Plant crop plus ratoon crop
*** First ratoon crop

Pineapples

Pineapples need large amounts of N but even larger amounts of K. In addition to its favourable influence on the yield, potassium has a beneficial effect on the weight and size of the individual fruit, the firmness of the fruit flesh as well as on the sugar and acid contents (29).

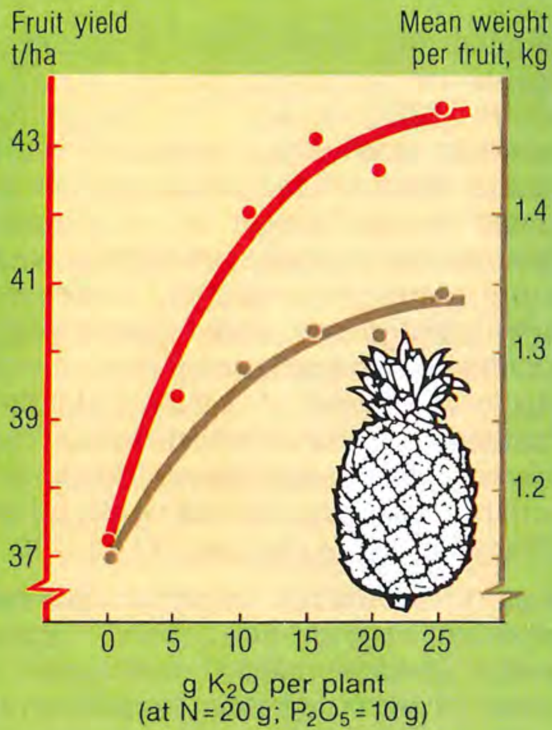
In Brazil the pineapple has been recommended as a crop for cultivation on savanna soil, the so-called "Cerrado", due to its adaptation to low pH, low soil P levels and its relative drought tolerance. Research carried out with the cultivar "Pernambuco" on a dark-red Latosol near Brasilia revealed little or no response to phosphorus but strong responses to nitrogen and potassium applied as K_2SO_4. From the results given in the table the authors concluded that higher rates of N and K would have increased the yield further (135). At a planting density of 35,000/ha the highest N and K rates used in the experiment correspond to 315 kg N and 525 kg K_2O/ha.

Response of pineapples to increasing rates of nitrogen and potassium on "Cerrado" soil. Fruit yield in t/ha. (Brazil)

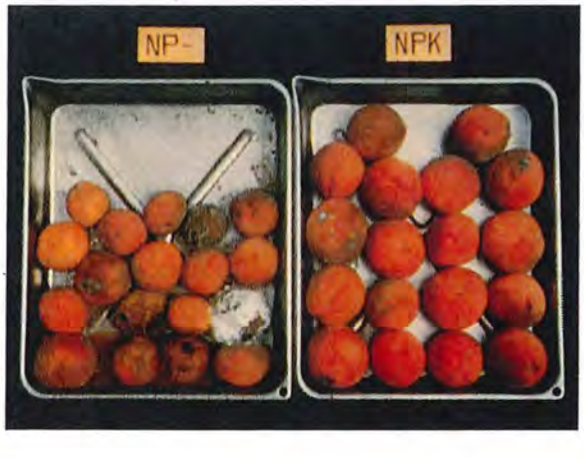
Levels of K (g K_2O/plant)	Levels of N (g N/plant) 3	6	9	Mean
5	11.9	19.3	17.0	16.1
10	13.5	18.2	19.7	17.1
15	18.6	18.3	24.1	20.3
Mean	14.7	18.6	20.3	

Effect of increasing potash rates on fruit yield and mean weight of pineapples (China)(120 b)

(33,000 plts/ha)



K enhances keeping quality of fruits



In contrast to fruits from trees adequately supplied with potash, potash-deficient fruits are prone to greater respiration and transpiration during storage and soon lose their value for marketing due to accelerated shrivelling and decay. The results of a storage experiment with **peaches** show these differences quite clearly.

Photo: American Potash Institute

Assorted tropical fruits of South America. Among them mangoes, papaya, grapefruit, orange, lime, lemon, quince and black maize, and some less common fruits, such as prickly pear, passion fruit, mammee, ciruelo, cahiua, granadilla, pacae and lucuma.

Mango

Little has been published on the mineral nutrition of the mango tree, although mangoes occupy the fifth place in world fruit production after oranges. The most important producer country is India where mango trees occupy more than 50% of the total area under fruit crops [121]. In a four year study by the Indian Institute of Horticultural Research in a mango orchard near Lucknow it was found that potash application up to 1–1.5 kg K_2O/tree greatly increased the number of fruits per tree [123]. Foliar K values in the "off" year 1978 were somewhat higher, but during the "on" years they remained below the critical level of 0.5% K [90].

According to the results of investigations carried out in Venezuela it was confirmed that nitrogen and potash are the most important nutrients for mango [4].

Effect of K application on leaf K and yield of mango (India)

Treatment kg K_2O/tree	1977*		1979*		Mean of 2 yrs. No. of fruits
	Leaf K %	No. of fruits	Leaf K %	No. of fruits	
Control	0.304	354	0.387	214	284
0.5	0.391	389	0.401	237	313
1.0	0.378	374	0.417	317	346
1.5	0.397	506	0.423	306	406
2.0	0.433	485	0.415	250	368

* 1976 and 1978 were "off" years

K and oil crops

Palm oil is the most important item in the world trade in vegetable oils. In 1980 total exports of palm oil amounted to 3.6 million tons (together with palm kernel oil: 4.0 mill. t), followed by soybean oil (3.2 mill. t) coconut oil (1.2 mill. t) and sunflower oil (1.1 mill. t). Large countries, e.g. India or Pakistan, which are self-sufficient in food grains, still have to import considerable quantities of edible oils.

Oil palm

Palm oil production has increased from 2 to 5 million tons between 1970 and 1980. Two thirds of the total quantity originate from Malaysia and Indonesia. As a result of the expansion in oil palm acreage, production is bound to increase further. The oil palm is the most efficient producer of vegetable oil per unit area and year. While annual crops (groundnuts, soybeans, sunflowers, rapeseed, etc.) or coconuts in general may produce 1–2 t of oil/ha, the figures for oil palms are 5–6 t of oil/ha. The maximum yield potential is about 8 t/ha. It may reach 10–12 t/ha by the turn of the century [133]. In accordance with the extremely high growth rate of the oil palm, the plant nutrient requirements are enormous (see p. 55). Of the major plant nutrients, potassium is taken up in the largest quantity. A substantial amount is contained in the harvested portion, the fruit bunches. About 60 % of the potassium taken up by the palms is permanently removed from the soil [125]. At an uptake figure of 300 kg K_2O/ha the removal would amount to 180 kg K_2O/ha, not considering leaching of K from leaves by rainfall. The regular application of potash, therefore, is the most important aspect of oil palm fertilization. On soils, where Mg deficiency is suspected or acute, magnesium sulphate has become an integral part of the fertilizer programme in many oil palm producing countries. An example of the interaction of potassium chloride and magnesium sulphate (kieserite) application is shown in the table, which summarizes experimental results from the Ivory Coast [51]. At the lower level of KCl, the response to $MgSO_4$ application was insignificant (2 kg/palm). But it increased ten-fold at the high potash rate of 3 kg KCl/palm. On the other hand the effect of potash was quadrupled (from 6 to 24 kg/palm) when kieserite was applied along with KCl.

Oil palm leaflets. From left to right: normal, K-deficient, Mg-deficient.

Effect of potassium, magnesium and sulphur on oil palm yield (Ivory Coast)

Potash rate kg KCl/palm	Fresh fruit bunches, kg/palm				
	Without $MgSO_4$	Response to KCl	With 0.5 kg kieserite/palm	Response to KCl	Response to $MgSO_4$
0.5	87	–	89	–	2
1.5	90	3	104	15	14
3.0	93	6	113	24	20

Soybeans

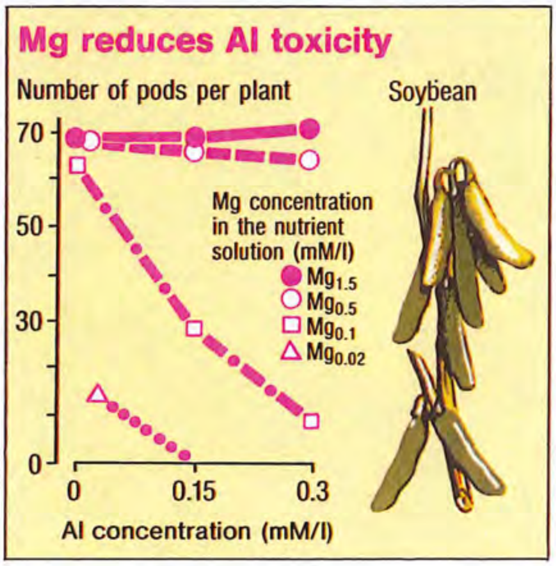
The USA and Brazil are the most important soybean producing countries. Soybeans contain large amounts of N supplied mostly through nitrogen fixation by nodule bacteria *(Rhizobium japonicum)*. As with other leguminous crops, N fixation is favourably influenced by phosphorus and potassium. This was confirmed in an investigation on a neutral clay loam soil in Orange, Virginia/USA, where P and K increased the number of nodules per plant (54). The effect of K application on soybean yield at 2 levels of P is shown in the table. There was a remarkable response to K in the P-treated plots up to the highest rate of K application. 2,220 kg of soybeans per 112 kg of K represent an efficiency of nearly 20 kg grain/kg K.

Young soybean plant showing severe K deficiency

Effect of two rates of P and four rates of K on yield of soybean (av. of two years (USA)

K rate (kg/ha)	Soybean yield (kg/ha)		Response to K at P = 60 kg/ha (kg grain/ha)
	P = 0	P = 60 kg/ha	
0	1607	1600	–
28	2756	2955	1355
56	2787	3216	1616
112	2940	3820	2220

Aluminium toxicity is a serious constraint to plant production on acid soils. This problem, widespread in the tropics and subtropics, can be somewhat diminished by the breeding of Al-tolerant varieties. The range of this Al tolerance can be extended by increasing the Mg concentration in the soil solution, as experiments have proven with barley, oats (38,39) and soybeans, as shown in the graph (40). In the absence of Al pod production was quite normal at Mg concentrations between 0.1 and 1.5 mM/l, though not at the extremely low Mg level of 0.02 mM. In this case pod development ceased completely when the Al concentration was raised to 0.15 mM/l. At 0.1 mM Mg/l this Al concentration induced or aggravated Mg deficiency to such an extent that pod production per plant decreased from 65 to less than 30. It decreased further when the Al concentration was increased to 0.3 mM/l. The plants receiving more Mg, however, showed only slight or no "toxic" effects of high Al levels on pod production.



Groundnuts

India, China and the USA are the main producers of groundnuts. In Africa the groundnut is an important export crop for a number of countries. Since groundnuts are leguminous crops, their response to N is generally small. Fertilizer mixtures contain only a small amount of N as "starter" nitrogen. As mentioned for soybeans, N fixation by the rhizobia is improved when the plants are well supplied with P and K. Calcium plays an essential part in seed development. In many cases groundnuts respond to the application of sulphur. A typical example from Senegal is summarized as follows [92].

Response of groundnuts to potassium and sulphur (Senegal)

Potash application ($kg\ K_2O/ha$)	0	12	24
	Groundnut yield in pods (kg/ha)		
Without sulphur	933	1220	1310
With sulphur	833	1340	1640

With 28 kg N/ha the response to potash (24 kg K_2O/ha applied as 40 kg KCl) was 377 kg/ha without and 607 kg/ha with sulphur application, a very strong interaction between K and S.

A groundnut plant growing on a K deficient soil

K deficiency symptoms in coconut palms start as small yellow spots, profusely scattered on the leaflets

Coconuts

In recent years hybrid coconuts which have an annual yield potential of 6–8 tons of copra or 3.6–4.8 tons of oil/ha have become available [133]. However, even ordinary coconut palms can produce quite high yields under proper field and fertilizer management. The most important coconut fertilizer is muriate of potash, containing K and Cl, the two elements taken up by the palms in the largest quantities. The effect of KCl application on nut and copra yield was shown in a long-term fertilizer experiment in the Philippines, the country with the largest copra production in the world.

The table shows part of the results (76). The highest number of nuts was obtained with 2 kg KCl/palm. But a further increase in potash application had a strong positive effect on nut size and copra per nut. The highest KCl rate of 8 kg/palm produced the highest copra yield and was the most profitable of all the treatments. The importance of chloride is illustrated by the leaf analysis values. The copra yield increased in parallel with the Cl contents, whereas the highest leaf K level was already reached with the 1 kg KCl treatment.

Effect of KCl on annual average production of nuts and copra (average of 5 years) and on nutrient contents in leaf No.14 (Philippines)

K treatment (kg/palm/year)		No. of nuts per palm	Copra (g/nut)	Copra (kg/palm)	Copra (t/ha)	Leaf nutrient contents (% dry matter)			
KCl	(K_2O)					K	Ca	Mg	Cl
–	–	87	159	14	2.16	1.27	0.50	0.22	0.04
1	(0.6)	110	187	21	3.22	1.46	0.45	0.21	0.32
2	(1.2)	129	192	25	3.87	1.39	0.43	0.20	0.55
4	(2.4)	112	215	24	3.76	1.35	0.40	0.19	0.57
8	(4.8)	114	250	29	4.45	1.43	0.48	0.22	0.70

The importance of K and Cl for hybrid coconuts becomes clear from the uptake figures of these nutrients in comparison with other elements (94). 138 bearing palms per hectare yielding 6.7 t copra will remove the following quantities.

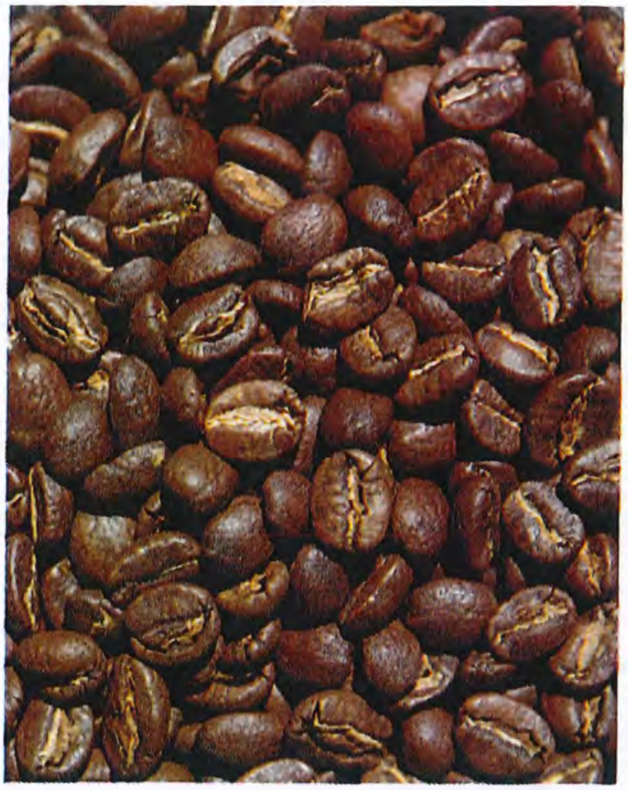
Nutrient removal/immobilisation by high-yielding hybrid coconut palms (kg/ha)

Nutrient	N	P	K	Ca	Mg	Cl	S
Removal in harvested portion	108	15	193	9	15	125	9
Annual uptake by whole stand, including trunks and fronds	174	20	249	70	39	249	30

Hybrid coconut palms require well balanced fertilizer applications right from planting to utilize their high yield potential. KCl should be the choice, because potassium and chloride are required by the palm in large quantities, plus kieserite to cover the Mg and S needs.

K and stimulants

Coffee



Over 60 % of the world coffee harvest is produced in Latin America, 37 % alone in Brazil and Colombia. Coffee growers in these countries attach great importance to proper fertilizer usage. Manuring schedules have been worked out according to soil types and soil nutrient contents, rainfall and rainfall distribution, yield expectation, etc. Most important is the adequate supply of nitrogen and potassium. An example for the yield response to these two nutrients is given in the table, which summarizes part of the results of numerous NPK experiments carried out in Colombia at 8 localities over four to five years (134). Application of N and K resulted in high and profitable responses.

Response of *Arabica* coffee to N and K application (Colombia)

Treatment kg/ha	Var. Caturra 5 localities (4–5 years)		Var. Borbón 3 localities (4–5 years)		Weighted average	
	Yield	Increase	Yield	Increase	Yield	Increase
N (SoA)	kg/ha		kg/ha		kg/ha	
0	2223	–	2287	–	2248	–
120	3556	1333	3123	836	3394	1146
240	3783	1560	3313	1026	3607	1359
K_2O (SoP)						
0	2778	–	2204	–	2555	–
120	3219	441	3281	1077	3243	688
240	3461	683	3321	1117	3408	853

On Mg deficient soils the application of kieserite is advisable. Data from Brazil show that the application of magnesium sulphate was very effective both in a year of low coffee yield, 1976, and in a year with good growing conditions, 1977 (105).

Effect of magnesium sulphate application on yield of young coffee on Mg-deficient soil (Brazil)

Treatment	1975 Yield kg/ha	%	1976 Yield kg/ha	%	1977 Yield kg/ha	%
No fertilizer	583	62	306	81	1513	63
NPK	935	100	376	100	2405	100
NPK+$MgSO_4$	1175	126	549	146	3380	141

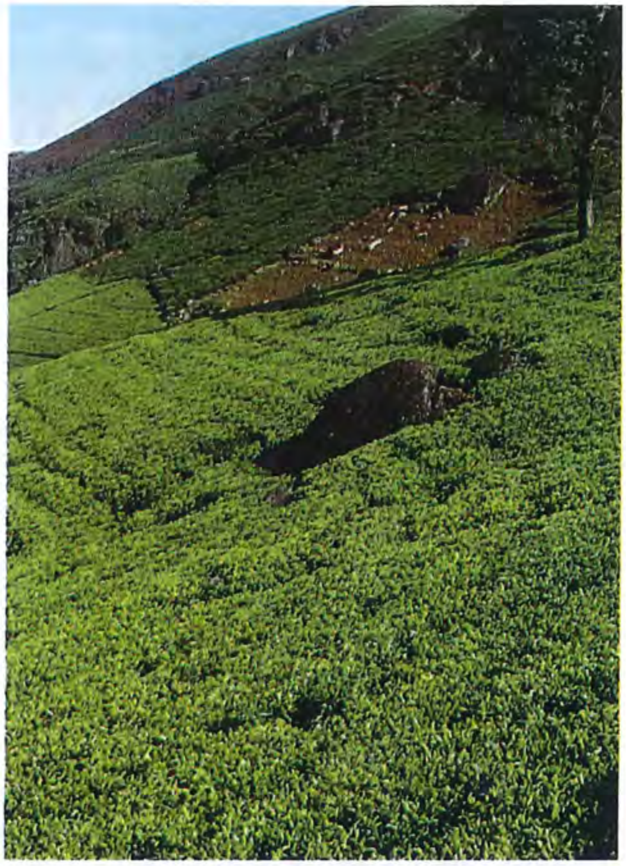
Tea

India is the largest producer of tea in the world, followed by China, Sri Lanka and the USSR. Between 1970 and 1980 tea output in India increased by one third, mainly on account of an appreciable rise in the yield per unit area which increased from 1.2 to 1.5 t made tea/ha. Improved management of tea gardens including the adoption of modern concepts of fertilizer use have contributed to this development.

In comparison with other plant parts, young leaves, the product harvested in tea plantations ("Two and a Bud") contain high amounts of nitrogen. The supply of adequate amounts of N is therefore one of the most important factors for the production of an economically profitable yield. However, tea researchers very soon began to recognize the importance of K for bush formation of young tea, for yield stabilization, for recovery after pruning, and for balancing high rates of N applied to vegetatively propagated tea [(23, 107)]. As a result of these efforts fertilizer application to tea in South India (75,000 hectares) about 1980 was well balanced, with a 1:1 ratio of $N:K_2O$, at an average level of about 180 kg N, 40 kg P_2O_5 and 180 kg K_2O per hectare [(52)]. Average yields in 1980 (3 yr. av.) amounted to 1.75 t made tea/ha.

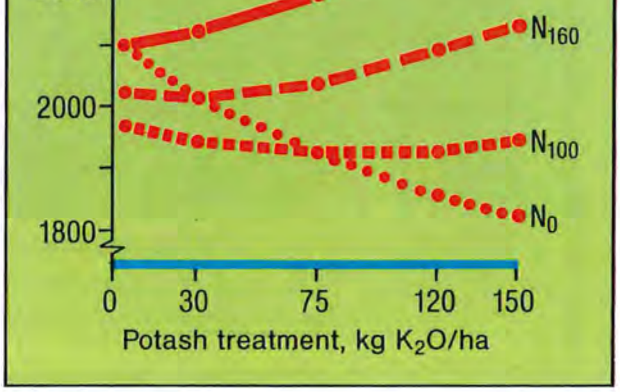
In Assam (North East India) a strong, positive interaction between N and K was observed at higher levels of nitrogen appliation. As can be seen in the figure, an increase of the K_2O rate above the

Older tea leaves showing typical symptoms of nutrient deficiency. Left: –Mg, right: –K.



maximum level of 150 kg/ha tested in the respective experiments would probably have resulted in a further yield increase at the highest N rate [(117)].

One additional reason for the positive influence of KCl on the efficiency of fertilizer nitrogen may be its contribution to the reduction of nitrogen losses, which was confirmed for Sri Lanka tea soils [(31)].

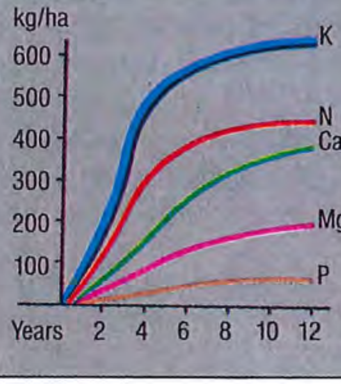


Cocoa

In recent years the Ivory Coast has replaced Ghana as the most important cocoa producing country in the world. There has also been a rapid expansion of cocoa plantations in Malaysia, partly under coconuts, partly as monocrop cocoa with lateral shade. Fertilizer response is sometimes erratic. It is influenced by the degree and nature of shade. But there is no doubt that cocoa trees immobilize considerable amounts of nutrients before they come into bearing [70, 124]. As shown in the figure, nutrient uptake follows a sigmoid curve with a steep increase from the second to the fifth year, the period of rapid growth including the first years of pod production. Within seven years from planting, K uptake reaches 600–700 kg/ha or 720 to 840 kg/ha in terms of K_2O.

Cocoa plants are heavy potash feeders (Malaysia)

Nutrient uptake of cocoa plants up to 12 years from planting



In Malaysia the response of young cocoa trees to N, P, K, Mg fertilizer application was tested on a sandy clay loam [75]. In general the best yields were recorded on plots which had received all the nutrients involved in the treatments. The largest responses were obtained from potash application. As shown in the table, the average yield increase due to K was about 300 kg of dry beans/ha or 3 kg/kg K_2O. Doubling of the K rate had no additional effect on the yield.

Response of young cocoa (1970 planting) to potassium application (Malaysia)

Fertilizer rates (kg/ha)	Yield of dry beans (kg/ha)				Av. annual response to potash	
N – P_2O_5 – K_2O – MgO	1973	1974	1975	1976*	kg/ha	kg/kg K_2O
82 – 38 – 0 – 11	578	888	1965	1496	—	—
82 – 38 – 103 – 11	840	1269	2354	1700	309	3.0
82 – 38 – 206 – 11	884	1271	2355	1693	319	1.6

* Yield decreases caused by drought

Ginger leaves showing yellow and necrotic leaf tips and margins indicating strong potassium deficiency

Litchi leaves on an older branch. Dark brown and necrotic apices and margins are the typical potash deficiency symptoms.

Tobacco

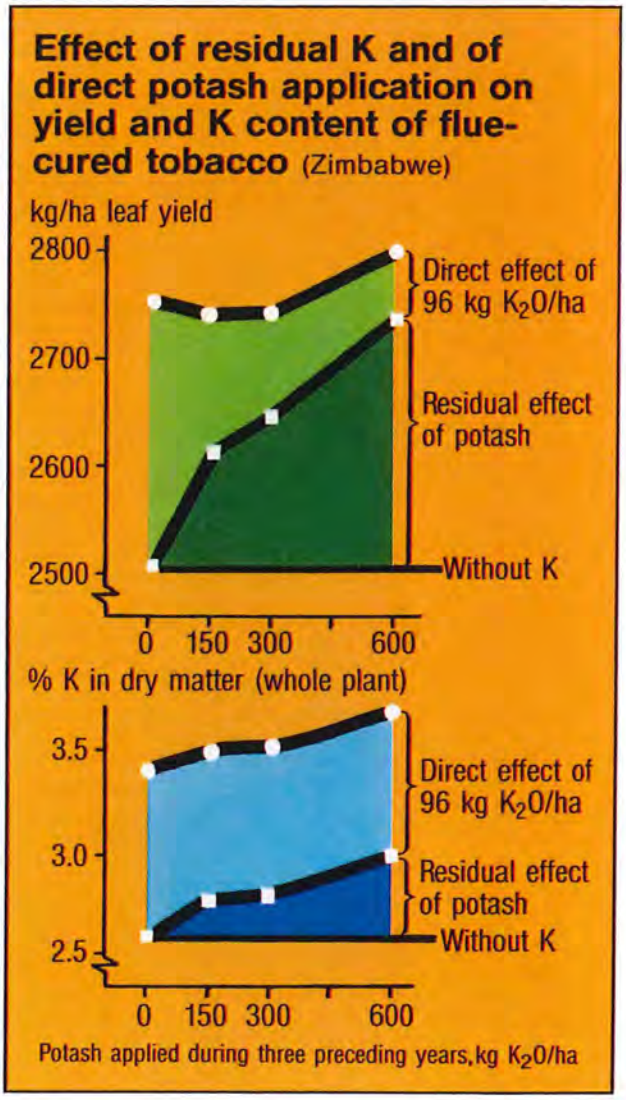
Zimbabwe is famous for its high quality flue-cured Virginia tobacco. In 1980 the country ranked third in world tobacco exports after the USA and Brazil. Potassium is regarded as the most important fertilizer element for the cultivation of tobacco. Tobacco is one of the few crops where "luxury consumption" of K is desirable. The quality of tobacco is usually improved by potassium far beyond the level of K needed for maximum yield. A high leaf K value is associated with favourable physical characteristics, such as burning quality, colour, fineness, elasticity, taste and colour of the ash.

In Zimbabwe the residual effects of N, P and K applications on subsequent growth of flue-cured tobacco were tested in a series of experiments. While the residual effect of N was very small, residual P and K increased the uptake and the concentration of these nutrients in the plant in line with increasing rates of previous application (112). The influence on tobacco yield was erratic. In the last year of a 3-year-study the yield of flue-cured leaf increased from 2502 to 2743 kg/ha due to the residual effect of 606 kg K_2O/ha (3 yrs × 202 kg K_2O).

The direct effect of 96 kg K_2O/ha applied in that year resulted in a production of 2765 kg/ha on the plots without residual K and a further increase to 2825 kg/ha on the plots with 606 kg/ha residual K_2O.

In Zimbabwe typical fertilizer rates for flue-cured tobacco are (kg/ha):
52 N + 117 P_2O_5 + 112 K_2O + 30 MgO (55a).
Potash is generally applied in the sulphate form.

In no other crop is the use of potassium sulphate of such decisive economic importance with regard to the quality of the crop. Here the reason for the use of K_2SO_4 is not so much the fact that this fertilizer also contains sulphur but that it does not contain chloride. Cl has a negative effect on leaf quality. It reduces the burning and glowing properties, promotes protein formation and imparts



a sweet unpleasant taste and aroma. Cl renders the leaf hygroscopic so that drying and fermentation become difficult and losses due to mildew and rotting may occur [140].

First visual symptoms of potassium deficiency are interveinal mottling with yellow or chlorotic spots starting at the tip of the leaf. They are followed by necrosis of tips and margins, eventually by shedding of the dead tissue. Where symptoms of K deficiency occur, the loss is tremendous not only in crop yield but because of the extremely poor quality of K deficient tobacco leaves (see picture on p. 89, taken at the Central Tobacco Research Institute, Rajahmundry/India).

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Vol. XXII, No. 1/1981

Potassium sulphate for tobacco

fertilizers in pictures

Cuba - 1931

K_2SO_4 improves combustibility of high-grade tobacco

Glowing time (seconds)	12	28	104
Fertilizer treatment	NP	NPK_1	NPK_2

*

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The production of first-grade leaves is a prerequisite for profitable tobacco growing. This requires sophisticated techniques of cultivation, including an ample supply of potash fertilizers low in chloride. The recommended form is therefore potassium sulphate. Agronomists in France even advise not to use potassium chloride for the crops preceding tobacco in the rotation.

Size, colour, structure and elasticity of the leaves as well as their combustibility (smoulded area) and glowing time are markedly increased at higher K contents. The longer glowing time due to K application was already demonstrated in experiments carried out about 50 years ago at a plantation near Pinar del Río/Cuba. The tobacco leaves from NP treatments without potash burned only 12 seconds, whereas the glowing time more than doubled in leaves of tobacco plants which has been treated with NP plus potassium sulphate and was even remarkably increased with reinforced potash application.

Source: Ernähr. der Pflanze, Vol. 26, No. 15/16 (1932)

Sulphate of potash for quality

The properties of potassium sulphate as a special fertilizer deserve particular attention. Not only is "SoP" essential for tobacco and certain other industrial crops but there are several characteristics which give this material superior qualities as compared with other fertilizers and indicate its use on other crops.

Special properties of sulphate of potash

- Two-nutrient fertilizer
- Low salt index
- Excellent physical properties
- Absence of chloride
- Fertilizer for high quality crops

Two-nutrient fertilizer

Sulphate of potash, K_2SO_4, supplies two plant foods: potassium and sulphur. Potassium is taken up by the roots as the cation K^+, sulphur as the anion $SO_4^{=}$, thus the two components of potassium sulphate can be fully utilized by the plant. Sulphate of potash is actually a more concentrated fertilizer than muriate of potash even though its K_2O content is lower:

Sulphate of Potash	Muriate of Potash
50 % K_2O + 18 % S	60 % K_2O 0 % S
68 % nutrients	60 % nutrients

Low salt index

Millions of hectares in arid and semi-arid areas are affected by salinity. High salt concentrations in the soil solution also occur in intensive vegetable growing and in glasshouses where heavy rates of fertilizer are applied. In all these cases it is imperative to use fertilizers with a low salt index. Here K_2SO_4 is definitely superior to KCl because the salt index of sulphate of potash is less than half that of muriate of potash.

Excellent physical properties

Sulphate of potash is non-deliquescent and stores well even in damp climates. It causes no problems when it is a constituent of fertilizer mixtures. It is available either as a crystalline powder (particle size 0.5–0.01 mm) or in granular form (particle size 3.6–0.8 mm).

Absence of chloride

Sulphate of potash is virtually free from chloride – containing normally less than 2.5 % Cl. K+S also offers a special 'low chloride' quality with less than 1 % or even 0.5 % Cl since these specifications are requested in certain cases.

Fertilizer for high quality crops

Presence of chloride is no major problem in areas with abundant rainfall. But there are a number of Cl-sensitive plants for which sulphate of potash is the correct K fertilizer even in humid climate. Crops which are very prone to chloride damage and on which Cl-containing fertilizers should not be used are tobacco, soft fruits, stone fruits, melons, peas, beans, onions. Other crops for which there is well-documented evidence that sulphate of potash should receive preference are potatoes, rape and other oil seeds, flax and other fibre crops, tree fruits including citrus, grapes, pineapples, high-quality vegetables, flowers, forest and ornamental trees.

K_2SO_4 improves the quality of

- Tobacco (leaf size, combustibility, glowing time)
- Potatoes (taste, starch content)
- Sugarcane (juice purity at high K rates)
- Rape and other oil seeds (oil content)
- Flax and other fibre plants (fibre quality)
- Fruits (colour, flavour)
- Vegetables (dry matter content, keeping properties during storage and transport)
- Pulses (protein content)
- Flowers (colour, durability)

K and forage crops

According to the FAO statistics for 1980 the worldwide area under permanent meadows and pastures of 3117 million hectares was more than twice as large as the 1452 million hectares of arable land and land under permanent crops (such as fruit trees or plantation crops). Most of the grassland is used extensively and produces poor yields because of too low rainfall or other constraints. However, under favourable conditions very high yields can be obtained from intensively managed grassland or from forage crops grown on arable land.

Grassland

Grasses generally respond to nitrogen application with a large increase in dry matter production. The efficiency of the fertilizer nitrogen is enhanced when the other growth factors are improved. As an example of the synergistic effect of nitrogen and potassium on the dry matter yield of orchard grass or cocksfoot (*Dactylis glomerata* L.) the results of a long-term fertilizer experiment in Aspach/France are shown in the table [22]. The average yield increase due to an annual application of 450 kg K_2O/ha over the 11 years of the experiment amounted to 33 %. But this effect of K varied very much with the level of N applied, from 2 % at 110 kg N/ha to 63 % at 330 kg N/ha. The increase of 5.33 t/ha (from 8.46 to 13.79 t/ha) by 450 kg K_2O/ha was equivalent to a response of 11.8 kg dry matter/kg K_2O.

In the case of mixed swards of grasses and legumes, potash application not only increases the yield but it influences the composition of the sward by promoting the growth of the legumes. In this way biological nitrogen fixation can be greatly increased. The table (upper right) gives the average annual amounts of N contained in the dry matter of alfalfa-orchard grass and ladino clover-orchard grass as influenced by annual applications of P and K (N was not applied) in the last 5 years of a 15 year fertilizer experiment on sandy loam soil derived from volcanic

Mean annual dry matter production of orchard grass (t/ha) in an eleven year NK experiment (France)

Treatment (kg/ha)	0 K_2O	150 K_2O	300 K_2O	450 K_2O
110 N	8.11	8.19	8.71	8.29
220 N	8.85	10.29	10.72	11.02
330 N	8.46	10.36	11.98	13.79
440 N	8.98	10.35	11.70	12.68
Mean	8.60	9.80	10.78	11.45
0 K_2O = 100	100	114	125	133

N uptake of forage (kg N/ha) in a long-term PK experiment, average annual amount during the 3rd five-year period (Japan)

Treatments (kg/ha)	K_0P_0	$K_{250}P_0$	K_{250}* P_{44}**	Effect of P	Effect of K
Ladino clover/ orchard grass	61.8	179.7	254.3	74.6	117.9
Alfalfa/ orchard grass	54.8	192.5	282.5	90.0	137.7

* K_{250} = ~ 300 kg K_2O/ha ** P_{44} = ~ 100 kg P_2O_5/ha

ash in Hokkaido/Japan [59]. Through K application the annual biological nitrogen fixation was raised by 118–138 kg N/ha.

A large proportion of leguminous plants in the sward improves the quality of the fodder in many respects. The palatability is enhanced, the protein content increases and – since legumes contain substantially more minerals (especially Ca and Mg) than grasses – the mineral content of the forage is also raised considerably.

Low-grade potash fertilizers produced in Germany contain a certain percentage of sodium and magnesium, two essential minerals for the maintenance of animal health. Numerous experiments have shown that the contents of Mg and Na in the grassland sward can be significantly increased by the application of

magnesia kainite

the special grassland fertilizer manufactured by K+S, which contains

12 % K_2O + 6 % MgO + 24 % Na_2O

Table 3 shows results obtained over three years in experiments in Schleswig-Holstein [27]. Observations with grazing cattle revealed that the animals preferred fodder from those plots which had received magnesia kainite and that feed intake on these sites was higher than on the control plots.

Cow with a vibracorder, an instrument to measure grazing frequency and duration in pasture experiments

Effect of different potash fertilizers on Na and Mg contents of a grass-clover sward (F. R. Germany)

	NP without potash		NP + potash (40 % K_2O)		NP + magnesia kainite	
Dry matter %	Na	Mg	Na	Mg	Na	Mg
1969	0.04	0.16	0.06	0.17	0.12	0.19
1970	0.04	0.19	0.05	0.18	0.17	0.21
1971	0.07	0.19	0.08	0.18	0.21	0.20

Tropical grassland

Under favourable conditions, cultivated grasses in tropical areas may respond to even higher rates of fertilizer application than in the temperate zones. Maximum yield levels of more than 50 t/ha of dry matter per year, in 6 cuts, have been recorded in experiments while the yield on well managed livestock farms may amount to 25 t DM/ha [20]. Normally the K content of such herbage would be between 1.5 and 2.5 % resulting in the removal of 400–700 kg K_2O/ha by 30 t dry matter [6]. Thus, heavy K applications are needed to maintain the soil K status. Even where the farmyard manure is returned to the field, fertilizer K will have to be applied since complete recycling of nutrients is impossible.

Results obtained in Colombia with Guinea grass (*Panicum maximum* Jacq.) on an alluvial soil and with Pangola grass (*Digitaria decumbens* Stent) on a red soil in the Medellín valley, in a moderately warm climate, are summarized in the table [72]. In this case the grasses received 100 kg/ha each of N and P_2O_5 per cut and 0 or 50 kg/ha of K_2O. Potash application raised the yield per cut by 1.1–1.5 t of dry forage/ha or by 22–30 kg of dry matter/kg K_2O.

The response of tropical grasses to K fertilizer varies according to farming intensity, soil fertility, rate of N and P applied, type of grass etc. Under very intensive management, response normally continues up to an annual application of 500 kg K_2O/ha. Experience shows that there will be a marked response to K whenever K content of the herbage at cutting is below 1 % in the dry matter. In most cases response will continue until the K content reaches 1.5 % [6].

At high levels of production, deficiencies of nutrients other than NPK may limit yields. Magnesium should be applied as soon as the Mg content falls below 0.2 % in the herbage dry matter. Sulphur deficiencies have been found in Latin America, East Africa and Australia [30]. Mg and S deficiencies can be corrected by the application of magnesium sulphate (kieserite).

Effect of fertilizer potassium on the yield of tropical grasses grown in moderately warm climate (Colombia)

Fertilizer treatment (kg/ha per cut)			Dry forage yield (t/ha per cut, av. of 5 cuts)	
N	P_2O_5	K_2O	Guinea grass	Pangola grass
0	0	0	3.06	1.34
100	100	0	5.52	3.72
100	100	50	6.62	5.20
Response to K	t/ha		1.10	1.48
	kg DM/kg K_2O		22	30

Leguminous forage crops

It is important wherever possible to take advantage of the ability of leguminous crops to fix atmospheric nitrogen. While the cultivation of lucerne (alfalfa) and clovers has a long history in the temperate and some subtropical regions, quite a number of other leguminous plants are under test in national and international research institutes throughout the tropics.

The importance of potassium in the fertilizer programme for alfalfa, the "queen of the forage plants" is well established.

Alfalfa or lucerne showing K deficiency

An ample supply of K is necessary for high yield, for resistance to frost damage during winter, for regrowth after cutting and for the persistence of the alfalfa as a perennial crop producing high yields over a number of years (77). The positive effect of K on disease resistance was confirmed by Russian researchers in Tashkent/Uzbekistan (131). As high rates of K are applied to alfalfa, potassium sulphate is superior to potassium chloride (111).

Berseem (*Trifolium alexandrinum* L.) is the most important leguminous forage crop in many countries of the Mediterranean area and parts of Asia. In Egypt more than one million hectares are planted to berseem. The above table shows the results of increasing rates of P and K at a basal application of 48 kg N/ha (93).

Response of berseem to increasing rates of P and K, t/ha of dry matter obtained in 3 cuts (Arab Republic of Egypt)

P_2O_5 treatment (kg/ha)	Potash treatment, kg K_2O/ha			
	0	72	144	216
0	7.17	–	–	–
40	7.31	7.97	8.08	8.13
80	7.28	7.53	8.07	8.31
120	7.41	7.74	8.49	8.86

At the highest rate of P the application of 216 kg K_2O/ha increased berseem dry matter yield by 1.45 t/ha (from 7.41 to 8.86 t/ha) or by 6.7 kg kg/kg K_2O. There was no luxury uptake of K. Potassium contents in the forage varied between 1.7 and 2.0% with 1.9% K in the 216 kg K_2O/ha treated plots.

In the humid tropics different lines of various leguminous forage crops are under screening for their tolerance to aluminium or manganese toxicity and to other adverse conditions. In Australian studies with tropical pasture legumes, such as *Centrosema, Desmodium, Phaseolus* and *Stylosanthes* species, regarding the effect of potassium, deficiency symptoms appeared at K contents below 1% in the dry matter (1). Under such conditions very high responses to K application can be obtained as shown in the Table below which summarizes the results of pot experiments using a low-K soil in Florida/USA (13).

Dry matter yield (g/pot) and K contents of three cultivars of *Stylosanthes* as influenced by potassium application (USA)

K rate kg/ha	*Stylosanthes guyanensis* Sw., Cultivar No.					
	1185		1155		1202	
	g/pot	% K	g/pot	% K	g/pot	% K
19	7.7	0.61	5.7	0.65	6.0	0.61
38	10.1	0.69	9.4	0.62	9.7	0.69
95	16.5	0.82	15.3	0.97	17.2	1.03

At high yield levels the removal of nutrients will be of a similar order as for tropical grasses. On the island of Réunion the following data concerning dry matter production and plant nutrient uptake were obtained in 7 cuts/year (2) (see table).

Dry matter production (t/ha/yr) and nutrient uptake by tropical leguminous forage crops under intensive cultivation (Réunion)

Crop	Dry matter t/ha	Nutrient uptake, kg/ha					
		N	P_2O_5	K_2O	CaO	MgO	S
Stylosanthes gracilis H.B.K.	19.0	566	140	532	363	105	58
Desmodium intortum (Mill.) Urb.	18.5	557	131	477	228	91	37
Glycine javanica L.	12.8	418	108	447	210	78	30

K and cotton, rubber, sugar cane and forest trees

Cotton

Of the major cotton producers in the world, India is the country with the largest area under cotton, China and the USSR the ones with the largest production. Due to high yields per unit area, the average production of seed cotton in 1979–81 amounted in the USSR to 3.06 t/ha against a world average of 1.28 t/ha. Irrigation and a rational fertilizer policy are among the factors contributing to favourable yields. In fertilizer experiments in Uzbekistan, infection by verticillium wilt (*Verticillium dahliae* Kleb. *et* V.) was reduced and cotton yield increased by the application of K in addition to N and P [115]. The yield responses obtained in two sets of experiments are summarized in the table. In other countries also it has been observed that balanced fertilizer application improves disease resistance of cotton plants. An abundant supply of potash has proved highly effective in restricting losses caused by typical diseases, such as "cotton wilt" (*Fusarium vasinfectum* Atk.) and "leaf blight" (*Cercospora* + *Alternaria*) [98]. "Red rust" which is actually a symptom of K deficiency can be completely controlled by K application. Furthermore, potassium improves fibre quality, as confirmed in many experiments [25].

Response of cotton to K application (USSR)

Treatment kg/ha			Seed cotton yield t/ha	Response to K_2O	
N	P_2O_5	K_2O		kg/ha	kg/kg K_2O
220	100	–	3.5	–	–
220	100	50	3.7	200	4
220	100	100	4.0	500	5
200	150	–	3.16	–	–
200	150	100	3.43	270	2.7
200	150	150	3.58	420	2.8

K increases the oil content

The favourable effect of K on the oil content of cotton seed was confirmed in Northern Nigeria [34]. The interaction of nitrogen (96 kg N/ha) and potassium (81 kg K/ha) with regard to oil percentage and seed weight is summarized in the table. Nitrogen increased seed and kernel weight but reduced the oil content, probably in favour of protein formation. Potassium increased oil percentage and seed weight. There was a strong positive N×K interaction.

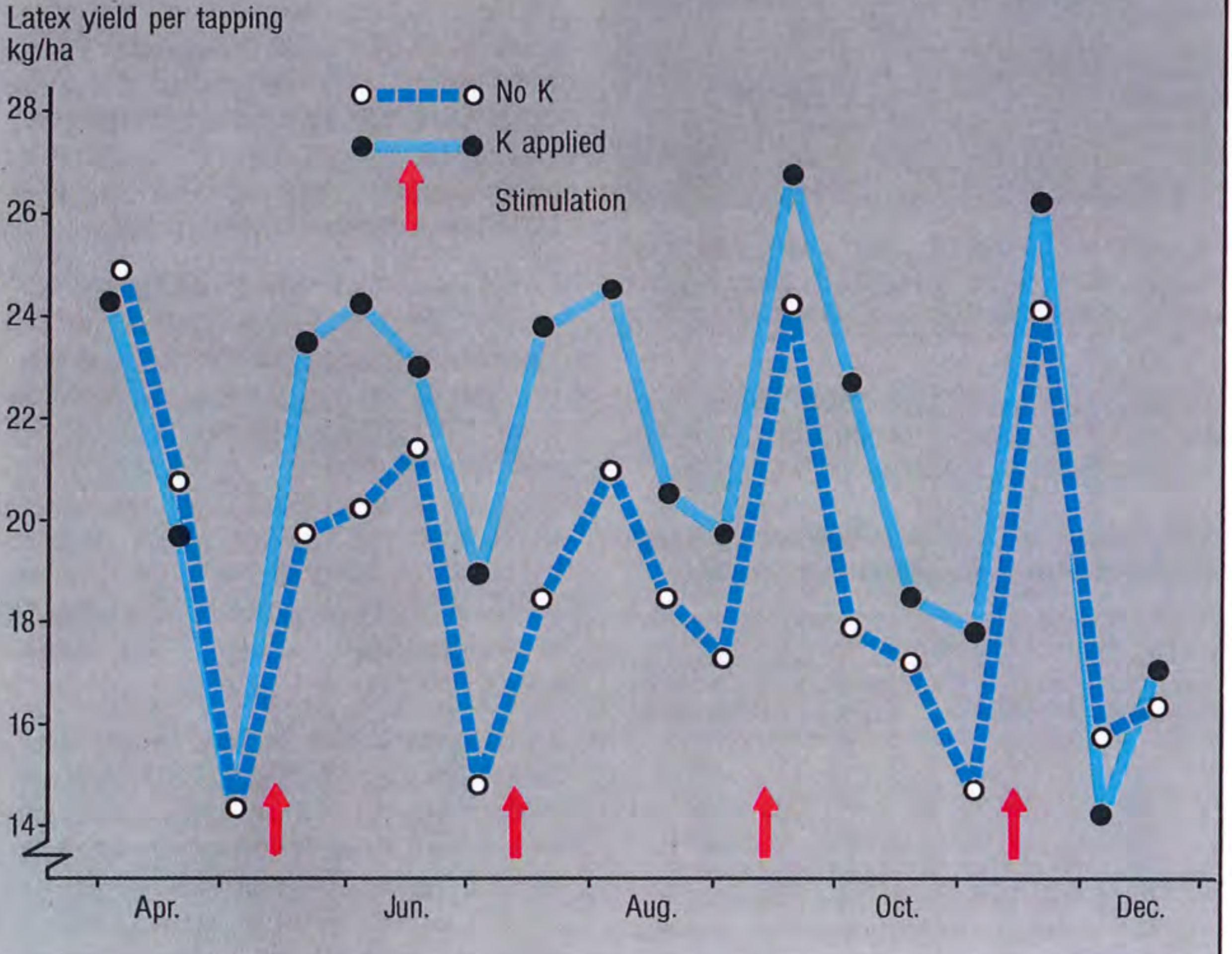
Combined effects of N and K on oil content and weight of cotton seed (Nigeria)

	Whole seed				Kernel			
	Oil percentage		Seed weight, mg		Oil percentage		Kernel weight, mg	
	K_0	K_{81}	K_0	K_{81}	K_0	K_{81}	K_0	K_{81}
N_0	18.9	21.9	76	81	34.8	40.1	55	55
N_{96}	12.9	20.7	65	89	26.4	37.4	47	64

Rubber

The economic importance of natural rubber has increased considerably since prices for crude oil, the raw material for synthetic rubber, have risen steeply. About 80 % of the world rubber production originate from the three countries Malaysia, Indonesia and Thailand. Malaysia alone accounts for more than 40 %. The productivity of rubber plantations has been improved by the introduction of high-yielding clones and advanced management practices, including leguminous cover crops in newly planted or replanted areas, latex flow stimulation by chemicals and a modern fertilizer policy according to the requirements for high production levels. The higher the yield or the yield potential, the more importance needs to be attached to an uninterrupted and adequate supply of potassium and a proper balance of K with other nutrients (133). Potassium gained additional importance with the introduction of ethephon (Ethrel) as a latex flow and yield stimulant (120). The figure gives an example of the effect of stimulation as influenced by K application. Stimulation promotes latex flow and at the same time increases the proportion of the serum at the expense of the dry rubber content. Since all the K is found in the serum, the effect of stimulation on K removal is most marked. A higher K concentration in the soil solution may be required to maintain adequate K levels in high yielding trees (133). The effect of potash application on yield and nitrogen fixation of a leguminous

Effect of K application on the response of *Hevea* rubber to Ethrel stimulation (Malaysia)



K deficient rubber tree. Note yellowish foliage and reduced growth as compared to the trees behind, well supplied with K.

cover crop is shown in the table which is based on results obtained by the Rubber Research Institute of Malaysia (106).

Response of kudzu (*Pueraria phaseoloides* Benth.) to potassium (Malaysia)

Level of K_2O kg/ha	Drymatter yield t/ha	Response to K	
		Drymatter t/ha	Extra N fixation, kg/ha
0	7.26	–	–*
75	11.72	4.46	133
150	12.98	5.72	170
225	13.17	5.91	176

* Nitrogen contained in the dry matter at K_0 amounted to 216 kg N/ha

Sugar cane

In the decade from 1970 to 1980 world sugar cane production increased by one third, mostly due to area expansion. In Asia the sugar cane acreage increased from 4.6 to 5.6, in South America from 2.5 to 3.6 million hectares. There was particularly strong growth in Brazil, the largest producer of sugar cane, where a considerable part of the cane is used in the manufacture of ethanol for fuel.

Judicious application of fertilizers plays an important role in sugar cane production. This is particularly true for potash which is needed by the crop in very large quantities (up to 400 kg K_2O/ha or even more, depending on the yield).

An abundant supply of potassium can improve sugar recovery thus increasing the percentage of commercial cane sugar, as shown in experimental results obtained in 1981/82 and 1982/83 at the Sind Sugar Industry Research Institute in Pakistan (116a). 200 kg K_2O/ha applied in the form of potassium sulphate along with 200 kg N and 100 kg P_2O_5/ha raised the average cane yield by 25 t/ha and improved recovery by 1 % so that the yield of commercial cane sugar increased by 4.9 t/ha over the treatment without potash.

Responses to K are often larger for the ratoon crop than for planted cane. In experiments set up in Brazil to study the fertilization of sugar cane ratoons in four great soil groups, the application of N, P and K resulted in significant yield increases on almost all soils. The response to N and K_2O which were applied at increasing rates from 0 to 180 kg/ha followed a linear pattern. The effect of K is summarized in the table (opposite page) (139).

Most remarkable is the result that the response per kg K_2O was larger at the higher rate indicating that good responses would have been obtained at even higher rates of application. This was confirmed in another experiment on a dark-red Latosol in São Paulo State

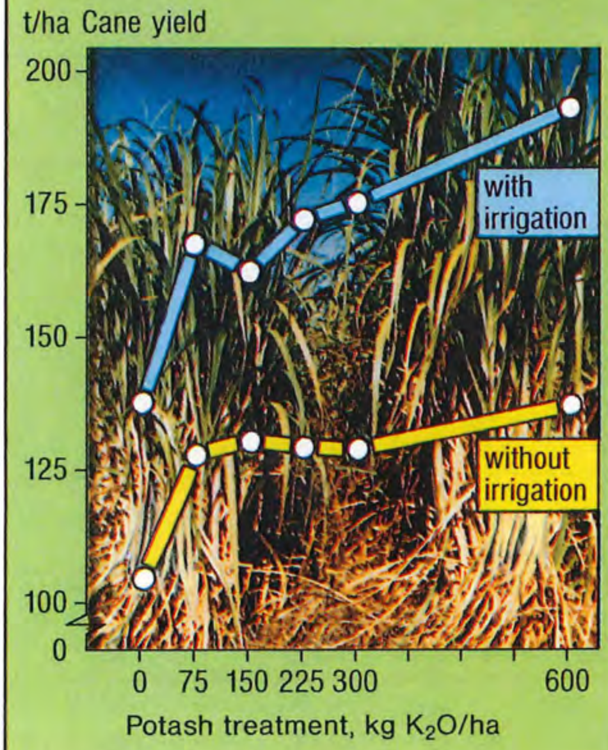
Response of sugar cane ratoons to potash application, average of 4 soil types
(Brazil)

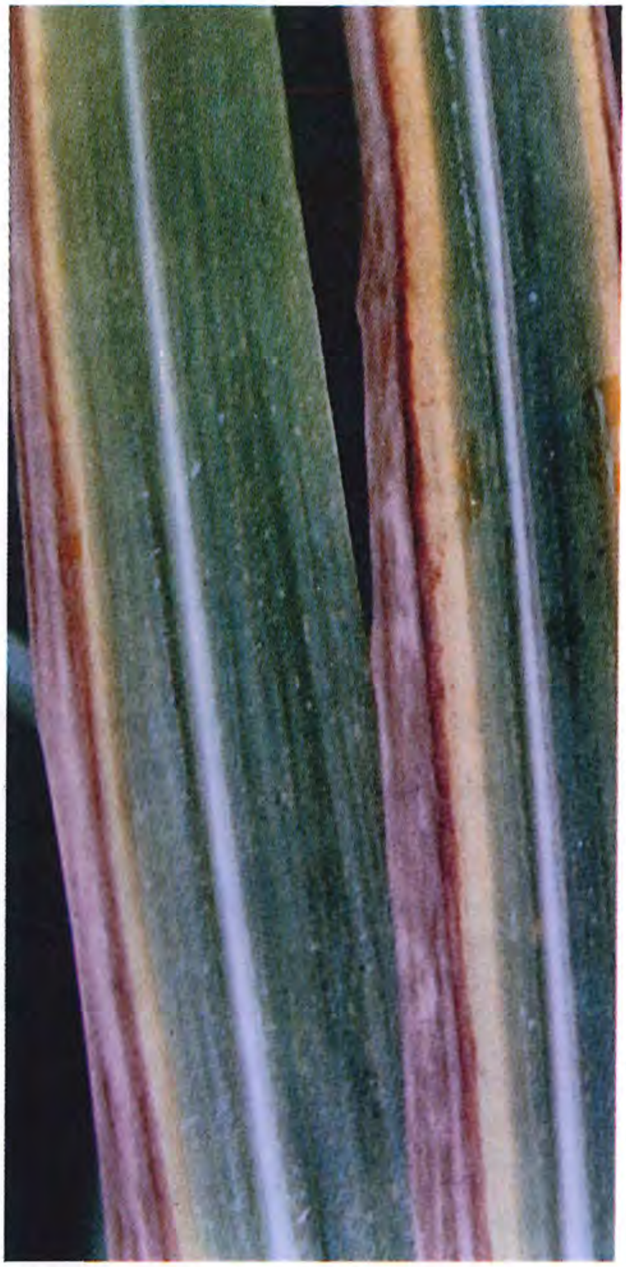
K treatment kg K_2O/ha	Yield t/ha Cane	Yield t/ha Sugar	Response to K application: Cane t/ha	Cane kg/kg K_2O	Sugar kg/ha	Sugar kg/kg K_2O
0	65	9.09	–	–	–	–
90	71	9.61	6	66.7	520	5.78
180	78	10.47	13	72.2	1380	7.67
180–90			7	77.8	860	9.56

where the effect of potash was tested with and without irrigation in the presence of 180 kg N and 300 kg P_2O_5/ha [103]. As can be seen in the figure, the response to the first 75 kg K_2O/ha was similar in both cases.

Beyond that rate there was hardly any rise in yield without irrigation. But with irrigation K application produced further substantial yield increases, even at K_{600} over K_{300}. At 300 kg K_2O/ha the response amounted to 37 t/ha or 123 kg cane/kg K_2O.

Response of sugar cane to increasing rates of K with and without irrigation (Brazil)





Sugarcane leaves with acute K deficiency. Discoloration starts from the margins and goes on towards the midribs. At later stages the tips and margins become necrotic, as shown in the picture.

K and forest trees

In recent years, problems connected with forestry such as the fuel-wood crisis in arid and semi-arid regions, the large-scale deforestation in the tropics or the damages by "acid rain" in temperate zones have become major issues of public concern. On the other hand, afforestation is being pressed ahead in many countries. This is a promising means of making the best use of poor land. Marginal soils may become reasonably productive when planted with trees. Forest is an important source of renewable energy, not only with regard to local needs of fire-wood but also to the world-wide growing demand for timber and pulp. Fertilizing is one of the most efficient ways to improve land productivity in forestry (5).

Responses to fertilizer application are particularly high in the case of fast growing broad-leaved trees, such as eucalyptus and acacia species. Results of fertilizer experiments with eucalypts have been summarized recently (116). The table shows maximum fertilizer rates and mean additional timber production obtained in experiments with NPK application. Yield responses up to 10 m^3/ha per annum have been recorded at some places.

The importance of fertilizer application for the promotion of early growth was demonstrated in an experiment with *Eucalyptus saligna* Sm. in Brazil (10). 60 g of ammonium sulphate, 90 g of superphosphate and 40 g of potassium chloride per tree applied at planting increased average tree hight at 120 days after planting from 49 cm in the control plots to 96 cm in the NPK treated plots, with weed infestation reduced to a negligible level.

Response of eucalyptus species to NPK application

Species and country	Maximum application rates (kg/ha)			Mean additional timber (m^3/ha)	Age (years)
	N	P	K		
E. grandis W Hill ex Maiden					
Brazil	60	35	83	18.5	5
Transkei	67	50	84	55.9	7
South Africa	46	37	336	98.5	9
South Africa	46	37	168	25.0	8
South Africa	62	28	40	89.7	8.5
South Africa	45	30	15	61.6	6
South Africa	35	12	33	41.6	8
E. globulus Labill.					
Australia	202	90	—	25.8	4
Australia	202	90	—	80.0	9.5
Portugal	400	52	149	80.2	12
Portugal	420	65	91	64.0	12
E. maidenii F.v.Muell.					
Portugal	280	79	17	47.8	11

The photo shows an *Eucalyptus grandis* plantation, 19 months after planting. The trees on the left received the full NPK application, the trees on the right no fertilizer.
By courtesy of the Wattle Research Institute, Pietermaritzburg, Rep. of South Africa.

Soil scientists discussing the results of a long-term fertilizer field experiment at Ludhiana/India

Imbalanced usage of potash in the world

The world-wide consumption of mineral fertilizers has grown very considerably over the past two decades. From 29 million tons of NPK in 1960/61 to 116 million tons in 1980/81, i.e. a fourfold increase. In 1980/81 the nitrogen consumption of 60 million tons accounted for more than half of the total, indicating a strong imbalance when plant requirements are considered. The N:P:K ratio has widened from 100:97:83 in 1960/61 to 100:52:40 in 1980/81.

World fertilizer consumption

Source FAO	Million tons 1960/61	Million tons 1980/81
N	10.27	60.34
P_2O_5	9.97	31.49
K_2O	8.50	24.26
Total NPK	28.74	116.09

This global imbalance was mainly caused by China with its annual consumption of more than 12.1 million tons of N as against only 2.7 million tons of P_2O_5 and scarcely 0.5 million tons of K_2O. Per hectare of arable land and land under permanent crops, the 1980/81 consumption in China was equivalent to 122.1 kg N, 27.7 kg P_2O_5 and 4.8 kg K_2O. This under-utilization of potash fertilizers and the continued use of high amounts of N has led to widespread exhaustion of the natural potash reserves, particularly in the soils of Southern China as shown on page 30. Potash deficiency symptoms on crops have appeared in areas where the soils were formerly considered rich in this plant food element.

Under-utilization of potash is not restricted to China but also applies to many other countries. If it continues, there will be a rising potash deficit in the soil nutrient balance with dangerous consequences for agricultural production. Scientists at research stations and officials at the departments of agriculture should be aware of this threat. But they cannot expect the same judgement from the farmers, who will easily observe the response of their crops to the application of N, but may not so easily notice the beneficial effects of K (or Mg or S) which become manifest in the grain yield or the quality of the crop rather than in the appearance of the plants during growth.

It is a matter for the agricultural researcher in cooperation with the economist to provide the advisory services with the information needed to convince the cultivator that potash application is necessary and very often highly remunerative. Besides this, Governments are called upon to provide adequate supplies of potash fertilizers, available at the farming villages in time together with nitrogen, phosphorus and other amendments. Only a well balanced nutrient ratio will improve the efficiency of the applied fertilizers.

As can be seen in the table, potash utilization is still very low in many parts of the world, particularly in those less industrialized regions with high population pressure or fast demographic growth.

Where yields are inadequate due to irregular rainfall, low soil fertility and low inputs, proper use of manures and fertilizers can improve the situation

Average K_2O consumption, in kg per hectare arable land and land under permanent crops, 1980 (FAO)

Japan	93.8
Europe	59.6
USA	29.7
USSR	21.1
Brazil	21.1
South Africa	10.3
Latin America (– Brazil)	5.4
Oceania	5.2
China	4.8
Asia (– Japan)	4.3
India	3.7
Africa (– South Africa)	1.5
World average	16.7

Shifting cultivation - no answer to the food problem

The area on earth which could realistically be converted into arable land is limited. Virgin forests cannot be indefinitely destroyed without serious consequences for mankind. The low input and low yield method of shifting cultivation, where cleared bush and jungle areas are left to fallow for several years after only 2–3 meagre cropping seasons, leads to soil erosion and fertility decline as farmers tend to shorten the fallow period in an effort to produce more food for the growing population. As a consequence, crop production decreases further due to soil exhaustion.

In order to break this vicious circle, scientists at research centres have developed systems of continuous cultivation with adequate fertilization and other appropriate agronomic practices, maintaining reasonably high crop yields and improving the soil fertility level. Special techniques have been developed, e.g. "alley cropping", to prevent negative influences of the humid tropical climate on soil properties (57,132). High yield cultivation of food crops with the use of fertilizer and other inputs on suitable land can help to save forests on marginal land.

In the long-term fertility trials carried out by the International Institute of Tropical Agriculture at Ibadan/Nigeria, maize yields of 5–6 tons of grain/ha were obtained on the complete fertilizer plots in the 10th year of continuous cropping with maize in the main season followed by cowpea in the minor season (136).

The results of long-term field experiments at Yurimaguas/Peru in the upper Amazon basin are summarized in the figure (114). After clearing of the rainforest by burning, maize and upland rice were grown in rotation with soybeans and groundnuts for eight consecutive years with and without complete mineral fertilization, including lime and micronutrient application where necessary. As shown in the figure grain yields of crops receiving complete fertilizer treatments could be maintained at fairly high levels, notably those of the oil crops, during the whole period of the experiment. Without fertilizer application, yields of all crops tested dropped to almost zero after only a few cropping seasons. As shown in the table, the balance between the total amounts of fertilizer nutrients added and crop uptake during 8 years was negative for nitrogen and potassium (114).

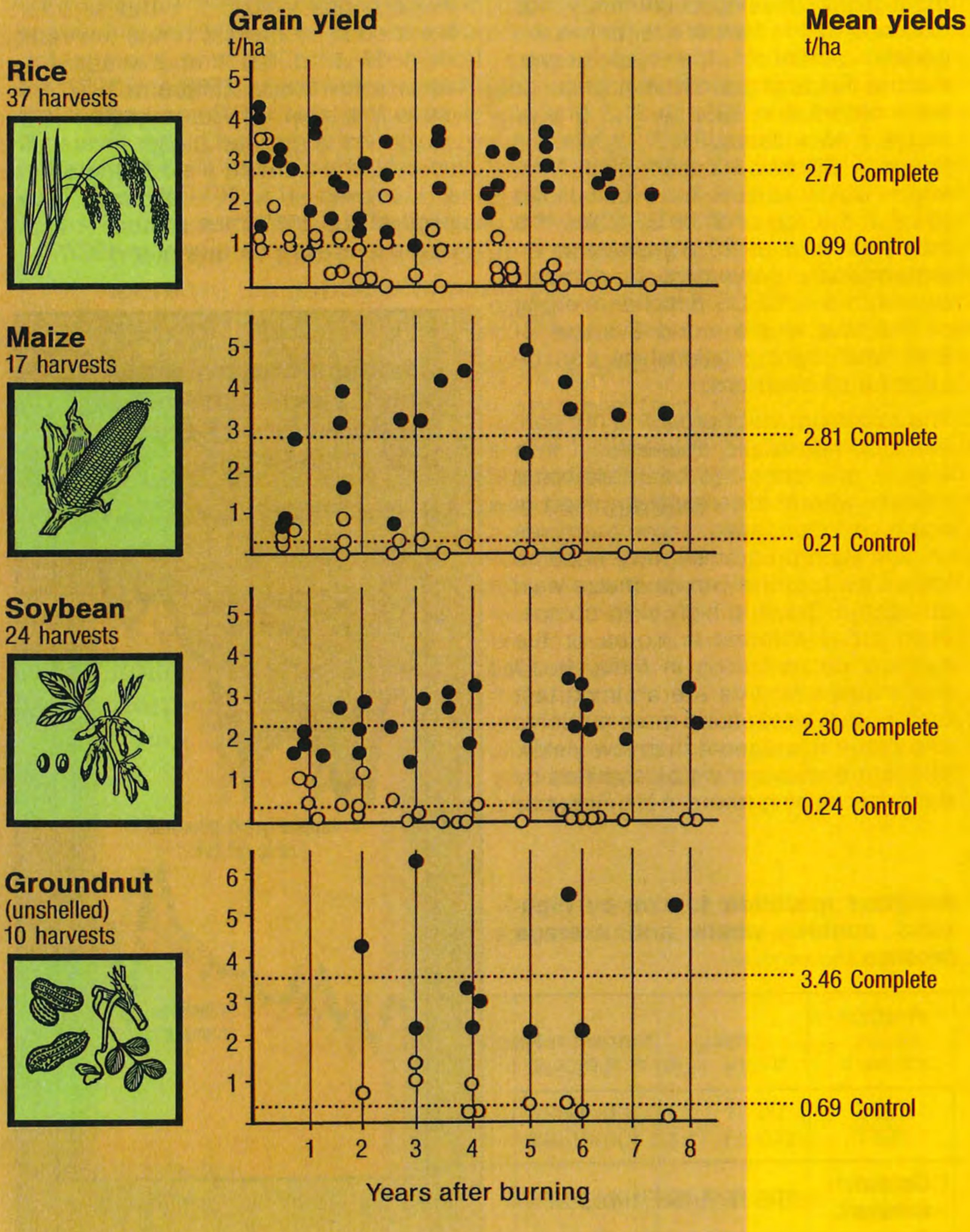
While the nitrogen figure can be explained by symbiotic N fixation by soybeans and groundnuts, the figure for K_2O indicates that the amount of fertilizer K applied has not always been sufficient to balance crop uptake.

Balance of fertilizer additions and crop uptake during 8 years (19 crops) after rainforest clearing (Peru)

Plant food element (kg/ha)	N	P_2O_5	K_2O	CaO	MgO	Zn	Cu
Fertilizer additions	1480	1950	2097	7325	480	11	15
Crop uptake	1960	639	2214	504	380	2.8	0.4
Balance	- 436*	1311	- 117	6821	100	8.2	14.6

* Two of the four crops (soybeans and groundnuts) are legumes which obtain most of their nitrogen from the air

Grain yields from 1st to 8th year after clearing of tropical rainforest with ● and without ○ complete mineral fertilization (Peru)
Each point is the mean of four replications



The maximum yield approach

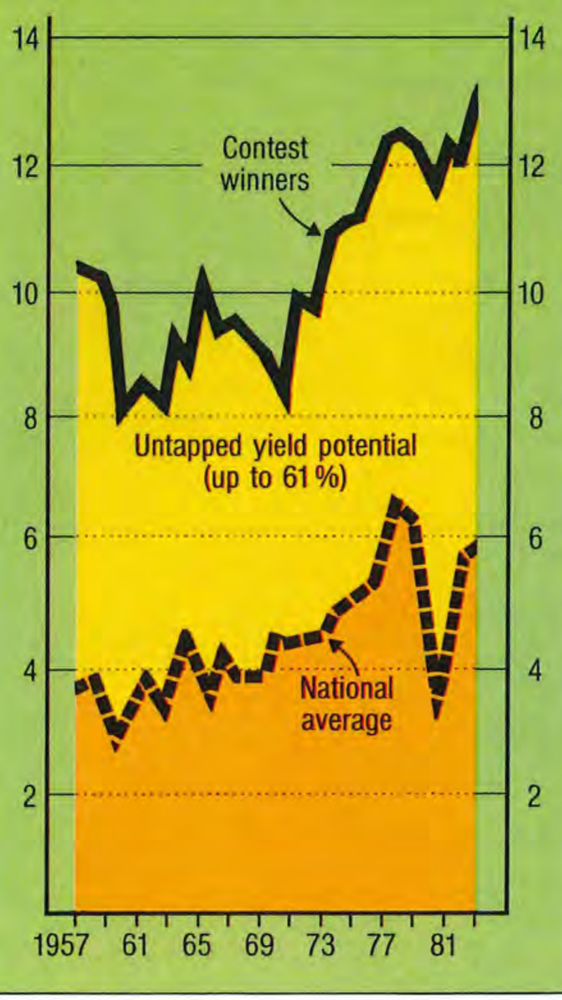
Everywhere in the world, even in the most highly developed countries, yields obtained by the farmer are far below the genetic potential of the crop grown. Record yields of grain from a single crop were reported in 1982 with 21.2 t/ha of maize in New Jersey/USA [3a]. While this figure is still below the theoretical maximum which scientists have calculated to be in the range of 31 to 37 t/ha [136] a maize yield of over 20 t grain/ha is an extraordinary achievement in comparison with the 1982 US national average of 7.2 t/ha and the world average of 3.56 t/ha. Similar relationships can be cited for all other crops.

The maximum yield approach is not confined to industrialized countries. It is a major challenge to the developing nations where the demand for food is rising very fast. Indeed, some examples of high yield programmes have become known such as the maximum maize yield contest in Brazil, the high yield competition for rice farmers in Korea or the national demonstrations in India. In all these cases fertilizers are an important factor. High yields require more nutrients and better management than low yields. The figure shows the yields obtained by the prize winning farmers in the Republic of Korea compared with the national average paddy yield [101]. Rates of fertilizers used by contest winners (average from 1957 to 1983) and average fertilizer use for rice in 1968 and 1977 are given in the table [60]. Remarkable is not so much the somewhat higher level of N used by the maximum yield farmers but the improved N:P:K balance. They applied about 2½ times more P and K than the average rice farmer in 1977.

Fertilizer application to rice by high-yield contest winners and average farmers (Republic of Korea)

Average of all farmers	kg/ha N	kg/ha P_2O_5	kg/ha K_2O	Nutrient ratio $N:P_2O_5:K_2O$
1968	96	31	20	100:32:21
1977	140	63	61	100:45:44
Contest winners	**196**	**177**	**145**	**100:90:74**

Maximum and average paddy yields achieved in the Republic of Korea from 1957 to 1983 (t/ha)



A key to improved food supply

"Intensification to increase food supplies from poor soils involves the introduction of much more nutrients to support the crops. The need for phosphate fertilizers has been recognized all over the world for a century or more, and much nitrogen is now applied in most countries. But in many developing countries the need to increase the supplies of potassium is not yet recognized, and very little K-fertilizer is used.

Many crops do take up as great a weight of K as of N, and larger yields will not be obtained from the meagre supplies of K in most tropical soils which have just sufficed to maintain the traditional farming systems. Work will be needed to assess the amounts of K-fertilizer needed for more intensive production" [21].

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