IPI
Research Topics
No. 9

Potassium Sulphate and Potassium Chloride

Their influence on the yield and quality of cultivated plants

International Potash Institute Bern/Switzerland

1981

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Published by:
International Potash Institute
CH-3048 Worblaufen-Bern/Switzerland
Phone: 031/58 53 73 Telex: 33430 ipi bech
1981

Printed by: Buchdruckerei 'Der Bund'
Bern/Switzerland

Contents

1. Introduction

There is no denying that supplying sufficient food for the rapidly growing population of the world presents one of the greatest challenges facing mankind at the present time. Because there is so little reserve land suitable for cultivation, it is only possible to increase food production by increasing crop production per unit area. But, it is not only the quantity of food produced that should concern us, its nutritional quality is also important. Supplying the world's food is the business of both farmers and research scientists in developed and developing countries alike.

Fertilizers offer the best means of increasing yield and of maintaining soil fertility at a level sufficiently high to ensure that good yields can be obtained consistently, year after year.

To many, whether they be farmers or laymen or even occasionally scientists, 'fertilizer' means 'NPK', but nitrogen, phosphorus and potassium are only three of the plant nutrients needed. Plants require also large quantities of sulphur, calcium and magnesium and small quantities of a number of minor elements, while some plants require appreciable amounts of sodium. In recent years the fertilizer industry has sought to supply fertilizers more highly concentrated in terms of N, P and K and this has meant that some of the other needs of plants may be overlooked.

The effect of a single nutrient (like K) in a fertilizer may depend upon the way in which it is chemically combined in the fertilizer material and this affects both yield and crop quality. Because potassium fertilizers are obtained from natural products they may contain substances other than K, S and Cl and these substances may affect plant growth. Thus, choosing the right kind of potash fertilizer can be as important as applying the right amount of potash to a crop. This book is concerned with this choice and seeks to answer the questions:

- What, for a particular purpose, is the 'best' form of potash? Here we are concerned essentially with the choice between the chloride and the sulphate.
- How is the value of a potash fertilizer affected by 'accessory' materials *e.g.* magnesium, sodium, sulphur, contained therein?

The booklet aims to discuss these problems, which are implicit in its title, thoroughly, but it makes no claim to being a complete and exhaustive review of *all* publications and experimental results. It brings up to date the information contained in an earlier publication *[139]*:

> KÄMPFER, M. and ZEHLER, E.:
> The importance of the sulphate fertilizers for raising the yield and improving the quality of agricultural, horticultural and sylvicultural crops.
> Potash Review, May/June 1967. Int. Potash Inst., Bern (1967).

A more recent publication *[171]* deals especially with results obtained with sulphate fertilizers in France:

> LOUÉ, A.:
> Le sulfate de potasse.
> Au Service de l'Agriculture, Dossier K_2O, No 11, SCPA Mulhouse (1978).

2. Plant physiology and the choice of potash fertilizer

2.1. The potash fertilizers

The usual potash fertilizers (Table 1) are of two main types in which the potassium is combined with either chloride (muriate of potash) or sulphate (sulphate of potash). Other special materials may be available, notably potassium nitrate, much used in intensive horticulture under glass, but we are not here concerned with these. There are two types of chloride fertilizers:

Table 1 Average composition of chloride and sulphate of potash fertilizers (in %)*

%	Kainit	Potassium chloride			Potassium sulphate	Sulphate of potash magnesia
		40%	50%	60%		
K_2O	<15	38–42	48–52	57–61	50 (47–52)	28 (22–30)
MgO	<15	<3.5	<2.5	<1.5	<2	8–12
Na_2O	24–29	10–18	5–8.5	1–4	–	–
Cl	39–43	41–53	42–50	47–54	0.5–2.5	0.5–6
S	3–9	<3	<2	<1	18	16–22

* The table states ranges of contents in materials from different mines.

a) Low analysis chloride based fertilizers which are crude or partly processed mineral salts. Chemically, they are essentially mixtures of potassium chloride (KCl) and sodium chloride, or common salt (NaCl). Some also contain kieserite (magnesium sulphate – $MgSO_4$) which may be part of the raw mineral or may have been mixed in. There is some variation in detailed composition of these materials as between different sources (mines). In most countries, regulations require the supplier to state the content of the essential nutrient either as a guaranteed minimum or as a mean with a laid down range of tolerance.

The sodium content of low grade KCl fertilizers is important not only from the point of view of animal health but also because sodium is an essential nutrient for some types of plant and increases their yield (Figure 1). Sodium can substitute for potassium to a varying degree in plant metabolism (Marschner, p. 50 in *[351]*). According to source, these materials may also contain magnesium which will be valued on low magnesium soils and which is particularly important for animal health. These materials contain traces of other elements but there are no important differences between them in this respect.

b) High analysis chloride fertilizers (muriate of potash). Nowadays these are tolerably pure potassium chloride (60% K_2O, equivalent to 95% KCl) the main impurity being salt (NaCl). Lower analysis materials (40 or 50% K_2O) materials are available near to the potash mines. These contain more salt and some also contain magnesium (<3.5% MgO).

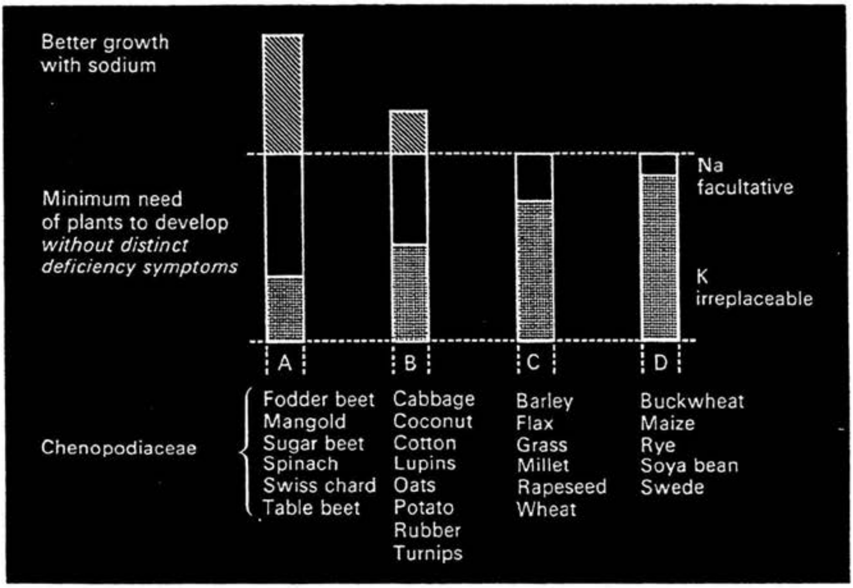

Fig. 1 Tentative scheme for classification of crops according to potassium-replacing power of sodium and independent sodium effect on yield. (From LEHR *(1953)*, cited by MARSCHNER, p. 51 in *[351]*)

There are also two types of sulphate fertilizer:

c) Sulphate of potash which, though it occurs naturally in mixture with kieserite, is usually manufactured by reacting the chloride with sulphuric acid. Normal sulphate of potash (50% K_2O) contains about 93% K_2SO_4 (range, according to source, 48–52% K_2O). The purest forms are virtually free of chloride.

d) Sulphate of potash magnesia. This is essentially a mixture of sulphate of potash and kieserite with 28% K_2O and 10% MgO. Again, there is variation between materials from different sources. This is a useful fertilizer to apply to non-chloride tolerant crops when there is also a need for magnesium.

The needs of the plant, soil conditions and climatic factors will determine which form of potash fertilizer is best suited to obtain high yields and good quality in any particular case. The main features to be considered are:

a) Content of accessory minerals. The most important of these are sodium and magnesium which are found in the crude minerals, in the lower analysis chloride fertilizers and in special products such as sulphate of potash magnesia.

b) Potassium sulphate and potassium chloride differ in their effects on plants in two ways: the anion accompanying the essential cation (K) has effects on the way in which cations behave and also directly affects plant metabolism, some plants being sensitive to chloride; and the sulphur in potassium sulphate is itself a major plant nutrient, being a constituent of proteins. Our discussion deals separately with these two aspects.

Though only 4.5% of all the potash produced in the world is sulphate, it is still an important fertilizer. Because of its special properties it can be regarded as a 'quality' product and it has consistently commanded a higher price than the more widely available chloride. Supplies of sulphate of potash have remained constant in recent years, production being 1.1 million tons in 1973 and 1978, though indications for 1979 and 1980 show that it may now be 1.3 million. Production of sulphate is concentrated in a few countries like Belgium, F.R. Germany, Italy, Spain, German D.R. and, on a smaller scale, Japan, USSR, Norway, Greece, Portugal and Israel *[338]*. Demand has remained steady, mainly from Western Europe, USA and Japan.

2.2. The effects of the accompanying anion

The potassium in a fertilizer (and here we are concerned not only with sulphate and chloride but with a whole range of possible materials) exists as a neutral, acid, or alkaline salt in which the cation K^+ is combined with an anion: NO_3^-, Cl^-, HCO_3^-, SO_4^{2-}, CO_3^{2-}, or with anions containing P (*e.g.* $H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}). These salts enter the soil solution when the fertilizer is applied and, when the plant takes up a K ion, it must also take up an anion in order to maintain electrical neutrality. Anions containing S, P or N are largely incorporated in plant material thus losing their ionic form but Cl remains in the ionic form. Thus the concentration gradient of Cl in the plant is less steep than that of the other anions. As well as affecting the physical and chemical properties of the soil *[254]*, the anions enter into physiological processes within the plant and affect the chemistry of plant colloids *[199]*. The various ions behave differently in the soil solution because of their differing valencies and degrees of hydration which affect their mobilities or rates of diffusion. The Cl ion has high diffusion coefficients of 2.03 and 0.5 cm^2/sec in solution and in soil respectively (Cooke, p. 381 in *[343]*).

The more mobile ions are more readily taken up by the plant and thus depress the uptake of less mobile ions and also affect the anion: cation balance. Table 2 shows the effect of the anion accompanying potassium in different salts on the uptake of K and anions by 25 day old barley seedlings. The Cl ion is more strongly hydrated and more mobile than SO_4 and therefore has a greater depressive effect on the uptake of other anions and, through the anion: cation balance, stimulates the uptake of cations (K). Similarly, the mobility of cations affects anion uptake, thus sulphate uptake increases in the following order:
$Ca < Mg < Na < NH_4 < K$ *[13]*.

Sulphate availability is also, obviously, affected by the solubilities of its various salts (Table 3) and this again reacts on cation uptake. The Cl ion increases Ca uptake at the expense of K and thereby leads to a narrowing of the K:Cl ratio while the Ca:K

Table 2 Ion uptakes from solutions of various potassium salts (HOGLAND)

Salt	Ion uptake in milliequivalents		
	K ion	anion	$K^+ : anion^-$
KNO_3	1.66	3.19	1 : 1.92
KCl	1.28	1.30	1 : 1.02
$KHCO_3$	1.20	0.84	1 : 0.70
K_2SO_4	0.74	0.40	1 : 0.54
KH_2PO_4	0.90	0.14	1 : 1.92

Table 3 Solubility of various sulphates (g in 100 ml water)

Sulphate	Solubility	Temperature °C
$CaSO_4$	0.07	100
$CaSO_4 \cdot 2H_2O$	0.20	20
$MgSO_4 \cdot 7H_2O$	35.60	20
Na_2SO_4	48.10	40
$(NH_4)_2SO_4$	75.40	20
K_2SO_4	11.15	20

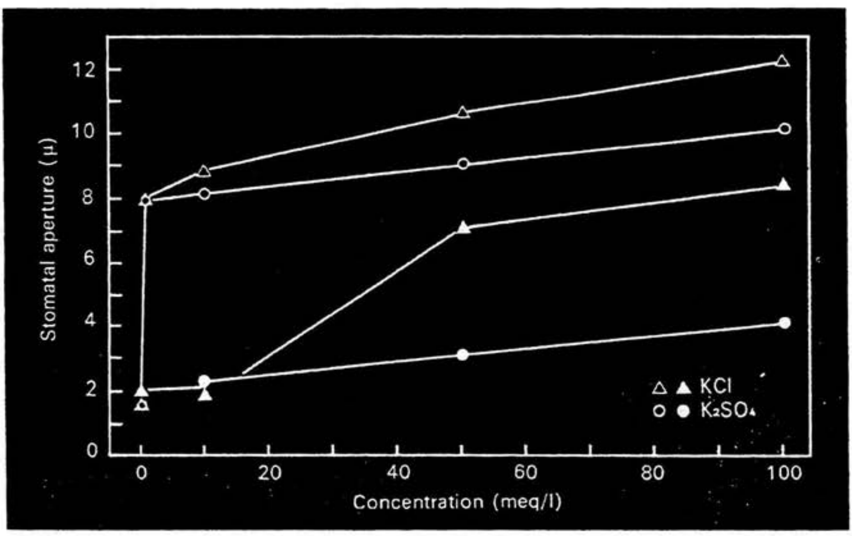

Fig. 2 Effects on stomatal opening of the anions Cl and SO_4 in light (open symbols) and darkness (closed symbols), when associated with K. (HUMBLE and HSIAO *(1969)*, cited by HÖFNER, p. 128 in *[351]*)

balance is shifted in favour of Ca. Physiological K deficiency symptoms may be the result. In contrast to Cl, SO_4, because of its lower speed of migration, reduces K uptake.

At equal K concentration, KCl produces more osmotically active ions than K_2SO_4. Because Cl is never de-ionised it always remains osmotically active and thus is responsible for rapid adjustment of the cell plasma. Both Cl and SO_4 are colloidally active ions regulating the water content of the plant but the more strongly hydrated Cl ion has a greater swelling effect than SO_4 and is therefore more effective in reducing transpiration and increasing water uptake. HUMBLE and HSIAO (p. 128 in *[351]*) found that KCl as compared with K_2SO_4 markedly increased stomatal opening (Figure 2).

As well as affecting hydration of the cells, these ions modify enzyme activity. Thus, SO_4 favours, while Cl reduces, the activity of anabolic enzymes (carbohydrases) so that SO_4 in comparison with Cl favours the accumulation of highly polymerised carbohydrates (starch) and more polymerised N compounds (proteins).
The results of high Cl concentration in the plant are:

- The chlorophyll content is lowered; as a result photosynthetic activity is reduced.
- The ratio soluble sugars: starch is altered.
- The proportion of amino acids is increased and that of organic acids reduced.
- The saturation of oils is lowered.
- The leaf cuticle is thickened.
- Growth and flowering are delayed.

2.3. Salt tolerance and chloride tolerance of plants

25% of the world's soils are salt affected (halomorphic); clearly, soil salinity can be important *[312]*. Soil salinity will always tend to increase whenever evapotranspiration exceeds rainfall, for, in these conditions, electrolyte is carried upwards in the soil solution and accumulates in the upper soil layers. The movement of solutes by mass flow of the soil solution towards the roots in answer to the call to satisfy the demands of transpiration leads to the accumulation of salts particularly in the rhizosphere (that part of the soil in close proximity to the root). The root has to operate against the osmotic pressure of the soil solution which is proportional to the salt concentration and, if the latter is too high, salt damage will occur and growth will be depressed. The salt concentration in the saturation extract is measured as electrical conductivity (EC) in mS/cm (or mmho/cm) at 25°C. The suction pressure which the cell plasma can exert is determined by the genetics of the plant and varies from species to species, but for all plants there is a limit, and hence a limit to which the osmotic pressure (or EC) of the soil may rise without causing wilting. Wilting damage generally occurs in salt sensitive plants at soil salt contents of >0.2—0.3 (EC ~4) *[155, 156]*. Concentrations which will limit yield are attained the more easily the lower the available water capacity of the soil and the drier the conditions *[116]*.

Table 4 classifies plants for salt tolerance on the basis of the salt content (or EC) of the growing medium which causes yield reduction *[19, 155]*.

Salt tolerance varies greatly between cultivars and with age. Salt tolerance by cereals and legumes *(e.g.* barley, wheat, millet, field beans) increases with increasing age and all are more sensitive as seedlings. This is the result of changes in sorption capacity of the cytoplasm for ions and changes in the solubility of ions in the cell sap. Salt tolerance increases when the sorption capacity of the cytoplasm is increased at the same time as the solubility of ions in the cell sap falls.

The effect of fertilizers on salinity is measured as the salt index (Table 5) which is defined as the ratio of the increase in osmotic pressure of the soil solution produced by the fertilizer material to that produced by the same weight of $NaNO_3$ (= 100).

Like all fertilizers, potash in whatever form increases the salt content of the soil solution. While the conductivity of equimolar solutions of the various salts increases in the order $KH_2PO_4 < KNO_3 < KCl < K_2SO_4$ the salt tolerance of plants falls in the order $KH_2PO_4 > K_2SO_4 > KCl > KNO_3$ *[278]*. K_2SO_4 is the exception to the rule that salt sensitivity increases with conductivity.

Quite apart from the effects of general salt sensitivity, certain plants are particularly sensitive to chloride and various reasons have been given for this *[87, 187, 239]*. Cl tolerance is a reflection of the different rates of Cl uptake shown by different plants. For the same final Cl content, Cl tolerant (halophytic) plants like sugar beet take up Cl more gradually than do Cl sensitive plants like lucerne. Increasing Cl uptake increases Ca uptake and halophytes are for the most part calcifuge. The narrowing of the K:Ca ratio is important in connection with the incidence of potassium deficiency which is enhanced by the physiological interaction of the K and Cl ions.

There is little relation between the botanical orders and the Cl tolerance of crop plants, though most of the chlorophile plants are found in the chenopodiaceae, cruciferae, umbelliferae and liliaceae. Most of the tree and berry fruits and citrus, the majority of vegetables, several conifers and ornamental plants are more or less chloride sensitive, and particularly so in the seedling stage *[87, 111, 118, 154, 171, 223]*.

Non-woody plants can stand Cl contents as high as 1000 mg/100 g dry matter while woody plants show leaf symptoms even at 500 mg/100 g dry matter. Cl sensitive plants (woody plants) tolerate only 5–10 me Cl^- in the soil saturation extract, Cl tolerant (non-woody) can cope with up to 30 me *[19]*.

The following maximum tolerable Cl contents in irrigation water have been quoted *[19, 197]*:

barley	2300 mg Cl/l	peas, beans	1500 mg Cl/l
oats	4000 mg Cl/l	tomato	4000 mg Cl/l
wheat	4500 mg Cl/l	cabbage	6000 mg Cl/l
sugar beet	15000 mg Cl/l		

Table 4 Salt tolerance of various crop plants: EC value for 50% yield reduction *[155]*

Salt content (% dry soil)			0.2				0.35								0.65
EC (mmhos/cm)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Salt tolerance	poor			moderate						good					
Fodder plants					rye (green fodder) wheat (green fodder) oats (green fodder)		lucerne fodder beet			clover	barley (green fodder)		*Cynodon dactylon* (Bermuda grass)		*Distichtis stricta* (salt grass)
Arable crops				sunflower (seed)			wheat (grain) oat (grain) maize (grain)	rye (grain)	cotton			sugar beet			barley (grain)
Vegetables	green beans	radish beans celery	cucumber	carrot onion	potato	lettuce	cabbage	tomato	asparagus spinach						
Fruits	apple cherry peach apricot oranges lemon		grapes		olive		fig								date palm

Table 5 Salt index of potash fertilizers *[235]*

K fertilizer		per unit of	
		K_2O	material
Sulphate of potash magnesia	(22% K_2O)	1.971	43.2
K_2SO_4	(52% K_2O)	0.853	46.1
KNO_3	(14% N, 47% K_2O)	1.219[1]	73.6
KCl	(60% K_2O)	1.936	116.3
$NaNO_3$	(16.5% N)	6.060[2]	100.0

[1] K_2O+N
[2] N

COUVENHOVEN and VAN DEN BERG (cit. *[260]*) list the Cl contents in the soil saturation extract from the 5–20 cm layer which will cause yield reductions of 10 and 25% in a number of crops (Table 6).

Table 6 Cl concentrations in the saturation extract causing yield reductions of 10 and 25% (mg Cl/l) *[260]*

Crop	10% reduction	25% reduction
Spring barley	4200	6070
Fodder beet	1030	4860
Sugar beet	2670	4550
Oats	2960	3950
Spinach	–	3300
Lucerne	1200	3600
Spring wheat	1940	2430
Flax	–	2430
Red clover	–	1800
Potatoes	910	1820
Onions	1100	1520
Beans	910	1210
Poppy	850	1010
Peas	240	360

3. The importance of sulphur for plant growth

Although it has been known for a long time that sulphur is an essential plant nutrient, until recently little attention has been paid to this nutrient because symptoms of S deficiency were very seldom seen. However, because many modern high analysis fertilizers are free of sulphur and some of the old fashioned plant protection materials have been replaced by S free compounds, and also due to the replacement of wood and coal as domestic and industrial fuels by oil, accretions of sulphur to the soil are decreasing and, in many countries, satisfaction of the plant's need for sulphur is becoming a problem.

Table 7 Sulphur uptake by various crops

Crop	Yield (t/ha)		S uptake (kg/ha total plant)	
	1)	2)	1)	2)
Cereals	2.5–3		10–13	
Wheat		5.5		22
Oats		4		21
Barley		5.5		22
Maize	4.5	12.5	26	37
Rice		8		14
Millet		9		43
Potatoes	20–23	56	8–11	25
Sugar beet	30–35	75	21–31	50
Sugar cane	100	250	22	96
Fodder beet	45		45	
Grasses	6–9		9–13	
Clover hay	6–9		17–22	
Lucerne hay	8–10		22–26	
Oilpalm	18		20	
Soyabean		4		28
Sunflower		4		18
Groundnuts	5	4.5	10	24
Cotton	0.7	1.7	13–17	34
Flax		1.3		7
Cacao	9		6	
Coffee	2		4	
Tobacco	2		12	
Tobacco (flue)		3.5		21
Tobacco (burley)		4.5		50
Pineapple	65		11	
Banana	35		5	
Oranges		60		31
Cabbage	33–35		21–42	
Onions	33–35		20–24	
Tomato		67		46

1) BROOK, 1979 *[33]*
2) Potash a. Phosphate Inst., Atlanta, Leaflet B-279, 1980

In general it can be said that the plant's sulphur requirement is of the same order as that for P and is in the range of 10–80 kg/ha S *[53]*. There is much variation in S requirement between crops, many of which *e.g.* the cruciferae (cabbage, cauliflower, kale, turnip, radish) and liliaceae (onions and asparagus) require much S while the needs of potato, grasses and many important tropical crops is less (Table 7).

Very detailed information on the sulphur requirements of and removals by the main agricultural crops and vegetables can be found in publications by BROOK *[33]*, SAALBACH, ANSTETT and MARTIN-PRÉVEL (pp. 23, 57, 81 in *[336]*).

3.1. The functions of sulphur

As well as being present in the plant in the shape of SO_4 ions, sulphur is a constituent of many plant substances which confer quality and it takes part in a number of processes, notably protein metabolism and enzyme reactions *[5, 54, 137, 177, 363]*. These processes are:

- Synthesis of the three essential amino acids cystine, cysteine and methionine which are the building blocks of plant proteins and which account for nearly 90% of the sulphur contained in the plant.
- Activation of proteolytic enzymes, *e.g.* papainase.
- Synthesis of the vitamins biotin, thiamin, vitamin B_1, glutathion.
- Formation of glucosidic lipids, *e.g.* leek oils in onion and garlic and mustard oils in crucifers.
- Formation of disulphide linkages which confer specific structure on the protoplasm. At the same time, a high content of sulphhydril groups increases resistance to cold.
- Sulphur is concerned in chlorophyll synthesis.
- Formation of ferredoxin which functions as electron transporter in photosynthesis.
- Formation of compounds similar to ferredoxin which are involved in the processes of N fixation in root nodules and free living bacteria.
- Activation of ATP enzymes which are concerned in S metabolism in the plant.

3.2 Sulphur deficiency and its recognition

Sulphur deficient *soils* are widespread in certain parts of the world. This is true of large parts of Australia, Africa, Asia and South America where, up to now, farming has been extensive (Table 8). But sulphur deficiency also occurs in appreciable areas of the USA, Canada and Europe and here it is a result of the intensive farming methods used *[302, 336, 360]*.

In the humid tropics *[363]*, high humidity and high temperature cause rapid breakdown of soil organic matter and leaching is severe so, as a result, the soils as a rule have low organic sulphur contents. 70% of all tropical soils are oxisols or ultisols with low

Table 8 Countries with sulphur deficiency *[302]*

Europe:	*Asia:*	*Africa:*	*North America:*
Czechoslovakia	India	Ghana	USA
France	Japan	Kenya	Canada
Germany	Sri Lanka	Malawi	
Iceland		Nigeria	*South and Central America*
Ireland	*Australasia:*	Senegal	Argentine
Netherlands	Australia	South Africa	Brazil
Norway	Fiji, Solomon Islands	Tanzania	Chile
Poland	New Guinea	Uganda	Costa Rica
Spain	New Zealand	Upper Volta	Honduras
Sweden		Zambia	Venezuela
Yugoslavia			Windward Islands

Table 9 Leaching of Cl and SO_4. % of labelled fertilizer (^{36}Cl and $^{35}SO_4$) remaining in the upper 40 cm of three soil types after 3 month periods in winter and summer *[325]*

	Humic sand	Parabraunerde/Lessivé	Peat
Winter (93 days)			
Rainfall mm	206	272	222
Cl %	0.0	1.4	0.4
SO_4 %	0.1	1.6	4.7
Summer (93 days)			
Rainfall mm	157	267	212
Cl %	15.4	11.7	10.6
SO_4 %	17.4	7.4	14.5

pH and their clay minerals have a low exchange capacity for SO_4 ions. Liming and the application of phosphatic fertilizer also lower the content of mineral sulphur in the soil by affecting exchange processes.

Burning of the natural vegetation in shifting cultivation brings about heavy losses of organic matter from the soil and converts organic S to mineral forms which are easily leached. Thus the latosols and red-yellow podsols can lose up to 90% of their mineral and organic sulphur through leaching. Accordingly, plant available SO_4 is always extremely low in tropical soils and plants suffer from latent or acute S deficiency.

Both sulphate and chloride are strongly leached in the wet months in the temperate climate (GACHON, p. 11 in *[336]*). Experiments in North Germany *[325]* have shown that, whatever the soil type, almost all the SO_4 and Cl applied in fertilizers in the autumn is washed out of the surface soil during the winter (Table 9). Chloride is more rapidly leached than sulphate.

The varying susceptibility to leaching of the anions also affects the ease with which K is washed out and this decreases in the following order:
$KCl = KNO_3 > K_2SO_4 > K$ phosphate. Potassium applied as chloride is sometimes better retained by oxi- and latosols of the tropics than when sulphate is used (BOYER, p. 96 in *[353]*).

Latent S deficiency in the *plant* is first shown by reduction in the formation of plant material in the above-ground parts. The visual symptoms are similar to those of N deficiency:

- Pale green colour of the leaves including the veins, first seen on the younger leaves.
- Brittle, woody stem, stunted growth, growth and ripening hindered.
- Reduced nodulation of legumes.
- Fruit pale green, and ripening delayed.
- Reduction in the constituents which confer quality: protein, sugars, S-containing lipids; a corresponding increase in the content of soluble organic and inorganic N compounds and nitrates.

To avoid the danger of acute S deficiency it is necessary to recognise latent deficiency in good time. *Plant analysis* can be useful in establishing the sulphur status of plants and the following criteria are all relevant: total S and SO_4-S content and the N:S ratio in the plant. Critical values have been established for a range of crops (Table 10).

On the average, plants contain about 0.25% S in the dry matter. The S content of leaves lies between 0.1 and 0.3% (max. 2%) and is generally higher than the S content of the roots. The average N:S ratio is 14:1 but varies with species *[302, 336]*.

3.3. Sources of sulphur and sulphur usage

Sulphur occurs in the soil and in the atmosphere. Unlike many microorganisms which can metabolize the sulphur in organic compounds, the roots of higher plants can only take up sulphur in the ionic form (SO_4). Plants can take up SO_2 from the atmosphere through their leaves. Some sulphur compounds like free sulphuric acid, sulphites, sulphides and carbon bisulphide are toxic to plants.

The sulphur content of *soils* varies between 0.02 and 0.2% in the temperate climate (TROCMÉ, p. 103 in *[336]*) and between 0.05 and 0.1% in the tropics (DABIN, p. 113 in *[336]*), BLAIR *et al.* *[23]* (Table 11). Most of the sulphur is contained in organic matter but some is adsorbed on clay minerals. That most of the S is contained in organic matter is shown by the fact that there is a close correlation between S content, organic matter and N contents; only about 10 or 15% occurs as water soluble sulphate. The N:S ratio of soil organic matter is usually in the range of 8–12:1. Sulphur is mobilised by weathering in which it is oxidised to sulphate.

Table 10 Critical sulphur contents, critical N:S ratios and highest S-contents of cereals, root and forage crops (SAALBACH, p. 50 in [336])

Crop	Critical S-content (% dry matter)	Critical N:S ratio (dry matter)	Highest S-contents (% dry matter)
Wheat			
grain	0.17	14.8	0.24
straw	0.10		0.20
Oats			
grain	0.20 (?)	9.1	0.34
glumes	0.04		
straw	0.10		0.26
Barley			
grain	?	13.0	0.26
straw	0.18		0.48
Rye			
grain	?	?	0.15
straw	?		0.15
Grain-maize			
grain	?	?	0.17
straw	?		0.19
Potatoes			
tubers	0.11	?	0.30
foliage	0.19		0.50
Sugar beet			
roots	0.12 (?)	?	0.42
leaves	0.13–0.33	15.0	0.97
Fodder beet			
roots	0.10	?	0.13
leaves	0.35 (?)	8.1 (?)	0.67
Green maize	0.11–0.15	11.0	0.31
Lucerne	0.22–0.30	11.0–12.0	0.47
Clover spec.	0.14–0.32	15.0	0.29
Gramineae	?	12.0–14.0	0.69

Table 11 Total S values for a range of soils from tropical regions [23]

Location	No. of soils	Total S (ppm)	
		Mean	Range
Malawi	14	66	35–139
Nigeria	3	43	38–52
W. Indies	8	248	110–510
N. Cameroon, Chad, Ivory Coast	31	70	20–300
Zambia and Rhodesia	–	–	60–100
Brazil	6	166	43–298

The plant available S content of the soil thus depends on the turnover of organic matter and the activity of the microorganisms concerned in the breakdown of S-containing compounds which convert part of the organic S compounds to sulphate. WALKER's investigations in Australia have shown that sulphur is critically important for the growth of clover and it is via clover that the organic matter content of these soils can be built up. The fixation of atmospheric nitrogen by legumes (up to 670 kg/ha) requires 67 kg/ha S, most of which becomes incorporated in the organic matter. Soils with 1% organic matter can liberate sulphur at the rate of 3.6 kg/ha/year *[302]*.

In humid areas, much S is leached leading to S enrichment of the subsoil. The average leaching losses are 14 kg S/ha/year in Europe and North America, 4 kg in South America and less than 1 kg in parts of Australia (COOKE, p. 92 in *[350]*). In comparison with phosphate, SO_4 is only weakly held by soil colloids *i.e.* iron and aluminium hydrated oxides and clay minerals (montmorillonite < illite < kaolinite). The soil's ability to adsorb SO_4 increases with increasing acidity but also depends on cation composition: $Na_2SO_4 < (NH_4)_2SO_4 < K_2SO_4 < CaSO_4$ *[254]*.

If the surface soil is high in SO_4 and reducing conditions are brought about by surface flooding (*e.g.* in rice paddies) or in hydromorphic soils it will be reduced to sulphide which is toxic to roots. The microbiological activity of soils is reduced by the application of mineral salts and by salt enrichment of the lower horizons of the rooting zone under arid conditions. Ammonification is less sensitive to this than is nitrification. Chlorides are more damaging to nitrification than are sulphates *[193]*.

Sulphur contained in the *atmosphere*, where it occurs as SO_2, H_2SO_4, sulphates, H_2S and methyl mercaptan (CH_3SH), can supply up to 50% of crop S requirement *[302]*, JUNGE, p. 285 in *[336]*, GERVY, p. 56 in *[361]*. It is estimated that from 200 to 400 million tons S are discharged to the atmosphere each year (ERIKSSON, ROBINSON-ROBBINS cited in *[302]*) (Table 12).

70% of the SO_2 originates from the burning of coal, oil and gas, 16% from motor vehicle exhaust, 4% from oil refineries, and up to 10% from smelting. On this account, atmospheric SO_2 concentration is higher in winter than in summer (Figure 3).

Plants take up SO_2 directly from the air through their stomata. If the concentration is too high photosynthesis is disturbed resulting in chlorosis and necrosis. The severity of this effect depends on a number of factors including temperature, light, plant water content, humidity, duration and level of SO_2 pollution, and plant species. Sensitive species may suffer damage at atmospheric concentrations of 0.2 ppm SO_2 but most plants will tolerate from 0.5 to 1.0 ppm (Table 13).

Oxidation of SO_2 to the easily soluble SO_3 increases rapidly as atmospheric humidity rises. This mostly forms SO_4-aerosols and only small amounts occur as H_2SO_4 which would drastically lower the pH of rainwater. SO_2 dissolves in the soil water (solubility 113 g per litre at 20°C) forming dilute sulphuric acid or sulphates and soil acidity due

Table 12 Emissions of S to the atmosphere (ROBBINSON-ROBBINS, in *[302]*)

Source	Annual emissions of S ($t \times 10^6$)		
	Northern hemisphere	Southern hemisphere	Total
SO_2 sources	68	5	73
Biological H_2S			
Land	49	19	68
Marine	13	17	30
Sea spray	19	25	44
Total	149 (69%)	66 (31%)	215

Table 13 Sensitivity of plant groups to SO_2 (ZAHN, p. 267 in *[336]*)

Plants	Limit of toleration mg SO_2/m^3 air
Cloverlike fodder plants	0.2–0.25
Cereals, leaf vegetables, beans, strawberries, roses	0.25–0.3
Root crops, oil seeds (rape), cabbage	0.3–0.4

to this cause can be a problem near to metalworks. If soil pH is lowered below 4 leaching of Ca is accelerated and pH of the groundwater is affected.

Figure 4 shows the amounts of sulphate S falling on the soil in winter rainfall. In country areas up to 10 kg/ha/year of atmospheric S enters the soil and in urban and industrial areas the amount may be two or three times as high. The average supply of S in rain in Western Europe is about 13–14 kg/ha but in parts of Scandinavia precipitation supplies only 3 kg. It is considered that, where rain supplies 10–12 kg S/ha/year, deficiencies in crops are unlikely (COOKE, p. 92 in *[350]*, GERVY, p. 56 in *[361]*).

Wherever the supply of sulphur from natural sources in insufficient it is necessary to use *S-containing fertilizers* as a matter of course (potash and magnesium fertilizers, single superphosphate, ammonium sulphate). Organic farm manures contain very variable amounts of S and its availability varies greatly (DECAU, p. 315 in *[336]*). Crude elementary sulphur (50–99% S) can be used for the correction of acute S deficiency. Gypsum ($CaSO_4 \cdot 2\,H_2O$) is used in the reclamation of saline and alkaline soils and this contains 15–18% S. MALAVOLTA and NEPTUNE, p. 229 in *[342]*, summarising the literature, say that in South America application of S increased the yield in 10% of all field experiments with maize, beans, soya, groundnut, cotton and coffee. The place of S fertilizers in the intensive agriculture of Western Europe was discussed in symposia in Brussels and Paris in 1973 and 1974 *[360, 361]*.

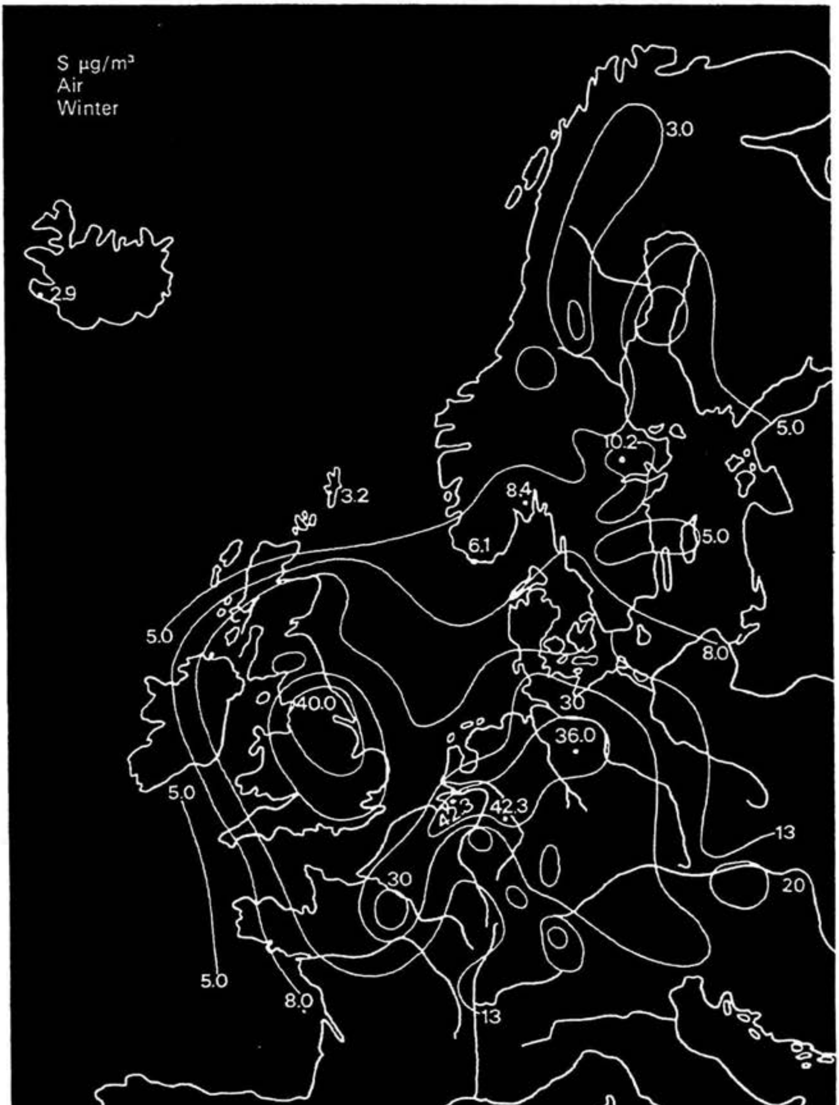

Fig. 3 Average concentration of SO_2-S in air for winter over Europe. (JUNGE, p. 238 in *[336]*)

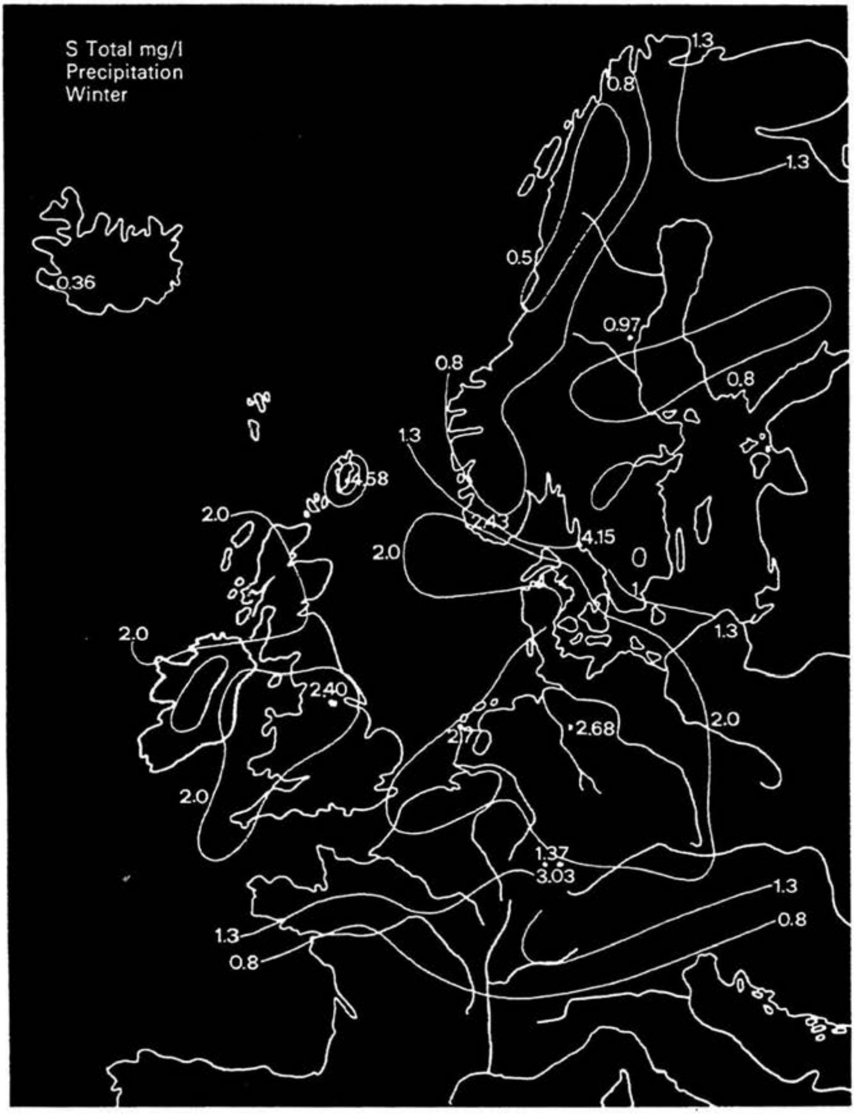

Fig. 4 Average concentration of total SO_4-S in precipitation for winter over Europe. (JUNGE, p. 243 in *[336]*)

Figure 5 shows world production and consumption of sulphur; it is estimated that in 1980 the Western World will apply 20.5 million tons S in fertilizers.

The present usage of sulphate of potash fertilizers is about 2.5 million tons per annum (excluding the Eastern Bloc). While in Europe the future demand-supply situation appears to be finely balanced, demand in the Mediterranean area and in the Third World is expected to grow rapidly. Between 1976 and 1977 consumption of S fertilizers increased by 34% in Africa, 13% in Asia ,11% in Oceania, 9% in North America and 7% in South America.

According to NICOLAS (p. 7 in *[362]*) supplies in the 1980s will be influenced by the following:

- Slackening of the rate of growth of S consumption in industrialised areas (Europe, North America, Japan).
- Rapid growth of consumption in areas with phosphate rock deposits (*i.e.* Africa) where fertilizer manufacture is being started.
- Rapid growth of consumption in the oil and sulphur producing areas (Middle East) including fertilizer production.
- Increased demand for sulphur in areas (*e.g.* India and Brazil) where it is economically essential to establish fertilizer industries.

DUMONT (p. 73 in *[362]*) thinks world demand for sulphate of potash will increase and draws attention to *commercial and technological factors* which may influence developments:

- Cost. K_2SO_4 may, according to circumstances, offer the cheapest source of S when it is required as a nutrient.
- Commercial. There may be a competitive advantage to a fertilizer manufacturer who can include sulphate based fertilizer in his product range and this can increase profitability.
- Technological. In the sense that both anion and cation are plant nutrients, potassium sulphate is a highly concentrated fertilizer.
  There is a risk of explosion in the presence of Cl in some manufacturing processes and this is avoided by using K_2SO_4. In certain processes the SO_4 is made to react with Ca in rock phosphate.
- Bulk blending. Until recently little sulphate of potash has been available in granular form, and bulk blenders have had to make do with muriate. As granular K_2SO_4 becomes more plentiful, the demand for bulk blending will increase.

The *agricultural advantages of sulphate of potash* can be summarised:

- It supplies the crop with both potassium and sulphur.
- It has the lowest salt index among the conventional potash fertilizers.

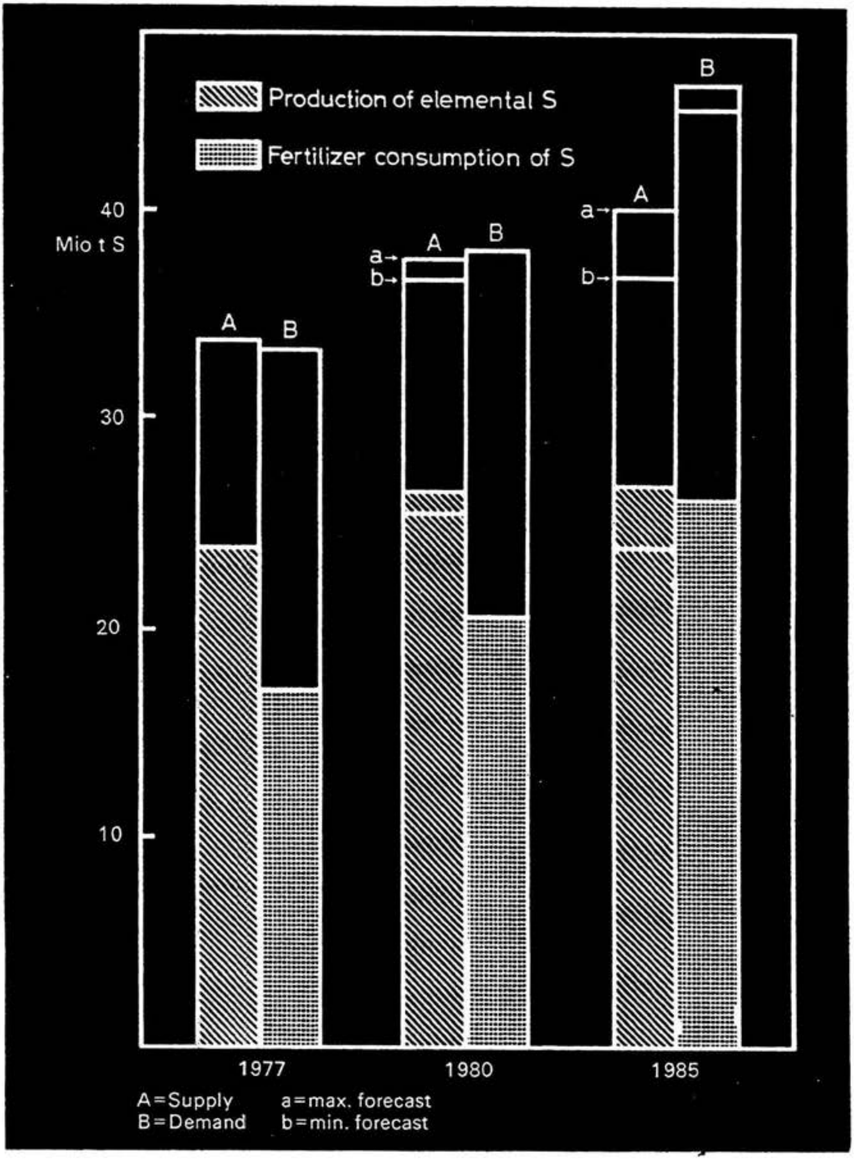

Fig. 5 Production and consumption of sulphur in the Western World. (NICOLAS, p. 17 in *[362]*)

- Being Cl free, it is to be preferred for Cl sensitive crops, especially high value crops like tobacco, fruit, vines.
- It has advantages when potash must be applied late, just before sowing.
- Quite apart from the results of research, the practical experience of farmers and growers has convinced them that sulphate of potash is good for crop quality (colour, taste, ability to tolerate storage and transport, resistance to unfavourable weather, disease and parasites). For high value crops and, particularly, where a premium is paid for quality, securing optimum quality may be more important than obtaining maximum yield per hectare and for these, though the sulphate is more expensive than the chloride, its use is amply justified.

4. The effects of sulphate of potash fertilizers on crop yield and quality

The preceding chapters have made clear that plants require a continuing and sufficient supply of sulphur. The fact that the use of modern highly concentrated fertilizers may lead to unbalanced plant nutrition suggests that sulphate based potassium fertilizer, which has up to now been used only for certain special crops, may have a wider application. Experiments to measure the effects of fertilizer have usually been concerned solely or chiefly with effects on crop yield, and in this respect there often has been, under normal conditions, little or no difference between the two forms of potash. However, as increasing attention is paid to the quality of crop produce to meet the needs of an increasingly discriminating market, the differential effects of KCl and K_2SO_4 on quality become much more important, and particular attention is given to this aspect in the following sections which deal with the effects of these fertilizers on individual crops.

4.1. Cereals

According to Bernstein *[19]* all cereals, including maize, can be regarded as fairly salt and chloride tolerant and this is confirmed by the fact that they are widely grown under arid, saline conditions. Even so yield reductions may be caused by the adverse osmotic effects of chloride-containing fertilizers in the soil solution reducing germination and establishment, especially when fertilizer is applied at the same time as sowing *[48]*. Young maize plants, are somewhat chloride sensitive and since this crop has a high K need, it requires heavy fertilizer dressings. Unfavourable side effects, especially when fertilizer is placed, can be avoided by using sulphate of potash *[331]*.

In other respects, maize should be relatively Cl tolerant since when Cl is the accompanying anion it is taken up in equivalent quantity to K, while when K_2SO_4 is used more cations than anions are taken up and the anion excess must be compensated by the formation of organic acids *[144, 227]*.

Recent investigations of the physiological behaviour of cereals in response to Cl and SO_4 show up the reasons why, in fertilizer form experiments, the best yields have sometimes been obtained with a mixture of KCl and K_2SO_4. The intensity of Ca flux and transport in young cereal roots depends upon the salinity and anion composition of the soil solution: SO_4 favours Ca accumulation while Cl increases translocation of Ca in the root *[272]*. Photosynthesis in young maize plants also seems to be improved by Cl through increase in the chlorophyll content *[118]*.

The form of potash has more effect on the grain than on the straw yield and the choice of K form (Cl or SO_4) may be dictated by effects on the chemical composition – amino acids, proteins, enzymes – of the grain which affect quality. For wheat, baking quality, for food grains, biological value and for malting barley, malting properties are particularly important *[7, 45, 121, 131, 347, 354]*.

These quality criteria are all improved by adequate sulphate supply, though it is not definitely established that enzymes in malting barley are adversely affected by Cl *[311]*. In feeding barley the contents of all the essential and inessential amino acids except serine, glycine, alanine and cysteine are lowered by KCl. These adverse effects, which do not occur with K_2SO_4, can be partly counteracted by increasing the rate of N fertilizer *[131]*.

The question as to which form of potash is to be preferred for grain yield cannot be answered unequivocally. As a rule the chloride fertilizers are used. On the other hand there have been many pot and field experiments *[15, 45, 60, 171, 363]* on different soils which have shown yield increases from application of S or of sulphate-containing fertilizer. Positive residual effects from application of sulphate to the crop preceding the cereal, particularly when the former was a legume, have also been recorded and have occured as often as increases due to direct effects of the application of N and S designed to achieve the desired N:S ratio for protein synthesis.

Though cereals have a relatively small sulphur requirement, S deficiency, and thus response to sulphate fertilizer, may occur in cereals, particularly in maize, anywhere in the world. In 10% of all fertilizer experiments in South America maize yield increased due to S fertilization (MALAVOLTA and NEPTUN, p. 299 in *[342]*). The S content of grain and straw of cereals varies between 0.1 and 0.3% S in dry matter (SAALBACH, p. 23 in *[336]*). With a grain yield of 3 t/ha, some 13 kg S/ha is removed by the crop rising up to 43 kg with increasing yields *([33], Potash/Phosphate Institute of North America)*.

Old experiments in Germany *[120]* showed that maize, spring wheat and oats especially preferred low Cl fertilizer, but, in long term experiments in München-Weihenstephan *[8]* continued for 60 years, there was no great advantage from any particular form of potash fertilizer so far as yield was concerned, though K uptake was higher with the Cl treatments than with SO_4. The same was found in a 12 year experiment at the University of Bonn comparing potash forms on a rotation of oats, wheat and barley *[146]*, as in the well known rotation experiment including rye which has been running at Bonn-Poppelsdorf since 1906 *[113]*, namely that there is no difference as regards yield between the potash forms. However, kainite produced the best 1000 grain weight and the lowest straw yield. Other authors *[7, 8, 121]* have also noted that Cl-containing fertilizers increase the 1000 grain weight. Long term experiments by BRUCHHOLZ *[34, 35, 37]*; p. 111 in *[342]* in the German D.R. with a rotation of oats, winter rye, winter wheat and silage maize showed either no difference between the K forms or a slight advantage in favour of KCl for cereals. However, similar experiments in the CSSR *[36, 308]* showed on the average of five years better yields of winter wheat from the sulphate, while the chloride gave significantly higher yields of spring barley and grain maize; for the latter crop, only when kainite was used.

Experiments with **wheat** *(Triticum aestivum)* have for the most part shown no definite difference in yield from the different forms of potash *[120, 171, 262]*. According to Russian investigations *[316]* the following yield increases were obtained with broadcast fertilizer: $K_2SO_4 + 7.9\%$, $KCl + 12.0\%$, $KCl + K_2SO_4 + 13.1\%$. When fertilizer was applied in the row potash-magnesia (whether or not combined with KCl) gave the best result. K_2SO_4 increased the protein content from 13.6 to 17.5%. LOUÉ *[171]* reports that at two localities in France (Ain and Charente Maritime) K_2SO_4 gave significantly higher yield increases in wheat than the other forms of potash, while in long-term experiments with **grain maize** *(Zea mays)* KCl gave the best results on strongly K fixing soils, and K_2SO_4 the best results on low S soils.

ARNON *[10]* and others *[210]* observed that, over several years in the American corn belt, both forms of potash were of equal value. Hungarian workers *[162]* have obtained higher grain and straw yields with K_2SO_4. KIEPE *[147]* concluded from 35 years work that grain maize gave the best results with SO_4, while silage and fodder maize tolerated Cl. On the average of eight years, grain production per kg K_2O applied was 4.3 kg/ha from KCl and 5.3 kg/ha from K_2SO_4. SCHMALFUSS *[257]* found K_2SO_4 better also for forage maize.

KRÜGER (p. 149 in *[355]*), discussing the effect of K in inducing resistance of maize to fungal diseases, especially stalk rot and root necrosis, says that, at least in some cases, the effect of K fertilizer on stalk rot was partly due to the effect of chloride and not solely to potassium *[331]*. Yellow rust in several winter wheat varieties was reduced by NaCl or KCl applied at up to 2260 kg/ha without any decrease in yield from the high rate of Cl *[246]*.

The other grain crop of equal importance with wheat and maize for man's food supply is **rice** *(Oryza sativa)* and rice cultivation has been much developed and intensified in recent years. High yields with the new varieties remove 2.0–2.5 times more nitrogen and phosphorus and 4.0–4.5 times more potassium as compared to improved traditional varieties (von UEXKÜLL, p. 391 in *[341]*) (=400 kg K/ha in wet and dry season). Nutrient availability, including that of sulphur, requires special attention in flooded soils. Special problems which may occur are:

- Lack of sulphur either in the soil or due to S contents in the irrigation water below 6.5 ppm S.
- Reduction of SO_4 to toxic sulphide or to SO_2 which is not plant available under wet anaerobic conditions and causing toxic levels of Fe and Al.
- Leaching of SO_4. In one way or another, S is becoming a limiting factor in rice soils especially in Brazil, India, Pakistan, Indonesia and the Philippines *[23, 60, 129, 323]*.

Sulphur removal by crops of 4–9 t grain/ha range from 17–40 kg S/ha, and S contents below 0.13% in grain signify insufficient S supply to the plant *[23]*.

While up to now the potash fertilizer used in rice growing has been almost entirely KCl *[93]*, there is a case for considering the use of K_2SO_4 to supply rapidly available S where it is required *[129]*. Because of the redox processes affecting S in paddy soils, it is extremely difficult to separate out the straight forward effects of the anions Cl and SO_4 on the physiological processes which influence grain yield and quality *[15]*.

In greenhouse studies with different salt concentrations, yield and N and P contents tended to be enhanced by low salt concentration but to be depressed at higher concentration. The chloride salts were most detrimental to yield and N and P contents, while the sulphate salts were beneficial when the electrolyte concentration and P in the soil were not high *[160]*.

On K deficient soils of Java with iron toxicity, K_2SO_4 yielded higher than KCl because the iron content in the plant was decreased more by the sulphate form (Table 14). On a calcareous soil of a long term fertilizer experiment of the IRRI/Philippines (TANAKA, p. 164 in *[353])* grain yields of high-yielding rice varieties were higher on the KCl than on the K_2SO_4 plots.

Table 14 Effect of potassium application on grain yield and mineral content of rice at Cihea, Java (ISMUNADJI, HAKIM, ZULKARNAINI and YAZAWA [1973] p. 163 in *[353])*

Treatment	Yield (kg/ha)	K (%)	Fe (ppm)
No potassium	2958	0.35	214
KCl (60 kg K/ha)	5594	1.00	167
K_2SO_4 (60 kg K/ha)	5932	1.00	139

In general in both temperate and tropical climates, the choice of form of potash is not of great importance for cereals; maintaining an adequate potash supply is the prime consideration.

4.2. Root and tuber crops, sugarcane

Potatoes *(Solanum tuberosum)*
Apart from tobacco there is scarcely a crop which has so often served as a test plant for comparing potash forms as the potato. While it has a relatively short growing season it has a high K demand *[345]*. Numerous experiments in Germany, Switzerland, France, Russia, England, the USA, etc. have led to the conclusion that the sulphur component of fertilizer can be responsible for appreciable increases in yield *[15, 20, 91]*. The tubers and stems have relatively high S contents, up to 0.3 and 0.5% in the dry matter respectively, indicating the high sulphur requirement of the crop (SAALBACH, p. 37 in *[336])*.

Apart from a mass of old evidence, a great deal of more recent experimental work in favour of KCl – in the UK, the CSSR and GDR for instance – which has gone into the influence of various external factors on tuber formation has reopened the discussion on the superiority of K_2SO_4 over KCl *[34–37, 62, 89, 287]*.

Soil fertility and yield potential of the soil
VANKA (cited *[139])* says that the relative efficiency of different K fertilizers is affected by the nutrient status of the soil in other nutrients. Sulphate has the advantage on low P soils since it improves P availability (BERGER *et al.*, cited *[171])*. When the P supply

is high, Cl reduces P uptake. HART and SMITH [112] found no effects on P uptake while Russian workers [97] found lower P levels in the plant after applying Cl fertilizers. In any case, sulphate is to be preferred when the soil is low in organic matter and K [168].

Experience in Brazil is that K manuring of potatoes does not always produce an increase in yield [31]. The results of 7 experiments on different sites in São Paulo State to compare the forms of potash are quoted in Table 15. On the average of all experiments there was only a slight advantage in favour of sulphate, but on the less fertile (more responsive) sites the advantage was considerable. This indicates that experiments on non-K responsive sites can lead to false conclusions. HAHLIN and JOHANSSON [108] also found that relative response depended on soil fertility and the level of fertilizer application, KCl giving higher yields at low rates while K_2SO_4 was superior at high rates of K application.

Table 15 Effect of form of potash on potato tuber yield in relation to soil fertility [31]

K form	7 experiments average		3 experiments un-responsive sites		4 experiments responsive sites	
	Yield t/ha	Increase %	Yield t/ha	Increase %	Yield t/ha	Increase %
K_0	9.14	—	12.44	—	6.66	—
KCl.........	9.82	+ 7	12.66	+2	7.69	+15
K_2SO_4.......	10.05	+10	12.48	—	8.23	+24

Soil type, texture and reaction

Fundamentally, the potato is chlorophobe; however the negative effect of Cl is more evident on light soils than it is on heavier better buffered soils. This was shown in experiments lasting 17 years on light loam [147] and 9 years on sand low in organic matter in Germany (OPITZ, cited [139]). Long-term experiments on sand and marsh soils in the Netherlands [56] led to the same conclusion (Table 16). The combined result was a reduction of up to 30% in starch yield on sand in comparison with clay. TEMME (cited [171]) found no difference on soil with 25% clay but a distinct advantage for sulphate at 17% clay. BARANOV *et al.* (cited [139]) reported no difference between

Table 16 Reduction of tuber yield and underwater weight on sandy and clay soils by KCl fertilization [56]

KCl (60%) kg/ha	Tuber yield (t/ha)		Underwater weight (g)	
	Sand	Clay	Sand	Clay
260	1.0	0.4	24	13
520	1.6	0.8	31	21
780	2.1	1.1	37	27

sulphate and chloride on chernozem in contrast to their behaviour on podsols. According to LIN *[168]* in Taiwan there was no difference in total yield and tuber size on loamy soils but KCl gave a higher proportion of small unmarketable tubers especially at high planting density.

According to NEMEC (cited *[139]*) soil pH has a marked effect and the danger of a reduction in starch content by Cl is much greater on strongly acid soils (pH 4.5–5.5) than on slightly acid or neutral soil (pH 5.5–7.1). On slightly acid Indian soils *[267]* there was a yield advantage in favour of sulphate which was not evident on alkaline soils.

Especially on chalky soils, sulphatic fertilizers reduce the incidence of cracking. This was established in 1952 by ALTEN (cited *[139]*) and has been confirmed in more recent work by HUNNIUS *[126]* with sulphate of potash magnesia and kieserite.

The effect of climate

SCHARRER and SCHROPP (cited *[139]*) found that the positive effect of K_2SO_4 on dry matter production and starch content depended on the light intensity. Unshaded plants gave higher yields with sulphate, but at low lighting, KCl had the advantage. Tests of the Cl sensitivity of 24 varieties showed that this depended upon the rainfall pattern and through-wetting of the soil *[334]*.

The effect of variety

Starch production varies greatly between varieties, and the different varieties react differently to the form of potash. This explains some of the inconsistencies which have been found in experiments comparing the potash forms. Fertilizer application should be adjusted to suit the physiological needs in order to realise fully the variety's potential for starch formation.

Time and method of fertilizer application

The effect of potash fertilizer on potatoes differs according as to whether it is applied in spring or in autumn-winter. The crop is especially sensitive to Cl in the early stages of development *[130]*.

It was found in Switzerland *[91]* that, if fertilizer is applied in autumn, there is little difference between the forms as regards tuber yield and starch content while, when applied in spring, even a low percentage of Cl in the fertilizer has adverse effects so that 60% KCl gives appreciably lower tuber and starch yield. Experiments over 12 years in the Netherlands with industrial varieties on sandy soils (Veenkultur) showed that only when applied in autumn did 40% KCl give comparable tuber yields and 'factory weight' (yield adjusted for starch content) with those obtained from sulphate of potash magnesia applied in spring (BRUGGMANN, cited *[139]*). PRUMMEL *[233]* also compared K_2SO_4 and KCl on sandy soils and his results are given in Figure 6. There were no yield differences between SO_4 and Cl applied in autumn or spring with 'Kennebee' potatoes in Canada *[243]*.

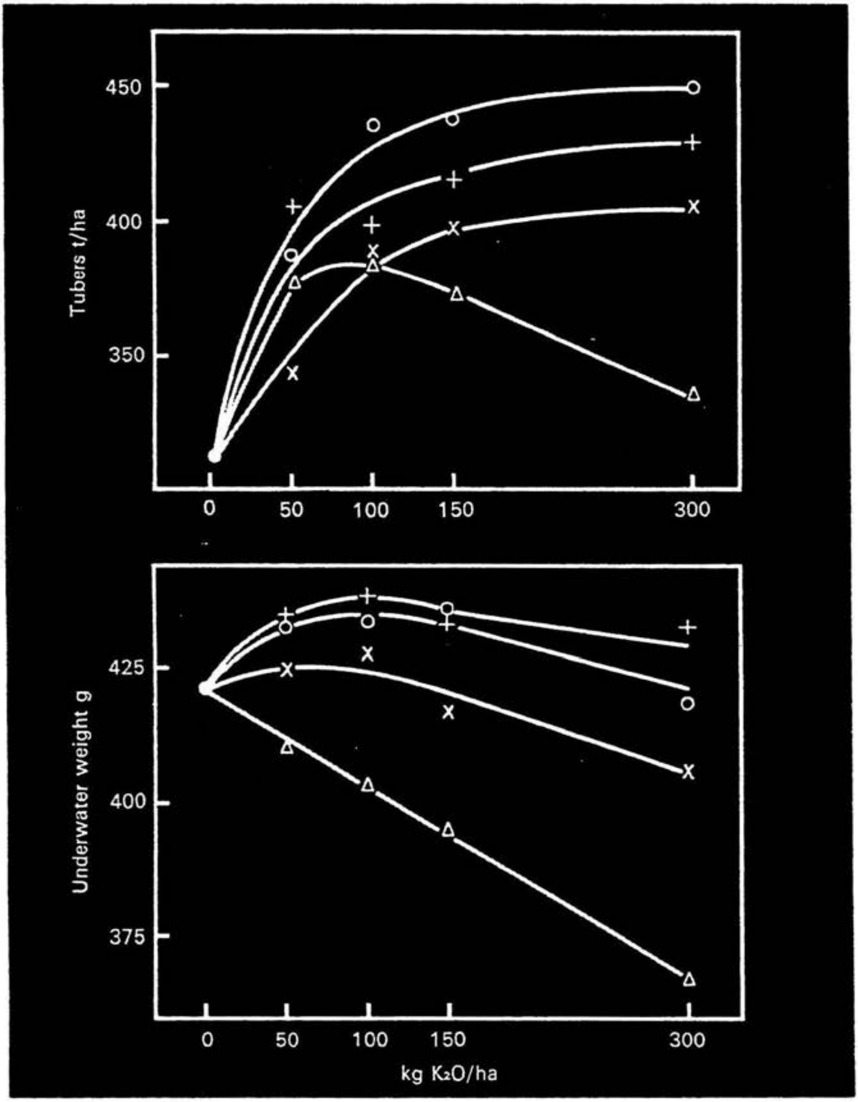

Fig. 6 Tuber yield and underwater weight after autumn and spring application of K_2SO_4 or KCl (40%) *[233]*

° K_2SO_4	– spring application	× KCl	– autumn application
+	– autumn application	△	– spring application

When fertilizer is applied in autumn, Cl is largely washed out by the winter rain *[56]*. However, MÜLLER *[204]* came to the conclusion that, when fertilizer is applied shortly before planting, the sulphate form should always be used.

If it is necessary to apply K by spraying for the emergency treatment of K deficiency, leaf scorch is more likely to be caused by Cl than by SO_4. PRUMMEL (cited *[139]*) and LAUGHLIN *[164]* have used succesfully K_2SO_4 sprays at up to 10%, while KCl solutions above 4% caused leaf damage.

Yield components of table and industrial potatoes

Tuber size and number determine tuber yield while dry matter content, specific gravity and starch content determine quality; all are affected by the form of K fertilizer. The favourable effects of K on carbohydrate translocation and on the enzyme systems (starch synthetases), with consequent effects on yield and quality, are to some extent offset by the unfavourable effects of rising K content in the plant which reduces starch content *[37, 184]*. In this connection there is no doubt that the form of potash fertilizer is most important, since, especially at high rates of application, Cl promotes the translocation of K into the tubers which lowers the starch content *[146, 228]*.

Practical experience and experimental work in all parts of the world where potatoes are grown are in agreement that for intensive potato growing the sulphate form, and especially sulphate of potash magnesia, is much to be preferred *[139, 171]*. Selected representative data from various countries are summarised in Table 17 detailing effects on tuber yield, starch content and starch yield (cited *[102, 22]*).

Table 17 Effect of form of potash on tuber and starch yield of potatoes *[22, 102]*

Country	K form	Tuber yield t/ha	Starch content %	Starch yield t/ha
USA	KCl	24.2	13.3	3.22
	K_2SO_4	24.4	14.6	3.56
	½ KCl + ½ K_2SO_4	24.8	13.8	3.42
Japan	K_0	18.6	15.7	2.92
	KCl	24.8	15.7	3.89
	K_2SO_4	26.3	16.3	4.29
Germany	K_0	20.9	17.6	3.68
	KCl	21.9	17.3	3.79
	K_2SO_4	23.5	18.0	4.24
	SPM*	24.1	18.0	4.33
Switzerland	KCl	30.5	15.0	4.57
	K_2SO_4	30.8	15.7	4.84
	SPM*	32.3	16.0	5.17

* SPM = Sulphate of potash magnesia

Contrary to the above, several recently published results *[146, 243, 287]* have reported yields as high or even slightly higher from KCl than from K_2SO_4. The same applied to chip quality *[228]* as demonstrated in Table 18.

Table 18 Starch and sugar contents, discolouration of tubers and colour of chips in 1971, 1973 and 1977 *[228]*

NPK Treatment		Starch %	Reducing sugars %	Total sugar %	Discolouration %	Chip colour Index[2]
1:0.8:0	Without K	19.1	0.33	0.33	67	4.8
1:0.8:1	Kainit	18.9	0.14	0.50	18	7.3
1:0.8:1	SPM[1]	21.4	0.21	0.58	20	6.3
1:0.8:1	KCl (50%)	20.6	0.19	0.52	22	7.3
1:0.8:1	K_2SO_4	20.9	0.21	0.55	32	6.7
1:0.8:1.8	Kainit	18.3	0.07	0.45	1	8.5
1:0.8:1.8	SPM[1]	19.9	0.08	0.47	5	8.3
1:0.8:1.8	KCl (50%)	18.8	0.11	0.42	1	8.0
1:0.8:1.8	K_2SO_4	20.5	0.12	0.51	7	7.2
P=0.5		1.35	0.065	0.14	–	0.75

[1] SPM = Sulphate of potash magnesia
[2] Index 1–10 (increasing quality)

The farmer will eventually make his decision as to which form of potash to use on economic grounds, balancing questions of tuber yield and starch content against the price advantage for the cheaper chloride and whether to apply in autumn or in spring. In the German D.R., where potash is virtually only obtainable as chloride there has been no lack of experiments in the past 20 years with the objective of supporting the use of KCl in potato growing *[34–37]*. Field experiments over 7 years in the German D.R. and CSSR showed yield increases over control (no K) of 9–14% for Mg-KCl (40% KCl + $MgSO_4$), 4.5–10 for KCl (60%) and 2–8% for K_2SO_4 (50%) *[35]*, BRUCHHOLZ, p. 111 in *[342]*).

Though experiments repeated in the following years *[36, 37, 308]* showed yield advantages in favour of SO_4, BRUCHHOLZ (p. 115 in *[342]*) concludes:

Chloride and non-chloride fertilizers have the same effect in terms of yield, within the margin of error. KCl is economically clearly superior to K_2SO_4.

The following, written by ZIEGLER *[333]* shows that in making the choice of form of potash a number of factors touching plant nutrition and practical farming conditions should be taken into account:

Sulphate of potash is the superior form of fertilizer for potatoes as shown by experiments carried out many years ago and supported by more recent results. The older work stressed particularly the effects on starch production. Potassium chloride is the most widely used and the cheapest K fertilizer and can be used for potatoes without harmful effects provided it is applied several weeks or months before planting as was advised in the older literature. This practice permits maintenance dressings of potash to be applied to suit convenience and the availability of labour.

Where in long term experiments there is little difference between the K forms as regards tuber yield, Starch content is always higher from SO_4 *[8, 89, 150, 228]*. MÜLLER *[202]* found that there was no influence on starch content from 50–50 KCl–K_2SO_4 (compared with K_2SO_4) but that further increasing the proportion of KCl reduced it (see also Tables 17 and 18).

Russian workers *[2, 6, 42, 84, 231, 270]* found starch content to be increased only by sulphatic K fertilizer while it was decreased by chloride. Petiole Cl content was inversely correlated with starch content *[132]*.

Particularly large yield differences were found in a long term K form experiment on a meadow podsol soil at the *Zhitomir Agricultural College* in the Ukraine *[335]* with tuber yields increased by 2.5 times and 1.1–2.0% higher starch content with higher protein contents on the K_2SO_4 treatment. Taste and cooking properties were also improved.
The characteristics of the starch are also affected, K_2SO_4 resulting in coarser grains. Applying KCl late, *i.e.* shortly before planting, can cause the formation of a high proportion of small starch granules, similar to those found under K deficiency *[95]*. For the manufacture of potato flour, the viscosity is an important quality criterion. DE WILLINGEN (cited *[139]*) reported that 40% potash gave a lower viscosity rating than K_2SO_4.

Starch content and starch yield are decisive for industrial and stock feed potatoes. *Specific gravity* and *dry matter content* are also important for table potatoes. High specific gravity indicates high dry matter content. A dense mealy potato is better suited for boiling with less loss in cooking. Chips and crisps manufactured from high specific gravity potatoes take up less oil, the product is more digestible and of higher value. There is no lack of experimental evidence to show that these quality criteria are favoured by sulphatic K fertilizer in comparison with the chloride *[102, 117, 139, 164, 171]*; HESEN, p. 173, and PÄTZOLD, HEILINGER, p. 157 in *[345]*.
In Canada, where for the most part there has been no difference in tuber yield, K_2SO_4 produces tubers with a higher specific gravity than KCl *[236, 242, 243]*. Long term American *[58, 194, 195, 206]*, Scandinavian *[108, 123]*, French *[171]* and Indian *[267]* experiments have all demonstrated that, even where there is no difference in tuber yield, K_2SO_4 always gives a higher specific gravity (or KCl a lower). Since high rates of potash cause a reduction in specific gravity it is advisable to use sulphate where generous K applications are called for in order to achieve a compromise between high yield and good quality.

Several years of experiment in the lower Rhine area at 10 sites on sandy loam showed that, at the same tuber yield, the dry matter content was reduced by 0.5%, corresponding to 0.82 t dry matter per hectare while the starch content fell by 0.3% (0.47 t starch/ha) *[243]*.

The increase in water content of the tuber by KCl is also important *[43, 123]* because, as well as resulting in a lower starch and dry matter content, the loss of weight in *storage* is increased. LIN *[168]* and HARWARD et al. (cited *[139]*) reported more tuber rot in store in Cl treated potatoes. FISCHNICH, HEILINGER and PÄTZOLD (cited *[139]*) did storage tests and found that K_2SO_4 reduced losses of starch and Mg and reduced the increase in sugar content.

The opposite influences of Cl and SO_4 on yield, starch content, dry matter yield and specific gravity of tubers have *physiological causes* partly through effects on the water economy and partly through effects on assimilation and enzyme activity *[163]*. According to LEMPITSKAYA *[166]* K_2SO_4 increases the rate of respiration during flowering and this is a measure of photosynthesis. All the 24 varieties tested by ZIEGLER *[334]* were Cl sensitive, and Cl reduced synthetic activity by up to 20% in comparison with K_2SO_4. Cl favoured the formation of insoluble starch in the leaf and reduced the translocation of soluble sugars from leaf to tuber.

When Cl alters the partition of assimilates between shoot and tuber, this causes reduced dry matter and starch contents in the storage organs, while the assimilates which cannot be transported to the storage organs increase shoot growth at the expense of tuber formation as pointed out by HAEDER *[107]* in Table 19.

Table 19 Tuber : shoot ratio, tuber yield, starch and dry matter (d.m.) contents *[107]*

K form	Cl	Cl/SO_4	SO_4
6 weeks after flowering			
tuber : shoot ratio	3.2	3.6	4.3
tuber yield (g d.m./plant)	131	143	153
d.m. (% fresh weight)			
leaflets	12.3	12.5	15.6
stem	10.6	10.1	12.8
tuber	18.2	18.9	20.1
At maturity			
tuber yield (g d.m./plant)	153	158	194
starch content of tuber (% fresh weight)	12.4	12.6	13.3
d.m. content of tuber (% fresh weight)	18.7	19.1	20.1

Possibly, the reduced transport of assimilates is connected with the formation of organic acids. Sulphate generally favours their synthesis. For example, the content of ascorbic acid is increased by K_2SO_4 while it is reduced by Cl *[107, 231, 258]*. The same applies to carotene content *[335]*.

The unfavourable effect of Cl on total protein content is known from Russian work *[97, 335]*. MURAKA et al. *[205]* noted that Cl reduced NO_3 nitrogen content and accumulation of N but did not affect the total protein N in the plants.

According to HESEN (p. 173 in *[345]*) and POLETSCHNY-KICK *[228]* sulphatic K fertilizer lowers the sugar content less than does chloride. STRICKER *[287]* found no significant differences between sulphate and chloride, the sugar content being influenced mainly by storage temperature. Various workers *[123, 139, 206, 228]* obtained more lightly coloured crisps from Cl treated potatoes (see Table 18). This favourable effect of Cl is accompanied however by reduced yields and dry matter contents so that many workers suggest using a 50–50 mixture of K_2SO_4 and KCl. Again, it must be born in mind that increased Cl contents in the tuber, accompanied by higher K contents, reduce susceptibility to blackening. This does not normally occur at K_2O contents above 2.5% *[22, 127, 203]*.

Crisp manufacturers advocate the use of sulphate to produce higher dry matter contents, and crisps which keep better.

The *consistency*, *taste* and *colour* of cooked potatoes in Canada appears not to be affected by form of K *[243]*. In Sweden *[108]* KCl is said to have a bad effect on the taste.

Zuk and Gupalo *[335]* ascribe the better taste and aroma of SO_4 treated potatoes to their lower total sugar and free amino acid contents. These form unpleasant tasting volatile compounds in cooking. Bruchholz in the German D.R. *[37]* found no significant differences in firmness, mealiness or after-cooking taste in K form experiments over 7 years.

The accompanying anion has effects on tuber size and disease resistance and this is important in *early potatoes* and for the *seed crop*. K_2SO_4 encourages the formation of small and medium size tubers, thus giving a better seed sample while KCl promotes formation of large tubers more suitable for table use *[62, 90, 117, 171]*. Holmes et al. *[124]* compared the optimum rates of K fertilizer and the cash returns obtainable from the two forms of potash, assuming differences in the price obtainable for tubers of varying size (Figure 7).

In USA experiments there was no difference in total percentage of No 1 tubers between the two forms *[195]*. According to Burghardt *[43]* Cl causes a higher water content and dispersion of colloids in the plant tissues which as a result are more susceptible to infection by virus and its spread within the plant. Vogt and Völk (cited *[139]*) were the first to report a 10% decline in virus infection on sulphate treated plots. Whereas Münster (p. 183 in *[345]*) observed no significant difference in short term experiments, Stricker *[286]* found that K_2SO_4 delayed virus infection of the tubers. Sulphate, as compared with chloride, reduced the virus infection in crops from once grown seed especially when lifted early. At the second lifting of the variety 'Capella' 49.5% of virus infected plants showed tuber infection, whereas the proportion of infected tubers on chloride plots was already 75.9%. Thus, Stricker advises the use of Cl free fertilizers for early crops not only because yield and quality is improved but because there is less danger from virus attack.

Tropical root crops

Cassava *(Manihot exculenta)*, **yam** *(Dioscorea* spp.), **cocoyam** *(Colocasia* spp.) and **sweet potato** *(Ipomea batatas)* are important food crops in the humid tropics. They

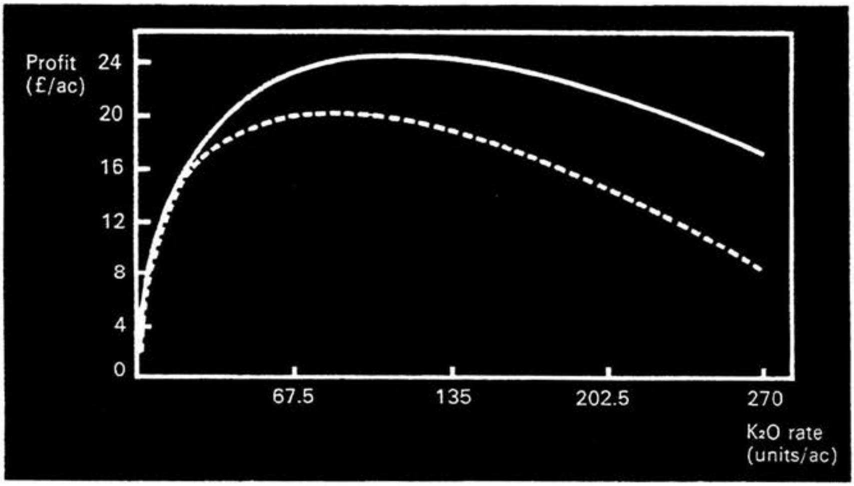

Fig. 7 Comparison of return from muriate (----) and sulphate (——) of potash applied to potatoes *[124]*
Price of large tubers – £ 10/t
Price of medium tubers – £ 25/t

have a high starch content and also contain essential vitamins and proteins. They require large amounts of potassium (content of aerial parts and storage organs ranged up to 9.5% and 2.5% K in dry matter resp.) (JÀNSSON, p. 277 in *[343]*; *[213]*.) Potassium is taken up in greater quantities than nitrogen and phosphate, uptake varying with variety and potential yield especially in yam as demonstrated in Table 20 (*[213]*, EZEILO, p. 193 in *[356]*). A great number of fertilizer experiments, esp. in West Africa, with cassava and yam have confirmed that, besides increasing the overall yield, K application considerably improves the dry matter and starch content and appreciably reduces the prussic acid content of the cassava tuber. OBIGBESAN's experiments (p. 439 in *[353]*) showed, however, that high rates of KCl, over 60 kg K_2O/ha, may reduce the starch content of tubers and that this was most likely due to the effect of chloride.

Table 20 Nutrient removal in the tubers of different yam species *[213]*

Yam species Dioscorea	Dry matter yield (kg/ha)	Nutrient removal (kg/ha) N	P	K	Ca	Mg
D. alata	9034	128.3	16.9	161.7	2.8	7.9
D. rotundata (var. efuru)	12133	155.3	18.2	175.9	3.9	10.7
D. rotundata (var. aro)	12197	140.3	18.1	154.9	3.4	11.2
D. cayenensis	15255	138.8	19.4	181.5	3.8	13.1

This author is therefore of the opinion (personal communication *[1979])* that K_2SO_4 should be the preferred potash fertilizer as this increases starch content and the proportion of marketable tubers. EZEILO (p. 196 in *[356])* writes: 'Potassium sulphate has been found to be more efficient than the chloride in increasing yield'.
ADUAYI *[4]* in Nigeria uses as standard manuring in field experiments on yam 25 kg $MgSO_4$/ha with 100 kg K_2O as K_2SO_4/ha. It has been found in Colombia *[209]* that, where the SO_4 content of soil is only 4.5%, sulphate of potash gives higher yields of cassava than KCl, but that there is no difference between the two forms at Pance where soil SO_4 content is 9% (Table 21). On soils which require S, high rates of KCl (240 kg K_2O/ha) not only reduced total root yield but also reduced tuber size. Pot experiments *[339]* also showed the superiority of K_2SO_4, especially when applied at high rates (Figure 8). In Tamil Nadu (India) the starch content of cassava tubers was greatly increased from 71.4 to 87.2% in dry matter with K applications up to 150 kg K_2O/ha together with N applied at a rate of 85 kg/ha although the chloride form was used *[39]*.

Sugar beet *(Beta vulg. saccharifera)*
Sugar beet, a member of the chenopodiaceae, is a halophyte and has definite requirements for Na and Cl. From experiments carried out in Europe, America and Russia it is known that, under the appropriate conditions, notably on low K soils, the crop responds favourably to low grade potash salts or to sodium chloride itself. As established by DRAYCOTT and DURRANT *[64–66, 69]* in a large number of field experiments, salt can largely replace potash fertilizer and both elements (K and Na) increase root and sugar yield *[29]*.

Sodium increases the effectiveness of K by a factor of three, Na taking over some of the less specific functions of K in the plant, *e.g.* the hydrophilic function of the ion in the water economy of the plant, and thus releases K to perform its specific functions in photosynthesis, carbohydrate metabolism and especially in protein metabolism. Owing to this, Na fertilized plants take up more nitrogen and 'noxious N' content of the juice increases if the K:Na ratio is incorrect. The monovalent cations have differing influences on the carbohydrate synthetases, thus, while Na increases the activity of saccharose synthetase in the leaves, in contrast to K it reduces the activity of starch synthetase *[329]*.

Solution culture experiments *[109]* in which varying proportions of K and Na were applied have demonstrated that Na has specific functions in the nutrition of sugar beet. When supplied with equivalent amounts of both Na and K, very young seedlings took up K preferentially but, as they developed further, this preference was no longer evident and both K and Na were taken up in proportion to their concentrations in the nutrient solution. Under conditions of K deficiency Na was largely able to substitute for K but in addition to this unspecific effect is was found that Na had specific effects on growth. In a series of treatments in which the Na:K ratio in the nutrient solution was varied, it was clearly shown that Na had the following specific effects: The leaves of Na plants were larger, glossier and longer and they were more succulent. The leaves carried about 25% more stomata per unit area and the stomata were more sensitive to changes in leaf water content, closing more rapidly in response to water deficiency.

Table 21 Effect of potassium sources and rates of application on total plant fresh weight and root yield of cassava 40 weeks after planting at Pance, Carimagua and Tranquero [209]

Site		Pance		Carimagua*		Tranquero	
K form	K_2O rate (kg/ha)	Total plant fresh wt (t/ha)	Root yield (t/ha)	Total plant fresh wt (t/ha)	Root yield (t/ha)	Total plant fresh wt (t/ha)	Root yield (t/ha)
KCl	0	42.0	29.0	-	-	17.2	9.5
	60	47.6	31.0	8.5	4.5	19.4	11.4
	90	-	-	9.0	5.0	-	-
	120	54.8	40.0	8.5	4.8	24.4	15.7
	240	65.8	44.3	8.5	4.5	23.7	13.9
K_2SO_4	0	46.6	31.3	-	-	-	-
	60	49.6	35.5	14.5	9.0	23.2	13.8
	90	-	-	15.0	9.0	-	-
	120	61.3	42.3	15.0	9.5	25.8	15.8
	240	62.5	43.4	18.0	11.5	30.3	19.0
KCl+S	60	-	-	-	-	24.8	16.1
	120	-	-	-	-	22.8	15.2
	240	-	-	-	-	29.3	18.4

* There was a serious outbreak of cassava bacterial blight 2 months after planting.

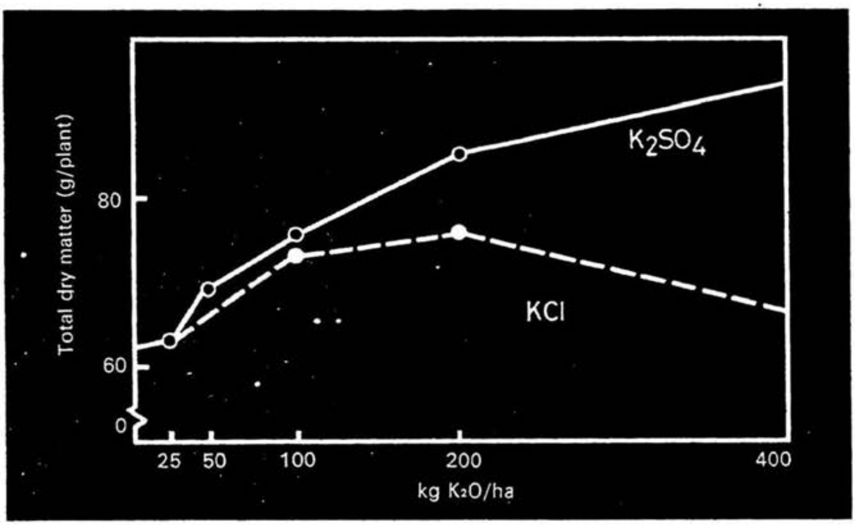

Fig. 8 Total dry matter production of six month old cassava plants as related to five levels and two sources of K applied to Carimagua soil in pots. (CIAT, p. 93 in [339])

The result was that plants receiving Na were more drought resistant and consumed less water than those receiving only K. Net assimilation was improved by Na because of its effects in improving the water economy of the plants. The beneficial effects of Na were particularly evident under short day conditions.

These findings confirm the statements by DURRANT et al. *[69]* that Na increases sugar yield through at least two different physiological mechanisms: it improves interception of radiation by the crop by increasing leaf area early in the season and it improves the efficiency of leaves under conditions of moderate water stress.

The anions accompanying K and Na are not without significance in the nutrient economy and metabolic process in the plant. Beet has a definite requirement for *chloride [157]* and when leaf Cl content is less than 100–200 ppm plants show deficiency symptoms. Cl contents in the petiole are often as high as 10 000 ppm. HUMBERT and ULRICH (p. 379 in *[208]*) say that the lower limit for Cl content of the petiole is 0.4% Cl in the dry matter. The Cl ion is osmotically very active, thus it has an important effect in increasing leaf succulence, increasing cell size and thickness of the leaf *[329]*. In consequence, with Cl as opposed to SO_4, the leaves remain upright longer and senescence is delayed. This is not unimportant as it allows sugar accumulation to continue later in the season. Cl fertilized beet is more drought resistant than SO_4 fertilized and, for the equivalent yield, has a lower water requirement.

Because of the physiological make-up of the chenopodiaceae, aspects of plant composition which determine quality are more favoured by Cl than SO_4. The influence of Cl on the carbohydrate economy of the plant, via photosynthesis, is especially significant.

While in most plants carbohydrate metabolism is favoured by sulphate and protein metabolism by chloride, in sugar beet, on account of its origin, carbohydrate metabolism is also positively influenced by chloride. Efficiency of assimilation is increased by Cl and the content of reducing sugars is lessened so that, though the total carbohydrate content is not much affected, the saccharose: glucose ratio in the root is shifted in favour of the more highly polymerised carbohydrates like saccharose, starch *[163]*.

This relationship has recently been confirmed in solution culture experiments comparing the effects of Cl and SO_4 as accompanying anions at varying concentrations *[329]*. The activities of saccharose and starch synthetases were increased by Cl as compared with SO_4 but the effect depended on the level of K supply. With abundant K supply, Cl increased the synthesis of higher molecular carbohydrates, but when K supply was low, the effect of Cl was to increase hydrolysis of these compounds. Thus Cl deficiency could either increase or decrease saccharose content.

Though the above discussion strongly suggests that the chloride form of fertilizer would be preferred, it must be remembered that sugar beet nevertheless has a definite requirement for *sulphur [33]*. The N:S ratio of beet protein is normally about 15:1 which would give a minimum S content in the leaf dry matter of 0.12–0.13%, so sufficient S should be available to supply this *[281, 336]*. Leaf S contents below 0.05% in dry matter indicate S deficiency.

Apart from the experiences already discussed with regard to the metabolism of sugar beet some other experimental work in the field comparing potash forms should be mentioned because the results were contradictory. Long term experiments *[8]* over a 60 year period in Munich-Weihenstephan (Table 22) and investigations in the German D.R. and in Czechoslovakia *[34]* showed no significant difference between sulphate and chloride. Sulphate of potash with magnesium had a slight advantage in the early years of the experiments but then, principally on low Mg soils. In a number of, mainly Russian *[316, 317]*, experiments the highest yields of roots and sugar were obtained from a mixture of Cl and SO_4. These workers remarked especially on the rapid formation and utilisation of sugar-phosphates. Experiments in France *[171]* in 1963–1975 using K rates up to 400 kg K_2O/ha showed the tendency for KCl to produce the best results up to 200 kg K_2O/ha while K_2SO_4 gave the best yields at K rates over 200 kg/ha. Sulphate also appeared to be better for root yield when much N fertilizer was applied.

Table 22 Effect of form of K on root and sugar yield of sugar beet, K uptake and K utilisation (average 1914–1975) *[8]*

Form of K	Root yield (dry matter/ha)	K uptake (kg K/ha)	K utilisation (% recovery of applied K)	Sugar (% fresh roots)	Yield of sugar (t/ha)
K_0	15.2	195	–	19.9	11.2
Kainit	18.6	262	50	20.3	12.4
KCl (40%)	18.4	268	55	20.4	12.7
KCl (50%)	18.8	277	61	20.2	12.3
K_2SO_4	18.9	259	48	20.2	12.2
P=0.5	1.3	24.5		0.7	0.7

Average annual dressing 133 kg K/ha

In Dutch experiments comparing all the different potash fertilizers (150–300 kg K_2O/ha as Mg-kainite, 20, 40 and 60% muriate, sulphate of potash magnesia and sulphate of potash on two sites *[319]* the interesting observation was made that the highest yields were obtained with sulphate or low sodium fertilizers, mainly due to increased root yield rather than to any effect on sugar content. This is explained by the Cl- and Na-containing fertilizers having reduced the plant population during germination. Physiological drought caused by high salt concentration in the environment of the germinating seed can adversely affect germination and the early growth of the crop. Germination experiments on sand beds with monogerm seed to which different salts in solutions of equal conductivity were applied confirmed this finding. The absence of adverse affects on germination may be the explanation that K_2SO_4 also produced the highest yields on sandy loam soils in Germany *[122]*.

Behaviour of the roots in the *factory* is also affected by sulphate and chloride. Sulphate is regarded as confering alkalinity. However, while the SO_4 and Cl contents of the juice depend mainly on root composition, they are also affected by the composition of the water used for extraction *[157]*.

Impurities in the juice lower beet quality because they may prevent sucrose from crystallizing and thereby reduce the recovery of sugar. Soluble nitrogenous compounds, which accumulate when much nitrogen is taken up by the plant, are particularly important in this respect. JAMES *[135]* observed that Cl applied as KCl reduced nitrate uptake especially when soil Cl was low *[172]*. This takes advantage of the $Cl\text{-}NO_3$ antagonism to minimise the adverse effects of too high a level of N in the soil.

Sugar Cane *(Saccharum officinarum)*
Much work has been done on the effects of K on this crop (100) but there has been little interest in comparing forms of K fertilizer because sugar cane is not thought to be chloride sensitive and when heavy rates of potash are applied on acid tropical soils, the chloride is rapidly leached out (HUMBERT and ULRICH, p. 379 in *[208]*). 60% muriate is the form of potash normally used. When applied at rates up to 200 kg K_2O/ha it increases yield and sugar content and improves juice purity (DE BEAUCORPS, p. 335 in *[343]*). DUTOIT (cited *[100]*) obtained the highest yields and sugar content (14.6%) at 220 kg K_2O/ha, with K_2SO_4. Leaf application of K_2SO_4 hastened early growth and gave eventually a higher cane yield than KCl *[274]*.

Application of gypsum to some soils in Hawai has increased yield by as much as 215% *[281]*, but there is little information on the effects of S deficiency in sugar cane. The S content of the plant varies much with age and between different parts of the plant. MALAVOLTA *[177]* quotes the following S levels: root 0.217, leaf 0.493, cane 0.509% in dry matter. CATANI et al. *[47]* give values for the unmanured crop: 0.042 to 0.165 for the cane, and 0.1–0.165% S for leaves and have established a connection between S uptake and dry matter production. S contents of 0.013–0.02% in the dry matter of 2 year old cane would seem to be desirable to maintain the optimum N:S ratio and for maximum yield *[281]*. A cane yield of 100 t/ha removes 22 kg S/ha *[33]*.

While from the plant physiological point of view there is no advantage in using K_2SO_4 on sugar cane, there is however an advantage under the technological aspect as high rates of KCl have unfavourable effects on juice purity. Thus, VON UEXKÜLL (in *[364]*) advises in the Philippines that, when more than 120 kg K_2O/ha are applied, sulphate should be used to supply the extra K_2O instead of KCl.

4.3. Grassland and fodder crops

The great bulk of animal fodder is supplied by the leguminous crops and grass. The *yield* and *quality* of these crops are the foundations of the raw materials which herbivorous animals convert into protein rich food. The legumes are particularly valued as suppliers of protein; the feeding value of grasses depends upon the composition of the carbohydrates and nitrogenous compounds contained therein, 80–90% of the N content being present as protein. The building blocks of proteins, the essential amino acids, and especially S-containing methionine and cysteine require for their formation a good supply of sulphur to the plant *[268, 345]*. Carotene content is also increased by S fertilization *[137, 279]*.

The fertilizer requirement of grassland depends on a number of factors: climate, soil type, botanical composition, the type of management and its intensity. Thus the requirements of grass vary greatly according as to whether it is used for grazing, and they vary with the stocking rate, or for conservation as silage or hay. This situation is very different from that which applies with most annual crops *[192]*.
On top of this, it is necessary to consider the mineral requirements of the animals through which the grass is utilised. Whereas the K content of high yielding grass, which has a high K requirement, is high (DE BEAUCORPS, p. 325 in *[343]*) the animal has a much higher need for Mg and Na than the plant. S content of fodder should according to animal nutritionists be in the range of 0.18 to 0.25% in dry matter *[304]*.

There is no doubt that fodder plants have an appreciable need for sulphur which amounts, according to yield, to as much as 50 kg S/ha. There have been many records of the occurence of S deficiency in fodder legumes and grasses and also of the behaviour of the two groups in competition for S when grown together in association *[12, 114, 186, 322]*. The sulphur content of fodder plants varies much between parts of the plant and with physiological age. Critical values are: for lucerne 0.2–0.22% total sulphur and for clovers and grasses a somewhat lower value of $<0.15\%$. Based on work in France in Normandy and Charente (HEDIN and DUVAL, DELAS, JUSTE et al., cited *[171]*) values of 0.3–0.5% should be aimed for in lucerne. In Canada plants grown on soil with less than 6 kg S/ha or plants having 0.15% S or lower levels suffered from winterkill and stand life was only 3 to 4 years *[12]*.

Most recently, measurement of the N:S ratio has been recommended for determination the S status as this appears to remain relatively constant at all stages of growth. The following values for N:S indicate S deficiency: lucerne >15, white clover >18.5, grass >12 *[5]*. TISDALE *[304]* and SAALBACH (p. 23 in *[336]*) recommend 10–12 as a desirable N:S ratio for permanent grass.
Recently, on account of its significance for protein synthesis, the SO_4-S content has been recommended as an indicator of S status and critical values between 150–500 ppm SO_4-S have been quoted for legumes and grasses.

The correct choice of potash fertilizer is important in meeting the nutrient demands of both plants and animals. On grassland, in addition to the yield increasing effect of K, the lower grade fertilizers and raw minerals ('Kainit' with 12% K_2O, 6% MgO, 24% Na_2O) are useful in raising the Mg and Na contents of the fodder and thus have a particular value. Sulphate of potash magnesia (Patentkali) offers the possibility of supplying both S and Mg, which are both important in animal nutrition *[217, 218, 259]*.

Grasses *(Gramineae)*
Protein synthesis in grasses involves the reduction of nitrate and sulphate ions in the proportion 0.027 mole S per mole N. S deficiency is indicated when total S content

does not exceed organic S, *i.e.* when no inorganic sulphate is present (DIJKSHOORN, p. 43 in *[344]*). Annual removal of sulphur by grasses in either cool or hot climates amounts to 40–50 kg S/ha for yields of 16–30 t dry matter/ha (pp. 105 + 126 in *[130]*).

Because of preferential uptake of Cl by grasses there is a danger of S deficiency if soil S supply is low in relation to Cl (*i.e.* application of Cl-containing fertilizer can jeopardise the S supply). This would explain results obtained by the French potash industry *(SCPA)* on permanent grass in Normandy (Table 23) *[171]*.

Table 23 Hay yields (t/ha at 86% dry matter) *[171]*

	1961	1962	1963	1965
K_0	5.6	2.1	4.95	8.53
KCl	6.5**	2.5	5.44	8.95
K_2SO_4	6.7*	2.5	5.82*	9.42[1]

* P=0.5 ** P=0.1

90 kg K_2O/ha applied (1965=100 kg/ha)

Comparison of the different potash forms in grassland experiments carried on for 75 years at Darmstadt *[259]* showed that at K rates of 120 and 160 kg K_2O/ha hay yields were 1–4% higher with SO_4 fertilizer and crude protein yield was also increased. The use of sulphate fertilizer resulted in better utilisation of K, which ranged from 65–70%, when the sulphate form was used. K_2SO_4 also reduced the Ca content of grasses less than did KCl.

There is little evidence of difference in efficiency of sulphate and muriate of potash for grassland and indeed there is no reason why there should be except on S deficient soils. Choice of fertilizer thus depends on cost and the cheaper chloride fertilizers will be the natural choice. In low sulphur areas sulphur deficiency can greatly reduce the yield of grass, and application of S then greatly increases yield, as reported for instance by HANLEY (p. 14–27 in *[361]*). DIRVEN (p. 403 in *[341]*) stresses the importance of legumes for improving the productivity of tropical grassland and points out their requirements for K and S. If there is a likelihood of response to S, then sulphate of potash, or preferably sulphate of potash magnesia which will also increase the Mg content of the herbage, offers an economic advantage. There are other ways of supplying sulphur, *e.g.* as gypsum or, in appropriate cases, elemental S, kieserite, etc. and again costs of the alternatives must be taken into account.

Legumes

The **clovers** *(Trifolium spp.)* are important constituents of grassland from the point of view of yield and quality, particularly in the less climatically favoured higher altitude conditions. They respond to both K and S and adequate supplies of these nutrients improve their ability to compete with the grasses in mixed swards, particularly when N fertilizer is used *[322]*. 35 kg S/ha are removed by 12 t dry matter/ha. Fertilizer treatment is therefore important in relation to botanical composition of the sward and for ensuring the survival of the legume component. From the point of view of nutritional quality of the sward it is desirable that the legume should contribute 30 or 40% of the sward. KLAPP *[148]* found sulphate of potash more effective than the chloride for sward improvement without reseeding (Table 24).

Table 24 Effect of form of K on botanical composition (%) of grassland *[148]*

Species	NP	NP-KCl (40%)	NP-K_2SO_4
Desirable grasses	69.5	67.8	59.6
Legumes	6.5	5.6	7.2
Herbs, etc.	24.0	26.6	33.2

Clover plays a dominant part in grassland husbandry in large parts of Australia *[358]* and New Zealand *[321]* and its growth is much improved by application of both K and S. Higher yields of both red *(T. pratense)* and white *(T. repens)* clover were obtained with K_2SO_4 in Norwegian pot experiments *[173]* though the same did not apply to alsike *(T. hybridum)*. Similar results have been obtained in long term experiments in Germany *[120]* and in Canada *[17]* on S deficient soils.

One of the reasons for the good effect of sulphate based potash fertilizer on clover may be found in the effect of SO_4 on the nodule bacteria in improving fixation of atmospheric nitrogen and thus producing more protein *[139]*. Feeding experiments have demonstrated the improved palatability and higher feeding value of legumes manured in this way *[17]*.

Potash fertilizer reduces the susceptibility of clover to mildew and its effectiveness in this is decreased by the accompanying anion in the order; $SiO_3 > Cl > SO_4$ *[288]*. This result is not surprising since SO_4 also favours the production of biochemical substances which constitute the substrate for fungi.

Lucerne *(Medicago sativa)* is much used, with irrigation, for fodder production in arid areas and this crop requires much potassium and sulphur and, at a yield of 18 t dry matter/ha 45–55 kg S/ha is needed to replace removal in leaves and roots *[186]*, GRIFFITH, p. 161 in *[192]*. According to KAFKAFI et al. *[140]* crops in the Mediterranean area may be cut 8 or 9 times a year to yield 20–25 t dry matter/ha and remove up to 540 kg K/ha. Lucerne may be more responsive to S than to P and K and, particularly on heavy soils, sulphur supply may limit the effectiveness of these two major nutrients *[185]*. Under saline conditions, P uptake is more adversely affected by chloride than by sulphate *[74]*.

KAFKAFI et al., *[140]* and SMITH *[277]* say that heavy applications of KCl, up to

950 kg K/ha, reduce the contents of N, P, S and Ca at the first cut and that, though this may not affect yield, the protein content is reduced. K and S fertilization, on the other hand, favour N uptake and the formation of crude protein (Table 25) *[12]*. The positive interaction between N and S in yield and protein synthesis of lucerne means that high N content should be accompanied by high S content *[235, 279]*. Comparison of the effects of 673 kg K/ha applied annually as sulphate or chloride to lucerne suggests that K fertilizer increases nodulation and N fixation. K_2SO_4 gave the greater increase in nodule mass, acetylene reduction, activity of N fixing nodule enzymes and per cent total N and K, while KCl gave the greater increase in shoot weight per plant, per cent starch and total sugars, though, at the third cut yields from the two forms were nearly equal. This indicates that Cl and/or S may alter or mask the effects of K fertilizer and that N fixation may occur at the expense of carbohydrate accumulation *[68]*.

Table 25 The effect of S on yield, S and N content of lucerne forage (5 year average) on an S deficient soil *[12]*

Rate S kg/ha	yield t/ha	S %	N %
0	3.62	0.10	1.4
17	6.20	0.16	1.8
34	9.60	0.21	3.0
51	11.98	0.23	3.3
68	11.65	0.23	3.4

Thus, when it is necessary to apply high rates of potash this should be given in the sulphate form *[98, 171]*. In this way in addition to yield being increased the protein content will be raised as shown in Figure 9 and Table 26. Chisci *[49]* in Italy reports significantly higher yields from K_2SO_4 as compared with KCl and also larger yield increase from K alone than from complete NPK fertilizer. Pot experiments on the chalky soils of Champagne showed that K_2SO_4 increased dry matter yield by 7.8% compared with KCl *[171]*. Heavy rates of KCl (672 kg K/ha) applied to lucerne grown in pots in soil with 205 kg exchangeable K/ha caused damage, presumably by the Cl ion *[276]*, the damage being especially severe at high temperature (32/27°C day/night). But there was no injury by K_2SO_4.

168, 336 and 672 kg K/ha applied as K_2SO_4 to soil with 120 kg exchangeable K/ha increased leaf, root and total plant yields, plant height and shoot number at flower emergence. The K content of K_2SO_4 treated plants was higher than in KCl treated ones. Lacroix, in Canada, compared Cl, SO_4 and HCO_3 as K carriers and Andrews and Robbins in Australia (cited *[276]*) also found higher plant mortality in KCl treatments, with Cl concentrations up to 5% or more in the herbage. Lucerne seedlings containing more than 2% Cl died after 8 weeks *[136]*. Brown (p. 75 in *[192]*) reports that placement of KCl below lucerne seed was somewhat harmful in the seedling stage and broadcast application of very high rates of KCl may cause temporary setback

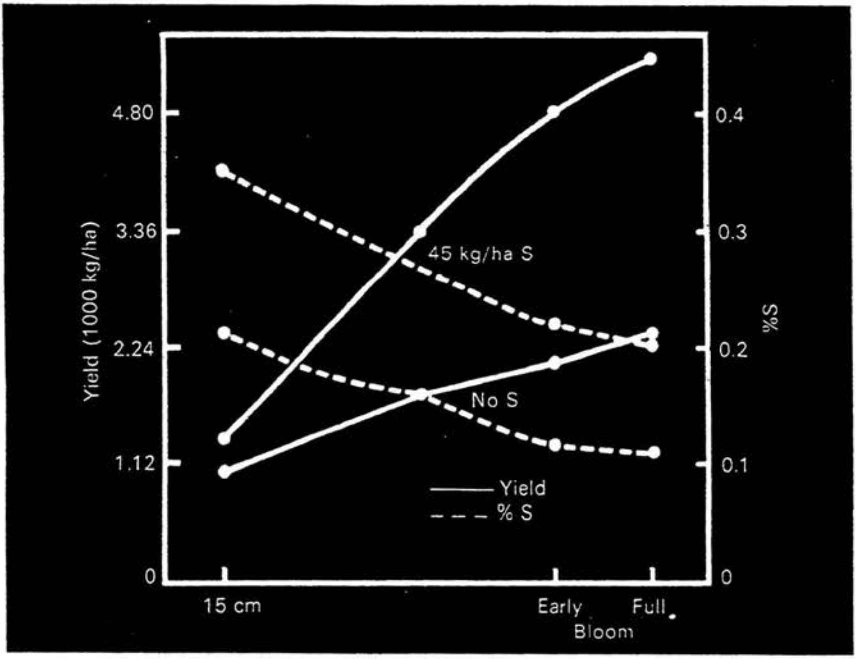

Fig. 9 Growth curve and % sulphur of first cut of lucerne *[235]*

Table 26 Effect of K_2SO_4 fertilization on the dry matter yield and protein content of lucerne *[119]*

Location	Yield (t/ha)		Protein (%)	
	No S	S*	No S	S*
Site A				
1st cut	2.60	3.54	12.6	15.2
2nd cut	1.86	2.64	15.4	16.8
Site B				
1st cut	3.63	5.09	8.7	10.4
2nd cut	1.50	2.62	13.6	15.0

* 56 kg S/ha applied as K_2SO_4

or thinning of the stand (Rhykerd and Overdahl, p. 158 in *[192]*). The young seedlings of the tropical fodder legume *Desmodium intortum* are similarly sensitive to KCl *[136]*.

The reaction of lucerne to the different forms of potash depends both on soil conditions and on variety and provenance. According to KIEPE *[147]* forms of *Medicago sativa* known as 'Provencal' lucerne performed better with KCl while hybrid lucerne definitely grew better with K_2SO_4. The difference was found both in yield and protein content (Table 27).

Table 27 Relative crude and true protein contents and yields of 'Mahndorfer' lucerne ($K_0=100$, 4 year averages) *[147]*

	KCl (40%)	K_2SO_4
Crude protein content	95.7	97.0
True protein content	96.3	97.2
Crude protein yield	101.5	106.5
True protein yield	102.1	107.6

Miscellaneous fodder plants *(Beta vulg.* ssp. and *Brassica* ssp., *etc.)*
According to the investigations of SAALBACH *[247]* other fodder plants like fodder beet, turnips, fodder rape, marrowstem kale have a high sulphur requirement, their leaves having a higher S content than the roots. In 32 out of 54 experiments in Germany SO_4 improved response in leaf yield to N fertilizer. The sulphur requirement of these plants increased steeply with increasing rate of N. Fodder beet, however, generally prefers low analysis chloride fertilizers esp. 'Kainit' as confirmed by KICK and POLETSCHNY *[146]* and BRUCHHOLZ (p. 111 in *[342]* on a number of sites in the German D.R. Mg containing K chloride fertilizers have been found especially effective for fodder crops in the German D.R. and CSSR *[34, 37]*.
Fodder lupins *(Lupinus* sp.*)* respond well to sulphate of potash in grain yield *[318]* and sulphate also gave the highest protein and oil content. The content of undesirable alkaloids was kept within limits by a combination of Cl and SO_4.

4.4. Oil crops

Two thirds of the world's food requirements in oils and fats are supplied by plants. Thus oil crops are of great economic significance, particularly in countries of the Third World where climatic conditions are well suited for the production of lipids.

These crops require relatively high amounts of potassium and sulphur for lipid synthesis and development of their protein rich storage organs *[343, 356]*. MALAVOLTA (p. 291 in *[342]*) summarising a large number of results in Latin American countries found an average yield increase of 10% through the application of S. The SO_4 ion has a special function in the metabolism of oil producing plants since in contrast to Cl it promotes the formation of saturated fatty acids. Seed and oil yields are greatly increased *[147, 315]*.

Soyabean *(Glycine max.)*
This is a most important source of protein and fat for both human and animal nutrition. Response to fertilizers (DAVIDESCU et al., p. 311 in *[356]*) has, in the past,

often been inconsistent and, in some areas, soyabean has had the reputation of being unresponsive despite the fact that large crops take up large amounts of N, P, K, Mg and S (NELSON, p. 161 in *[341]*, CHEVALIER, p. 329 in *[356]*). Being a N fixing legume, the crop needs plentiful supplies of S for the proper functioning of the nodule bacteria and S fertilization is practised for instance where it is grown in North Nigeria *[96]*. DHILLON and DEV *[61]* indicated for India that the soyabean is quite responsive to S application and that it has a high S requirement owing to higher quantities of proteins and S-containing amino acids. The nutritional value depends on methionin content which is improved by sulphur fertilization *[268]*. Leaf chlorosis and necrosis may occur at high rates of KCl, while the leaves of K_2SO_4 treated plants retain a healthy green and continue to assimilate efficiently *[55]*. Many varieties of soyabean are most susceptible to the fungus *Diaporthe sojae*. Though the disease level on seed decreased with increasing K (up to 1690 kg K/ha) neither KCl nor K_2SO_4 entirely prevented the disease *[59]*.

Oilpalm *(Elaeis guineensis)* and **Coconut** *(Cocos nucifera)*

In recent times there has been a great accumulation of experimental results and practical experience about the suitability of the different forms of potash and the topic has been discussed at various meetings of the *International Potash Institute [341, 343, 353, 356]*.

Earlier, the frequently expressed preference for the sulphate form for oilpalm, which led, in Sumatra for instance, to the exclusive use of sulphate of potash can probably be ascribed to sulphur deficiency in the soils and the positive influence of S on chlorophyll and oil synthesis *[281, 314, 315]*.

Sulphur deficiency in coconut has been studied in detail by SOUTHERN *[280]*. The nuts are small and the flesh seems normal when fresh but, when dried, the copra is rubbery and cracked and quite unsuitable for industrial use; it is only ground with difficulty to a spongy and intractable meal which reabsorbs the oil after pressing. In severe cases, the oil content is reduced to as low as 38%. The oil from rubbery copra is richer in unsaturated fatty acids due to increase in the proportion of the brown skin (Table 28). Applying sulphate (1.5 kg K_2SO_4/tree) corrects these defects and oil content is restored to over 60% in as little as six months after treatment *[293]*.

Table 28 Analysis of various grades of rubbery copra *[280]*

Grade	Moisture %	Oil % dry basis	Sulphate-S ppm dry basis
Extremely rubbery	4.8	38.4	31
Very rubbery	4.8	47.0	37
Rubbery	4.3	51.6	22
Slightly rubbery	2.5	64.4	107
Normal	2.4	64.9	141

Earlier, WERKHOVEN *[326]* and TEIWES *[300]* from results of a large number of fertilizer trials in West Africa and Malaysia, concluded that KCl and K_2SO_4 were equally efficient as regards yield of oilpalm and coconut. More recently the *Institut de Recherches pour les Huiles et Oléagineux (I.R.H.O.) [178]* has done much work with young coconut comparing the different anions accompanying K, Na and Mg in fertilizers. The highest yields were given by nitrate, followed by sulphate (Table 29).

Table 29 Influence of anions on coconut yield *[178]*

Form of fertilizer	Yields Nuts/tree		Copra/tree	
	No.	Relative	kg	Relative
KCl	61.6	100	12.6	100
K_2SO_4	67.6	110	13.8	109
$KCl + MgCl_2$	63.6	103	13.1	104
$K_2SO_4 + MgSO_4$	62.1	101	12.8	101
KCl + NaCl	57.0	92	12.7	101
$KNO_3 + NaNO_3$	88.5**	144	16.9**	134

** P=0.1

A review of Malaysian experiments on oilpalm between 1964 and 1970 (NG SIEW KEE, p. 357 in *[341]*) made no mention of any particular effects of Cl but more recent work in the last 10 years has shown that Cl can have as important effects on the yield of oilpalm and coconut as can potassium itself (OLLAGNIER, OCHS et al., *[215]*; p. 215 in *[353]*; p. 269 in *[356]* for results from South America (Colombia), West Africa (Cameroons and Ivory Coast) and South East Asia; MARGATE, MAGAT et al. *[183]*; summary in a recent series of publications *[178]* by MANCIOT, OLLAGNIER and OCHS).

The application of KCl brings about changes in the relationships between Ca, K and Cl in the leaves, Cl increasing the uptake of Ca which in turn causes the K level to drop from a level much above the critical value to a level close to or only a little above it.

Increasing the leaf Cl content up to optimum levels of 0.5–0.8% is correlated with increasing yield of bunches, oil and nuts (Figure 10).

High yielding hybrid coconuts (6700 kg copra/ha) remove a total of 250 kg Cl/ha per annum, half of this being contained in the nuts, and especially in the husks, compared with only 30 kg S/ha of which 9 kg is accounted for by the nuts (mainly in the albumen) *[178]*. VON UEXKÜLL (*[310*; p. 291 in *[343]*) and PRUDENTE and MENDOZA *[232]* have concluded from experiments in the Philippines in which leaf Cl content was correlated with yield that Cl is an essential nutrient for oilpalm and coconut.

One reason why Cl deficiency was not brought to light earlier is that K was so frequently a limiting nutrient and responses to KCl were naturally credited to the K, while much of the effect of KCl was in fact due to the effect of the Cl content. Further,

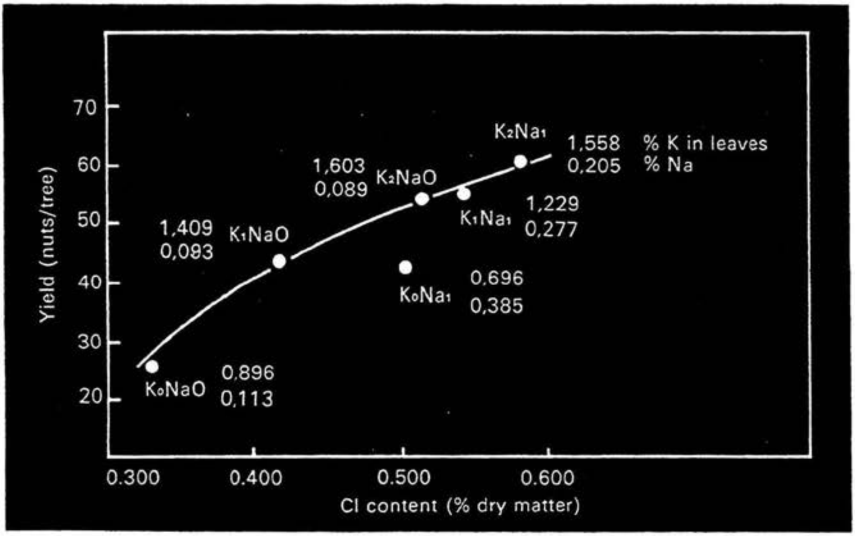

Fig. 10 Relationship between the Cl content in leaves (rank 14) and the yield of coconut after application of different levels of chloride of K and Na (0, 1, 2. Dabou/Ivory Coast *[178]*

Cl deficiency symptoms resemble K deficiency symptoms. The trees react very easily to application of Cl in increasing leaf Cl level.

Cl deficiency affects size and shape of nuts, copra yield, N uptake and the water economy of the plant but it is not yet known how it affects oil content. Long term investigations of the effect of KCl on seedling and bearing coconuts in the Philippines *[183, 214, 232]* and Ivory Coast *[178]* have shown the effect of Cl in improving vegetative growth. Cl always significantly increased girth (Table 30) while S sometimes increased the height of seedlings.

Table 30 Effect of Cl on girth of coconut *[178]*

K form		Cl contents (% dry matter)	Girth (cm)
KCl	1976	0.538	42.3
	1977	0.743	66.9
K_2SO_4	1976	0.196**	39.8
	1977	0.101**	61.2**

** P=0.1

KCl induces earlier flower induction and thus improves fruiting with increased nut and copra yield. In the experiment to which Table 31 refers, leaf Cl level was increased by KCl while the effect on K level was only slight so that nut and copra yields were correlated with Cl while there was no correlation with leaf K content. Cl has also been found to reduce the incidence of leaf spot disease.

Potassium, magnesium and ammonium chlorides might be considered useful fertilizers for oil palm and coconut, supplying as they do four essential nutrients. On all soils high in Ca but low in K and Mg it may be preferable to use K_2SO_4 and $MgSO_4$ (kieserite) along with KCl.

Table 31 Effect of KCl on average nut and copra production (1972–77) *[183]*

Treatment kg KCl/tree/year	Nut/tree No.	Copra/nut g	Copra/tree kg
0	87.1	158.7	13.85
1	109.7*	187.4	20.65**
2	128.5**	192.4*	24.83**
4	112.2**	214.5**	24.11**
8	114.0**	250.2**	28.54**

* P=0.5; ** P=0.1

Groundnuts *(Arachis hypogea)*

There is much variation in the yields obtained from this crop which is very widely grown (600–4500 kg shelled nuts/ha corresponding with 200–1500 kg oil/ha) due to climatic and soil differences, variety and cultural methods. Consequently fertilizer practice varies much. Whilst in certain regions as in India *[39]* significant yield increases of oil can be obtained by potash fertilization (90 kg K_2O/ha), in most areas, phosphate and calcium are considered most important; but there have been many records of sulphur deficiency in groundnut *[50, 229, 281]* indicating that the crop has a high sulphur requirement.

At the high yields obtained in the USA the crop removes up to 24 kg S/ha while investigations by *Institut de Recherches Agronomiques Tropicales (I.R.A.T.)* and *Institut de Recherches pour les Huiles et Oléagineux (I.R.H.O.)* in West and Central Africa indicate removals of up to 10 kg S/ha by a crop of 2.5 t nuts/ha (MARTIN-PRÉVEL, p. 88 in *[336]*). Especially in West Africa, the soils are not capable of covering this demand. In Senegal, Gambia, Ghana, Nigeria and, also, India, small applications of S (5–25 kg S/ha) given as single superphosphate (S × P interaction), or gypsum have given significant yield increases and higher S-containing amino acid content with higher oil content. Response was particularly noticeable on soils with a high C:N ratio of 15–17 newly brought into cultivation. Supplying enough S means that N fixation by the plant is improved and there is no need to consider the use of N fertilizer which has the effect of reducing oil content.

PREVOT and OLLAGNIER *[229]* reporting results of more than 50 experiments say that sufficient S supply is indicated by a N : S ratio in the leaf of 13–15. S deficiency results in enrichment with carbohydrates leading to the formation of undesirable types of protein and in reduction in the number and size of root nodules and delayed ripening *[134]*.

Sulphatic K fertilizers are to be preferred for seedbed application since they ensure a supply of available S for the first 20–30 days of crop development. Experiments in Senegal *[26]* showed better response by K deficient groundnuts to sulphatic fertilizers applied at 55 kg K_2O/ha (Table 32). *I.R.H.O.* (OCHS and OLLAGNIER, p. 287 in *[356]*) has encountered the problem that fertilizers, while increasing pod yield, can cause a decrease in oil content of the nuts and analysis of several experiments in Senegal has led to the same conclusion (Table 33). SCHILLING and HIRSCH *[255]* found great variation in leaf Cl levels in Senegal leading them to think that Cl was important. They obtained good responses to K but no difference in the effects of KCl and K_2SO_4 (Table 34). In further investigations they found that Cl content was positively correlated with yield of pods while there was no correlation of yield with the contents of other elements but, though the K and Cl contents of the leaves were negatively related, they still found no difference in the effects of KCl and K_2SO_4.

Table 32 Effect of form of potash on yield of groundnuts (kg/ha) *[134]*

K form	Pods	Leaves
Without K	970**	850**
KCl	1390	1270
K_2SO_4	1840**	1730**
KCl + $MgSO_4$	1780**	1660**

** P=0.1

Table 33 Fertilizer effect on pod yield and oil content of groundnuts in Senegal (p. 289 in *[356]*)

Treatments	Oil/seed %	Yield kg/ha
NK	56.4	1760
NPK	57.1	2350**
NPKS	56.3	2790**
Control	54.4	692
NPK	54.1	859**
NPKS	53.3	1191**
NP	55.1	970
NPK	54.7	1390**
NPKS	54.4	1840**

** P=0.1

Table 34 Effect of KCl on pod yield and leaf Cl content of groundnuts *[255]*

	Darou 1968			Bambey 1970/71		
	K applied*	Yield kg/ha	Cl %	K applied**	Yield kg/ha	Cl %
1st year	K_0	1775	0.405	1970 K_0	1210	0.530
	KCl	2097	0.603	KCl	1610	1.263
				K_2SO_4	1620	0.723
3rd year	K_0	1085	0.287	1971 K_0	2165	0.347
	KCl	1432	0.565	KCl	2900	0.474
				K_2SO_4	2900	0.356

* 20 kg KCl/ha ** 80 kg KCl resp. 100 kg K_2SO_4/ha

Rape *(Brassica napus)*

Since the introduction of varieties low in erucic acid, rape has attracted much attention as a useful break crop for intensive cereal rotations in temperate regions; a crop which, with proper manuring can give high and profitable returns (Appelquist, p. 261 in *[356]*). Rape is one of the crops with large requirements for both K and S. It takes up 50–80 kg S/ha *[241]* and 100 kg rapeseed removes up to 7.4 kg K_2O and 6.8 kg S (compared with 6.2 kg N and 2.5 kg P_2O_5). Thus there is a danger of S deficiency when rape appears often in the rotation.

S uptake is greatest at the end of flowering when the grain is being formed, but S deficiency symptoms may be seen in spring if winter rainfall is high (leaching) and especially if low temperature restricts the mineralisation of S *[182, 241]*.

Aulakh and Pasricha *[11]* found antagonistic effects between S, K and Mg in pot experiments, the rape responding to both S and K, but when Mg was applied along with S and K grain and straw yields were depressed. Mg hindered the uptake of S indicating preference for sulphate of potash rather than sulphate of potash magnesia.

Widespread occurence of S deficiency in France *[171]* led the French potash industry *(Société Commerciale des Potasses et de l'Azote [S.C.P.A.])* to carry out experiments in different areas and, in these, spring applied K_2SO_4 gave better results than autumn application of K. When the two forms of potash were applied in autumn in combination with increasing rates of P, K_2SO_4 greatly outyielded KCl and interacted with P *[182]* as shown in Table 35.

Rollier and Ferrif *[241]* advise splitting the K application between autumn and spring so as to ensure that easily available sulphate is provided to meet the peak demand. While they found that applying S increased oil content of the seed, Polish experiments (Babuchowski, cited on p. 262 in *[356]*) showed the contrary. Johansson (p. 155 in *[341]*) says that K must be balanced with a good supply of S to ensure high

Table 35 Influence of K form on the yield of rape seed (kg/ha) *[182]*

P_2O_5 kg/ha	K_2O kg/ha		
	0	150	
		KCl	K_2SO_4
0	500	700	1200
75	550	560	1470
150	570	550	1760

yield and good quality of the oil (low glucoside content). The effect of K in increasing protein and oil (FORSTER, p. 305 in *[356]*) can be related indirectly to increase in sap flow through the phloem and to possible effects on the chloroplasts (APPELQUIST, p. 264 in *[356]*).

K, S and Cl have similar effects to those described above on *other oil crops* like sunflower, olive, cottonseed, linseed and castor (see also chapter 4.5).

Sunflower *(Helianthus ann.)*
The effects of mineral fertilizers on oil content and oil yield have been reviewed by DAVIDESCU et al. (p. 311 in *[356]*) and APPELQUIST (p. 257 in *[356]*). Work in nutrient solutions showed that KCl raised the Cl content and lowered NO_3 content. K_2SO_4 increased total S content, NO_3 and organic acids and increased greatly the total amino acids, mainly aspartic and glutamic acids and alanine *[198]*. ROGALEV (cited *[255]*) found that KCl reduced the oil content.

Olive *(Olea europaea)*
Based on practical experience it is advised in Brazil and Italy to apply potash mainly as K_2SO_4 *[134]*, MORETTINI (p. 139 in *[346]*).

Linseed *(Linum usitatiss.)*
In Germany, Japan and the Netherlands K_2SO_4 gives a higher oil content whatever the level of K applied. Mg interacts positively with K_2SO_4 and negatively with KCl *[314, 315]*.

Castor *(Ricinus comm.)*
This is known to prefer sulphate *[134]* and the usually recommended dressing is about 100 kg K_2SO_4/ha.

4.5. Fibre crops

Fibre crops are generally thought to have medium tolerance for salt and Cl *[1, 141]*. The effect of potassium in producing large thick-walled fibre cells can be strengthened by appropriate choice of the anion, chloride leading to thinner cell walls and large lumina with loose bundles while sulphate promotes strong and fine fibres and fine bundles of higher quality *[171, 305]*.

Cotton *(Gossypium spec.)*
On the whole, N and P favour the formation of coarse fibres while K generally improves fibre quality as shown in fineness, maturity, strength and increases boll weight, lint per boll and lint percentage which results in higher fibre yields *[39]*. Sulphate of potash supplies two nutrients which are important for yield.
Even on high K soils, spray application of K_2SO_4 (2 kg/ha) will increase yield and, according to variety, the effect is equivalent to that produced by soil application of 350 kg K_2SO_4/ha *[104]*.

The salt tolerance of cotton, especially of the different organs and tissues, may depend upon their K contents. Chlorides, for instance in irrigation water, increase total cation uptake, mainly of Na, more than do sulphates, and thus the K:Na ratio is shifted so that K supply to the tissues is reduced. On the other hand it has been shown that sodium sulphate has a greater depressive effect on boll weight and number per plant than sodium and calcium chlorides *[141]*.

Against this other results comparing different K fertilizers indicate that the combination of SO_4 with Mg may be particularly effective *[94, 358]* as experiments in Brazil have shown (Table 36). Russian experiments also found K_2SO_4 superior to KCl for irrigated cotton (cited *[139]*). Jacob and von Uexküll *[134]* and Bolle-Jones *[28]* also recommend the use of K_2SO_4 in Africa. All fertilizer experiments reported from Egypt, Morocco, the Sudan, Trinidad and Pakistan have used K_2SO_4 while in USA, India, Central Africa and Peru KCl has been used with good effect *([94]*; Dubernard, p. 279 in *[353])*. In Uganda, arable cropping for 2½ years removed 128 kg K/ha from the topsoil and the recommendation for the cotton crop would then be 67 kg K/ha as KCl but there is a danger in using too high rates of KCl on acid soils as Mn toxicity may result from the effect of Cl in making Mn more available (Anderson, p. 421 in *[353])*. Older experiments (1939–1943) in Alabama showed that sulphate

Table 36 Effect of form of K on cotton yield (Instituto Agronômico, Campinas, Brazil, p. 19 in *[94])*

Fertilization*	Yield kg/ha	relative
Without fertilizer	429	100
NP + $MgSO_4$	405	95
NP	369	86
NP + SPM**	2724	635
NP + KCl	2665	621
NP + K_2SO_4	2655	619

* K applied at 70 kg K_2O/ha — ** Sulphate of potash magnesia

fertilizers increased seed cotton yield by 16% above that given by chloride fertilizers *[137]*. However, recent experiments on alluvial soils in the Mississippi valley *[180]* showed good responses to K over three years but no difference between KCl and K_2SO_4. Similar results in Turkey were reported 1976 by Kovanci *[153]*.
Removal of S by the cotton crop is considerable (34 kg S in 4.3 t seed cotton) and there are many reports of S deficiency from cotton growing areas in the east of the USA (cited *[281]; [137, 140]*). S deficiency is expected if the N:S ratio in the leaves is greater than 15–17. S contents in leaves of 3 month old plants of 0.2–0.28% are reckoned sufficient for maximum yield, though other authors say deficiency is indicated by leaf contents in young leaves of 0.13–0.17% *[177]*.

In francophone Africa where the crop takes up 9 kg S/ha, for a crop of 1.5 t seed cotton, average fertilizer recommendations include 10–12 kg S/ha (in Senegal 50 kg K_2SO_4/ha) (Richard, p. 241 in *[341]*; Martin-Prével, p. 81 in *[336]*). In fertilizer experiments in the Ivory Coast on K depleted deforested soils (23–42% yield reduction in absence of K fertilizer) cropped for 4–5 years it is normal to include 24 kg S/ha in the fertilizer dressing (Déat, p. 485 in *[353]*).

As cotton growing is intensified the crop's demand for available K and S increases and fertilizer rates must be increased. K is taken up rapidly over a period of only six weeks and this is a critical period for the crop. Under these conditions, K_2SO_4 gives very good results and it is economically well justified to use this form.

Flax *(Linum usitatiss.)*
In former times flax was an important crop in France, Germany and Holland and the results of experiments at that time (cited *[139]* and *[171]*) showed that sulphate of potash influenced the morphological properties, improving quality *e.g.* fibre content, fineness, fibre strength. K_2SO_4 produced higher yields of fibre with smaller and thicker walled cells than KCl *[150, 176]*.
The percentage of phloem tissue, and thus fibre quality, falls off with increasing salinity *[1]*. Seed yield is not so much influenced by salinity as is quality *e.g.* thousand grain weight and oil percentage.
When heavy rates of potash are used, especially over 200 kg K_2O/ha, two thirds of the dressing should be given in autumn, as KCl, and the rest as K_2SO_4 at sowing in the spring *[171]*.

Hemp *(Cannabis sat.)*
is very sensitive to Cl, especially in early growth, as shown in loss of yield and coarse, weak fibre, while SO_4 especially improves fibre strength *[138]* as is most important for the manufacture of ships' cables, nets, etc. (Table 37).

Jute *(Corchorus capsul.* and *olitor.)*
is manured with KCl in Taiwan, Pakistan, India (West Bengal) and Bangladesh. It has a relatively high K requirement and the yield of dry fibre is increased by K. Liming and potash fertilizer together control stem and root rot diseases. *C. capsularis* is more susceptible to S deficiency suggesting the suitability of fertilizers containing Mg and S (*[179]*; Kanwar, p. 261 in *[342]*).

Table 37 Effect of Cl and SO_4 on yield (g/pot) and quality of hemp *[138]*

Proportion of anions in fertilizer		Total yield	Stem	Grain	Fibre	Fibre %	Breaking strength kg/cm	Oil %
Cl	SO_4							
100	–	50.7	17.3	6.1	3.18	–	–	–
75	25	54.9	21.1	6.1	3.91	24.5	23.8	34.4
50	50	60.0	25.4	5.9	4.19	24.5	30.2	34.2
25	75	64.4	26.8	5.9	5.06	24.2	34.6	34.5
–	100	68.9	31.2	4.2	4.98	22.6	33.5	33.8

Sisal *(Agave sisal.)*
Trials with different forms of potash have shown no important differences as regards yield, fibre length and strength *[133]*.

Ramie *(Boehmeria nivea)*
is one of the salt sensitive fibre plants and KCl is more apt to cause root damage and yield depression than K_2SO_4 *[128]*.

Reed *(Juncus eff.)*
grown in Japan for making floor matting, is improved by K_2SO_4 which increases the proportion of first quality fibre and gives a better colour and sheen which improve its commercial value *[313]*.

Kenaf *(Hibiscus cannab.)* and **Manila hemp** *(Musa text.)*
KCl is the potash fertilizer normally used for these crops *[134]*.

4.6. Rubber *(Hevea brasiliensis)*

The use of latex stimulants, coupled with the large scale planting of high yielding clones, has revolutionised rubber growing in recent years. As potential yield has been raised, fertilizer applications have been increased and soil and leaf analysis are widely used to refine recommendations. Applications for K fertilizers have been greatly increased during the last 10 years as pointed out by von Uexküll (p. 302 in *[343]*), Bellie *([16]*; p. 345 in *[341])*, Kanwar (p. 276 in *[342])* and Pushparajah in Annual Reports of the *Rubber Research Institute of Malaysia*.

In Malaysia, the standard recommendation for bearing trees yielding up to 5 t latex/ha is now 30–70 kg K_2O/ha according to soil texture and the wind resistance of the clone while the standard rate of MgO is 15 kg/ha. K is now recognized as being especially important for clones susceptible to wind damage and reports of the *Rubber Research Institutes of Malaysia* and *Sri Lanka* and of the *Institut de Recherches sur le Caoutchouc en Afrique (I.R.C.A.)* have all shown that K enhances growth (girth), latex yield, bark renewal, phloem thickness and size and number of latex vessels per unit bark.

The rate at which K moves to the latex vessels controls latex production and the serum of a healthy bearing tree should contain $> 0.3\%$ K. Latex stimulation also doubles the drain of Mg from the tree. While Mg is essential for the growth of young trees, too high a level in the mature tree accelerates latex coagulation thus bringing the flow of latex from the tapping cut to an early halt. It has been found in Malaysia that where yield on low K soils is depressed through this cause, this can be corrected by applying K fertilizer.

Properly balanced fertilizer has a K:Mg ratio of 3:1, exactly the proportion of the two nutrients in sulphate of potash magnesia *([134]; Rubber Research Institute Sri Lanka)*.

Up to recently the question of the choice of Cl or SO_4 fertilizer has been given little attention and SYS *[294]* has no preference for either. Recommendations in Malaysia, Sri Lanka and the Ivory Coast are based on KCl and since the latex contains only 30–70 ppm S, the S removal by quite high yields only amounts to 1 kg S/ha or so (MARTIN-PRÉVEL, p. 81 in *[336])*. BEAUFILS (cited *[16])* specifies leaf S:P ratios > 1.3 as high, 0.8 as satisfactory and < 0.7 as low for good bearing trees.

Mention of undesirable effects of Cl on growth in its Annual Report of 1966 led the *Rubber Research Institute of Malaysia [275]* to investigate the effects of different forms of N and K fertilizers (KCl, K_2SO_4, K_2CO_3, KPO_3). Cl showed some tendency to depress growth (girth) on light soils while SO_4 was disadvantageous on heavy soils. N and K uptakes were higher with KCl especially when applied with N and leaching was reduced due to higher nutrient uptake. Growth and nutrient uptake were good when urea was used with K_2SO_4 especially on clay soils and this is a good combination when K-Mg fertilizer is not appropriate, should there be a need to reduce the Mg level.

4.7. Beverages and stimulants

Hops *(Humulus lupulus)*
The quality of hops is expressed in their content of the extracts required by the brewing industry. Potassium is most important for yield and quality and the form of potash fertilizer is equally important. There is no doubt among hop growers that sulphate of potash should be used exclusively and that sulphate of potash magnesia, on account of its magnesium content, is especially valuable for hop yield and resin content *[207, 347]*.

Tea *(Camellia sinensis)*
As tea gardens have aged and the levels of N fertilizer have increased, K fertilizers at 60–200 kg K_2O/ha have been found to have large effects on yield (KANWAR, p. 272 in *[342]*; DE BEAUCORPS, p. 337 in *[343])*. In new plantings, the socalled 'yellow disease' has been diagnosed as due to S deficiency and this condition is largely combated in Sri Lanka, India, Indonesia, Russia and East Africa by using sulphate based N, P and K fertilizers *[15]*. S is a most important nutrient for tea. Leaf S contents range from 1.53–2.2% S in dry matter according to site *[145]*.

Tea growers prefer to use sulphate of potash as, with KCl, Cl is rapidly taken up and this reduces the total dry matter and starch content of the leaf, while, on the other hand, SO_4 favours the formation of essential amino acids. K_2SO_4 increases yield and improves the quality of tea *[145, 167, 240]*.

Coffee *(Coffea spp.)*
As yields increase, so does the importance of potassium. K is essential to sustain high yields, preventing physiological dieback, over-bearing and alternate bearing (VON UEXKÜLL, p. 308 in *[343])*. Though the removal of S in harvested beans is not very great (about 4 kg in 2 t beans) this is only one third of the total S requirement of the crop (MALAVOLTA, p. 331 in *[341]; [33])* and several investigations have pointed to the importance of S for the crop. The S content of the plant is greater than that of P and only slightly less than that of Mg. FORESTIER and BELEY *[77]* quote average values of 0.213% S in dry matter and normal leaf contents between 0.18 and 0.26% S in the third leaf of one year old shoots for *C. robusta*.

MALAVOLTA *et al. ([177];* p. 331 in *[341])* regard 0.25% as optimal and <0.1% S as indicating deficiency. They report that S deficiency adversely affects the root system more than the above ground part of the tree. Pale green chlorotic symptoms first appear on the young leaves. Latent S deficiency manifests itself not so much in reduced flowering as in reduced flower set.

From work in Brazil, LOTT *et al. [118]* conclude that most of the S occurs in the leaf in organic combination but that SO_4 content is a better indicator of S deficiency in soil and plant than total S. They give critical values for the third leaf of < 200 ppm SO_4-S with 0.13% total S. Up to now, MALAVOLTA (p. 331 in *[341];* in Brazil has recommended KCl. The function of Cl in nutrient metabolism and its effects on growth were first investigated by FURLANI and results are reported in his University of Piracicaba dissertation of 1973 *[83]*. Leaf Cl contents of KCl treated plants were higher than with K_2SO_4 and there was a relation between high leaf Cl content, reduced growth, necrosis and defoliation. However, no ill effects were seen until leaf Cl content exceeded 0.76% Cl for all leaves or 0.94% for leaves from the lower third of the plant. Plants receiving KCl had less P and more Cu in the leaves than the ones which received K_2SO_4.

There is no point in using K_2SO_4 if the S requirement of the crop can be covered by using sulphate containing N fertilizer. It is likely, though, that sulphate of potash magnesia will become more important in the future as Mg deficiency becomes more likely *([61];* VON UEXKÜLL, p. 308 in *[343])*.

Cacao *(Theobroma cacao)*
Cacao is physiologically very sensitive and the tolerable range of nutrient levels is more restricted than in any other tree crop. A slight nutrient imbalance can cause premature leaf fall as can low soil moisture, or high temperature.

K and Mg are particularly important when cacao is grown unshaded or under light shade when yields are high. A planned yield of 4 t dry beans/ha would require 385 kg

K_2O/ha and 100 kg MgO/ha and it is recommended that these should be applied as sulphate of potash magnesia or KCl + kieserite *([134];* VON UEXKÜLL, p. 311 in*[343])*.

Experiments with different forms of K in Trinidad *[134]* and Brazil *[201]* showed good responses to K but no difference in effect between KCl and K_2SO_4. Apparently S uptake by the crop is low so that applied S has no effect. Cacao beans contain, according to variety, 0.18–0.24% S and S removal in the whole fruit would be about 6 kg S/t dry beans (MARTIN-PRÉVEL, p. 81 in *[336])*.

Tobacco *(Nicotiana tabacum)*
For no crop is there more scientific and practical evidence in favour of sulphate of potash than for tobacco. We mention especially here the comprehensive work of CHOUTEAU *et al. [51, 52]* and LOUÉ *[171]*.

Characteristics which determine quality, particularly combustibility, are more important than total yield in determining the economic returns from the crop, and these are much affected by manuring *[57, 76, 92, 115, 139, 165, 221, 226, 248]*. Potassium plays a fundamental role in increasing yield, improving external properties (leaf size, specific weight, colour) and improving quality through affecting the biochemical processes which determine the contents of important constituents like alkaloids, organic acids, amino acids and sugars *([165, 252];* DE BEAUCORPS, p. 339 in *[343])*. A high K content (> 5%) not only improves the pliability and disease resistance of the leaves but also improves their burning properties.

Cl has a negative effect on all these quality improving properties. It reduces the organic acid content, promotes protein formation and imparts a sweet unpleasant taste and aroma. On account of its hygroscopic properties it makes drying and fermentation difficult and increases mildew and rotting. Increasing Cl content of the leaf causes it to lose its good burning and glowing properties. The combustibility varies with Cl content as follows *[115, 139, 248]:*

< 1% Cl = excellent
1–2% Cl = good to satisfactory
2–3% Cl = unsatisfactory
> 3% Cl = poor

Leaves with over 1% Cl would be rejected for cigar manufacture, while for cigarettes up to 2.4% is tolerable, provided the leaf has good elasticity, Cl rich soils and irrigation water containing more than 20 ppm Cl are quite unsuitable for tobacco growing *[73, 143, 174]*.

Excess Cl can be recognized by brittleness and thickening of the leaf which rolls upwards at the margin and takes on a glossy appearance. While yield may be increased by applying KCl, quality may be lowered so much by the Cl content that the total return in cash terms is lowered *[115]*. For example, applying 134 kg K/ha as KCl increased yield from 2655 to 2854 kg/ha (10.7%) but lowered the price by 11% *[165]*. In France *[171]* applying a total of 300 kg K_2O/ha to tobacco and the preceding crop as sulphate gave twice as much cash return as chloride. It is interesting that in an effort to improve tobacco quality, the Government of Colombia in 1979 forbade the use of chloride-containing K fertilizers.

There are no risks of quality deterioration when sulphatic fertilizers are used and S supply to the crop is assured. Tobacco leaves well supplied with sulphur are of a uniform brown-red colour. Up to 50 kg S/ha can be removed at normal leaf S contents of 0.3–0.4% for burley, or 0.7% for flue cured, in dry matter. S deficient plants, exhibiting chlorosis similar to that of N deficiency, are low in alkaloids and organic acids and have high values for sugar and protein N. Applying sulphate reduces leaf pH by decreasing organic acid content *[307]* and lowers the Cl content *[171]*.

Excessive sulphate can, however, also cause blackening of the leaf and, though to a lesser extent than Cl, can cause the organic acid content to fall *[92]*. CHOUTEAU (cited *(171])* blames too high S content for the appearance of dark coloured leaves which have a low market value.

Countless results of K form experiments highlight the beneficial influence of K_2SO_4 on combustibility (cited *[115]*). According to SAEZ, while even 50 kg KCl/ha has an unfavourable effect, combustibility is improved by 2% by 150 kg K_2SO_4/ha and by about 100% by 750 kg K_2SO_4/ha. According to BOWLING duration of glowing is affected as is shown in Table 38.

Even foliar application of K_2SO_4 42–53 days before picking can improve the yield of the middle and upper leaves and improve combustibility *[142]*. LOUÉ *[171]* basing his opinion on results obtained by the French potash industry (S.C.P.A.) says that the finest quality tobacco is produced with sulphate fertilizers.

In summary, sulphate of potash, should be used on tobacco, and, on light soils, sulphate of potash magnesia is recommended to ensure the supply of sufficient magnesium.

Table 38 Effect of form of potash on combustibility of tobacco (BOWLING, cited *[171]*)

Rate of K_2O kg/ha	Glowing duration in seconds K_2SO_4	KCl	K_0
0	–	–	4.4
27	5.8	3.5	–
188	46.3	2.1	–

4.8. Vines and fruits

Vine *(Vitis vinifera)*
K is a most important nutrient for grapes not just because it increases yield (number of fruit per plant) but rather because, through its influence on metabolic processes, including photosynthesis, it directly influences the quality of the grapes by increasing

their sugar content and this indirectly improves the quality of the vine (MALQUORI, p. 287 in *[343]*).

The vine is moderately tolerant of salinity and chloride. Further, in practice, S deficiency (light green colour of the upper, mainly immature, leaf blades, and brittleness) is seldom encountered. These are the reasons why, according to soil conditions, variety and the use for which the grapes are intended, sulphate of potash is not exclusively used. However, the majority of investigations in all vine growing areas of Germany, Austria, Switzerland, France, Portugal, South Africa and Australia have led to the conclusion that sulphate of potash has a better effect than KCl on vine growth (higher chlorophyll content of the leaves), grape yield, sugar content, must yield, acidity (ascorbic acid content), colour and tannin content. (For comprehensive surveys see *[139, 171, 346]*).

Wherever emphasis is laid on the quality of the grapes (either for dessert or wine making) and also for young vines, sulphate should always be used. Sulphate also reduces the susceptibility of vines to botrytis. However, exclusive use of either Cl or So_4 fertilizer can lead to disturbed anion balance in the vine and to growth depression. K uptake is increased by Cl while it is lowered by SO_4 with simultaneous increase in the uptake of Mg and P *[171]*.

Like DILLEY *et al.* *[63]* before him, EDELBAUER *[71, 72]* has recently investigated the effect of different $KCl:K_2SO_4$ ratios on yield, composition and frost resistance of 'Grüner Veltliner' rootstocks grown in solution culture (Figure 11, Table 39). He concluded:

- Fruit yield in treatments 1 and 2 was considerably below that of the other treatments. There were fewer bunches per plant and weight per bunch was lower.
- Regarding components determining juice quality, sugar was lowest in treatment 1 and polyphenol content was distinctly higher in treatments 2 and 3 than in other treatments. Form of potash did not appreciably affect titratable acidity.
- Treatment 2 gave the highest N content in juice, followed by treatment 3 and the total free amino acid content followed the same pattern. This was considerably influenced by the $KCl:K_2SO_4$ ratio.
- High frost resistance of the buds was correlated with K content of leaves and was highest in treatment 3.

This confirmed the findings of other authors in France (LÉVY, CHAMPAGNOL, COUILLARD, cited *[171]*) and Switzerland *[337]* that basically Cl had little effect on quantitative and qualitative characteristics of the vine though, as a rule, it reduced grape and vine yield. LOUÉ *[171]* also came to the same conclusion from 10 years work comparing potash forms in the Gironde and from other experiments in France.

Essentially, therefore, KCl is only used at low rates of application of K, the application being correctly timed before the beginning of growth, and in old vineyards.

It is probable that the Mg needs of the vine will receive more attention in the future. On soils with Mg contents from 8–20 mg/100 g soil the danger of Mg deficiency is increased by a high K:Mg ratio and this should not exceed 2.5:1 *[40]*. Obviously, sulphate of potash magnesia has special applications in vineyards.

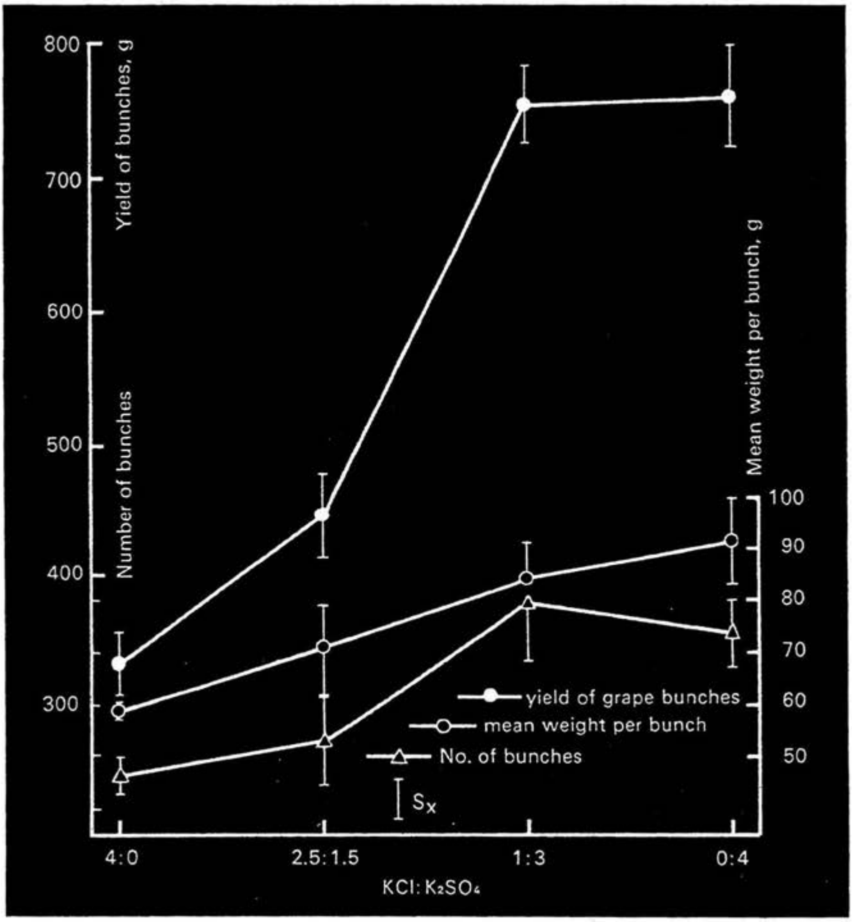

Fig. 11 Relations between the KCl/K_2SO_4 proportions in the nutrient solution and yield of grapes per 3 culture vessels, mean weight per bunch and number of bunches per 3 culture vessels *[72]*

Table 39 Concentrations of sugar, titratable acidity and polyphenols (tannins) in grape juices and frost susceptibility of the buds in relation to proportion of KCl to K_2SO_4 in the nutrient solution *[71, 72]*

Treatment $KCl:K_2SO_4$	Sugar		Titratable acidity as tartaric acid		Polyphenols		Frost susceptibility	
mg-atoms K	g/l	rel.	‰	rel.	mg/l	rel.	%	rel.
1 4.0:0	153.8	94	7.30	99	185	82	30.8	120
2 2.5:1.5	173.4	106	7.55	102	253	112	24.6	96
3 1.0:3.0	166.2	102	7.10	96	259	115	18.9	74
4 0 :4.0	160.2	98	7.65	103	208	92	28.6	111
Mean	163.4	100	7.40	100	226	100	25.7	100
P=0.5	18.9	12	0.42	6	60	27	6.4	

Berries, pome fruit and stone fruit

In fruit culture generally, fertilizers are used regularly and generously so that real deficiencies, of S for example, rarely occur *[15]*. However, because fruit requires large amounts of N and K in the ratio 1:0.8–1 the problem of salt and chloride tolerance of the trees does arise and so sulphatic fertilizers are mostly used in practice *[103, 244, 345]*. K improves fruit size, colour and flavour, for example it increases acidity in apples and peaches (Malquori, p. 296 in *[343]*). Fruits can be classified for salt and chloride tolerance as follows *[19, 63, 116, 139, 171]*:

Fairly sensitive: blackcurrant, strawberry, peach
very sensitive: blackberry, blueberry, apple, pear
extremely sensitive: redcurrant, raspberry, stone fruits.

Even at quite low Cl contents in the soil **red-currants** *(Ribes rubrum)* and **raspberries** *(Rubus idaeus)* react with typical marginal leaf scorch similar to symptoms of K deficiency *[32]*. Vegetative growth and fruiting is quickly and sharply reduced as indicated by the pot experiment quoted in Table 40 *[222]*. Sulphate of potash should be used exclusively for raspberries and redcurrants. Cl sensitivity of **strawberries** *(Fragaria)* depends on variety. There is a danger of leaf scorch from KCl particularly when rainfall is low, and the strawberry has a high potassium requirement. The extent

Table 40 Yield and shoot growth of raspberries (3-year average) receiving sulphate or chloride of potash *[222]*

Form of K	Yield	Shoots/plant	
	g	length (cm)	weight (g)
K_2SO_4..............................	1145	1066	462
KCl..................................	693	834	335

of salt damage which might result from using saline irrigation water depends on the age of the plants and depth of the root system. MATZNER *[188]* favours sulphate though, in his experiments, there were no significant differences between the potash forms as regards quality determining constituents; Cl delayed ripening and significantly reduced yield. MAPPES *[181]* and GRUPPE *[103]* advise the use of Cl free fertilizer, particularly sulphate of potash magnesia, for strawberries in Germany as does BIAR *[21]* in France. BÜNEMANN *et al.* *[41]* warn against too high use of Cl because it reduces yield and lowers the uptake of major nutrients. HABRAN and LEMAITRE *[106]* advise sulphate of potash for Belgian conditions.

Sulphur and sulphate fertilizer are useful for creating the appropriate soil conditions for **blueberries** *(Vaccinium myrtillus)* with pH values of between 4.5 and 5.0 and an adequate supply of sulphur *[359]*.

Quite low leaf contents of Cl in **pome** and **stone fruits** may lead to growth depression. According to DILLEY *et al.* *[63]*, taking the relative growth as 100 for a Cl content of 0.01–0.02 in leaf dry matter, growth of apple *(Malus)*, peach *(Prunus persica)* and cherry *(Prunus ceresus)* reduced by 15, 22 and 60 with Cl contents of about 1.0, 0.2 and 0.3% respectively. In winter, the roots of fruit trees are never inactive so there is a danger of Cl damage even when KCl is applied in autumn (TROCMÉ, cited *[171]*).

Dutch experiments have shown that K_2SO_4 gives higher yields of **apples** than KCl and that the extent of the difference varies with rootstock. The results of a 13 year experiment at the *Geldermasen Fruit Research Station* are quoted in Table 41 *[88]*. The advantage of K_2SO_4 increased as the trees aged. Another Dutch experiment *[283]* on a heavy river loam with Jonathan clearly pointed to the advantage of sulphate over chloride (Table 42). K_2SO_4 improved yield, quality and market value.

K form experiments in Alsace with 'Melrose' and 'Reine des Reinettes' apples showed no yield differences but slightly better fruit colour with K_2SO_4 *[171]*. BEATTIE's experiments (cited *[171]*) in Ohio (USA) gave a higher percentage of well coloured fruit from K_2SO_4. According to CASSIDY (cited *[263]*) sulphate of potash is preferred in former Rhodesia (Zimbabwe) for both apples and pears. South African recommendations (cited *[139]*) advise different K fertilizers according to soil reaction:

pH	Form advised
<5.5	sulphate of potash magnesia
5.5–6.5	KCl or K_2SO_4 and sulphate of potash magnesia every other year
>6.5	K_2SO_4

BRUCHHOLZ and FIEDLER *[38]* carried out experiments on K rate and form for many years in the German D.R. and found no great difference between KCl and K_2SO_4 as far as concerned growth, yield and storage properties, while optimum K fertilization significantly improved fruit set, fruit size, ripening, fruit constituents, colour, taste, aroma and storability. In many older and in some more recent experiments with apples, sulphate of potash was compared with potassium chloride of lower grade than 60% K_2O. It is only to be expected that the difference between sulphate and chloride will be less marked when the highest grade of chloride is used.

Table 41 Yield increase of apples from K_2SO_4 compared with KCl *[88]*

Variety	Rootstock	kg/tree
Golden Reinette	EM XVI	20.5
	EM I	19.0
	EM IV	25.0
Jonathan	EM II	27.5
	EM XIII	2.1

K_2O application 316 kg/ha/year

Table 42 Four year average yields of apples from different forms of potash *[283]*

	Average 1953–56		1956	
	KCl (40%)	K_2SO_4	KCl (40%)	K_2SO_4
Total yield (kg/ha)	13 360	14 376	22 750	23 950
relative	100	108	100	105
Grade I	11 523	1 2673	20 000	21 795
Grade II	1 837	1 703	2 750	2 155
Cash return (hfl/ha)	3 135	3 371	5 469	5 806
relative	100	107	100	106

K_2O application 350 kg/ha/year

With sour **cherries** there is always risk of frost damage and fruit splitting. Morelles which receive much N show improved frost resistance by young buds and cortical tissue when K_2SO_4 is substituted for KCl, and it has been established that fruit splitting in cherries is lessened by sulphate *[189, 190]*.

A good general recommendation for fruit of all types is to use sulphate of potash alone or in combination with Mg as in sulphate of potash magnesia, and especially so when fertilizer is applied late or by placement, as quality and marketability are both improved.

Citrus *(Citrus sp.)*
Rate of potash fertilizer is more important for yield and quality of citrus than the type of anion. The rate determines available K content of the soil and K content of the plant. However, Bar Akiva (p. 160 in *[350]*) found in experiments over 4 years that the anion, as well, influenced K availability in the soil and leaf K contents and, at high rates of application, K_2SO_4 was more effective than the chloride (Table 43). Other authors have also found higher leaf K contents with K_2SO_4 *[151, 152]*.

Trees well supplied with K show leaf K contents of over 1.1–1.2% in orange and 1.55% in grapefruit. High K contents are correlated with superficial and inherent quality characteristics and with frost resistance (Georgia, USSR); premature fruit drop is

Table 43 Effect of potassium fertilization on the soil ΔF values and the leaf K composition of Shamouti orange leaves 7 (after four years of differential fertilization) (BAR AKIVA p. 163 in *[350]*)

Treatment**	K in leaves % in dry matter	ΔF value*
K_0 control	0.57	−3280
K_1 as KCl	0.69	−2600
K_3 as KCl	0.79	−2010
K_1 as K_2SO_4	0.68	−2520
K_3 as K_2SO_4	1.06	−2190

* ΔF = free energy change in cal/mol/°C of Ca/K ion exchange
average of 3 layers 0–30, 30–60 and 60–90 cm
−2500 to −3000 indicates optimal amount of available K
−2000 or less indicates excessive amount of available K
−3500 to −4000 indicates deficiency amount of available K

** K_1 = 250 g K/tree/year; K_3 = 750 g K/tree/year

lessened by K_2SO_4 (*[78, 151, 152]*; MALQUORI, p. 287 in *[343]*). The incidence of blight is associated with low K and high Na and Cl contents in the leaves as shown by survey *[330]* in a 35 year old commercial orange grove (Table 44).

Table 44 Mineral content in the leaves of healthy and blight-affected citrus trees *[330]*

	Percent					ppm	
	N	P	K	Ca	Mg	Na	Cl
Blight*	3.06	0.157	1.02	3.88	0.38	1586	947
Healthy*	3.00	0.138	1.45	3.45	0.41	895	568

* Composite samples based on 6 trees each

EMBLETON and JONES have done much work on the effects of nutrition on citrus yield and quality at the *Riverside Agricultural Experimental Station*, California, and the results pertaining to K have been summarised by HERNANDO (p. 206 in *[357]*) in Figure 12. It is interesting that the effect of K on peel thickness and juice content in lemon is the opposite of that in orange. K especially increases the acid content.

Because the danger of salt, Na and Cl sensitivity in citrus cannot be ruled out, the sulphate forms of potash may be more effective than the chloride.
HERNANDO (p. 195 in *[357]*) says that the use of irrigation water with 500–700 ppm salt should be avoided as it may be detrimental.

HARDING *et al.* *[111]* carried out exhaustive investigations on irrigated oranges in California and found a positive connection between high K:Na ratios in the soil and

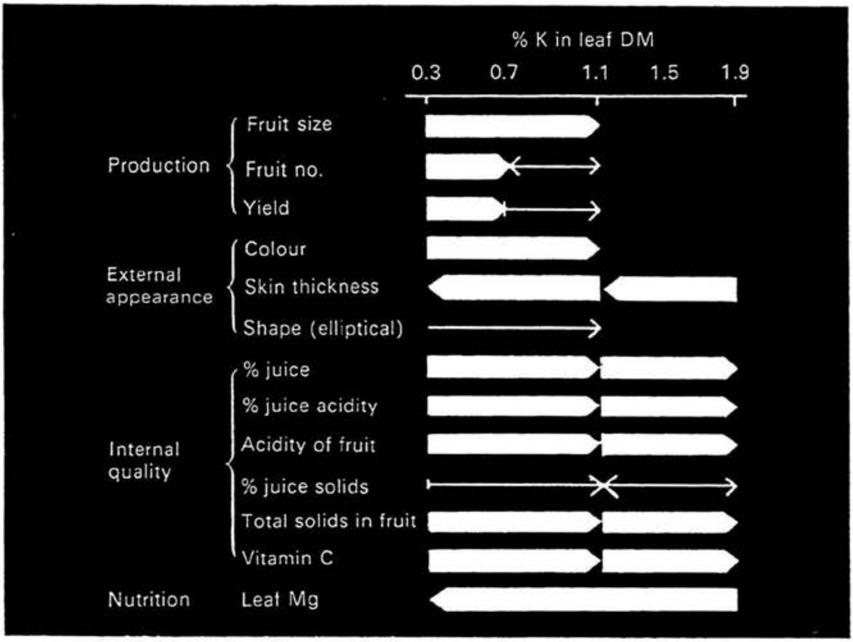

Fig. 12 K content in orange leaf and its effect on production and quality factors. (EMBLETON and JONES (1964–1978), cited by HERNANDO, p. 206 in *[357]*)

in leaves and higher productivity and larger fruit size. Low K : Na ratios had bad effects on both criteria.

Salt sensitivity is especially likely to affect the root growth of seedlings and young trees, and trees on soils with compacted layers which have shallow root systems (*[151, 152]*; ZUSMANN cited *[309]*).

As cited in *[309]*, JACOB *et al.* found leaf damage on trees grown in the glasshouse only when KCl was used and the damage increased as fertilizer rate increased; there was no damage from sulphate. The cation/anion balance was affected by the anion, being 3.7–3.9 in those receiving K_2SO_4 and 8.1–9.0 in those receiving KCl, and this in turn disturbed the functioning of chloroplasts and protoplasm. The Cl content of the leaf is decisive for differences in total anion content. Similarly, KOVERGA encountered Cl induced chlorosis in the Crimea on soils with Cl contents from 0.05–0.11%. ROMERO, in Italy, advised the use of sulphate to avoid undesirable side effects from KCl, but ROY could find no statistically significant differences in juice composition between the two forms.

Although S deficiency is scarcely known in practice, there have been reports of improvement in growth and yield due to S fertilization *[15]*. Table 45 quotes values of S and Cl contents for oranges indicating deficient to surplus conditions (cited p. 201/203 in *[357])*.

Table 45 Leaf analysis for diagnosing S and Cl status of oranges (cited p. 201/203 in *[357]*)

	Deficient	Low	Optimum	High	Excess
S	>0.14	0.14–0.19	0.20–0.30	0.40–0.50	>0.50
Cl	—	—	<0.15	0.20–0.30	>0.40
Cl	—	—	<0.40*	0.40–0.60*	>0.70*

* According to EMBLETON-JONES; all other values according to CHAPMAN

In most citrus growing areas in the world it is recommended to use only sulphatic (mainly K_2SO_4) K fertilizer, as in Spain, Italy, North Africa, Australia, Surinam and Chile. K_2SO_4, KCl and KNO_3 are all used in Israel, South Africa, Brazil and Florida *([309];* HERNANDO, p. 195 in *[357])*. Wherever there is a problem with soil salinity, the sulphate form is to be preferred and sulphate of potash magnesia is used where there is a need also to supply magnesium *[151, 152, 309]* as, for example, in some Spanish areas where Mg supply from the soil is insufficient and Mg deficiency symptoms occur (HERNANDO).

Tropical fruits

Banana *(Musa sapientum)* and **plantain** *(M. paradisiaca)* have a high K requirement and appear not to be very Cl sensitive as, in most places, KCl is used to good effect *[219]*. Up to now there have been no experiments with different potash forms. In the tropics Cl is rapidly leached out of the surface soil, but under irrigation with Cl rich water, K_2SO_4 should be used to avoid building up soil salinity. K_2SO_4 is advised in Honduras because of the occurence of S deficiency. Fox *et al.* *[79]* on the basis of recent experimental results with banana and plantain quote critical values of 0.25–0.3% S in the third leaf for optimum yield; higher or lower values result in yield reduction (Figure 13). As a rule, and especially in Africa, S contents are lower than those quoted by Fox, indicating latent S deficiency and under these conditions MARTIN-PRÉVEL (p. 81 in *[336]*) recommends applying 50 kg S/ha in the form of K_2SO_4.

The low mobility of S in the plant means that a high SO_4 concentration is needed in the soil solution in order to avoid undersupply of S which causes poor vegetative growth, and thin brittle leaves, and, in extreme cases, reduction in number of leaves *[79]*. In spite of the high physiological S requirement, S removal in fruit is low in comparison with that of Cl. MARTIN-PRÉVEL and BROOK *[33]* say that a 35 t crop immobilises about 14 kg S but only removes about 5 kg. KODIA *et al.* *[149]* reckon 120 g S/t, against 1.0–1.4 kg Cl/t (Table 46).

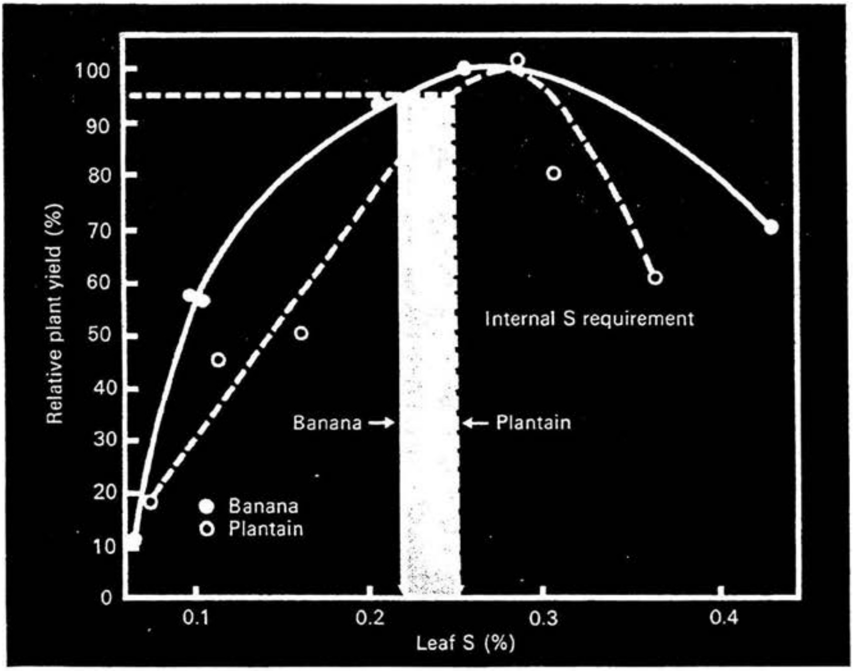

Fig. 13 Relative growth of banana and plantain in relation to the percentage of S in the midleaf section of leaf in position III *[79]*

Bananas and plantains remove more K and Mg than other major elements from the soil and K deficiency is more often encountered than excess. When K supply is optimum, flower initiation is earlier as is ripening, and the number of bunches and hands per bunch are both increased. K improves the acid : sugar ratio and storage properties of the fruit; it also improves disease resistance. Premature yellowing of the pulp is a particular defect in K deficiency and this can also be due to excess Ca or Mg. The high K requirement of banana and the fact that it is often grown on low S soils make sulphate of potash an eminently suitable fertilizer.

Pineapple *(Ananas comosus)*. Choice of K form is less important from the point of view of Cl sensitivity than from the point of view of ensuring a good supply of K. The K nutrition of this crop is critically important (MALQUORI, p. 228 in *[343]*). As well as increasing growth and fruit size, K favours the formation of desirable fruit constituents such as sugars and acids, especially ascorbic acid, and influences fruit colouring *[296–299]*.

Table 46 Analysis of banana, plantain and avocado fruit *[149]*

Fruit and Country	Reference	mg/100 g fruit							
		Ca	P	Fe	Na	K	Mg	S	Cl
Banana	[1])	12	32	0.8	4	401	41		
Ivory Coast ..	[2])	8	28	0.7	1	420	31	12	125
	[3])	11	28	0.6	3	380	35	12	100
	[4])	12	30	0.7	3	382	35		130
Banana Cameroon	[4])	14	32	0.8	4	323	37		128
Plantain	[1])	18	38	0.6					
Ivory Coast ..	[3])	11	31	0.6			35		
	[4])	25	43	0.9	5	435	38		143
Plantain Guadeloupe	[4])	22	42	0.9	4.7	432	40		134
Avocado	[1])	12	26	0.7	2	278	36		
Ivory Coast ..	[2])	10	42	0.6	3	340	30	25	10
	[3])	16	46	0.7	3	680	41	35	16
	[4])	25	47	0.8	3	333	34		25
Avocado Israel	[4])	21	46	1	2.8	351	38		21

[1]) FAO *(1976)*; [2]) Geigy *(1972)*; [3]) Randoin *(1976)*; [4]) Kodia *et al. (1968)*

High Cl concentration hinders the uptake of K so that Cl damage (leaf necrosis) is accompanied by decrease in fruit size, lower sugar and starch contents but higher acidity, all symptoms similar to those of extreme K deficiency (Sideris and Young, cited *[301])*.

Total uptake for a 65 t crop is 55 kg S/ha of which about 10 kg is removed with the fruit (Martin-Prével, p. 81 in *[336])*.

From a summary of K form experiments one would conclude that K_2SO_4 should have the preference *[15, 134, 301]*, though Jacob and von Uexküll *[134]* quote data showing that potassium chloride fertilizer can also be used to good effect for soil application in Jamaica, Brazil, Malaysia and South Africa.

K_2SO_4 gave higher yields, larger fruit and better fruit colour than KCl in Florida, Natal, Puerto Rico, Taiwan and Guinea. Cannon (cited *[139])* in Queensland obtained larger fruit with higher sugar and acid contents, *i.e.* better tasting, with K_2SO_4. Su and Lee *[289, 290]* compared KCl and K_2SO_4 in field experiments in Taiwan and obtained higher total yields, larger fruit and earlier ripening with improved fruit quality (higher percentage of fruit with 'sound flesh') as shown in Table 47.

Further evidence of the good effect of sulphate of potash on yield and quality comes from Puerto Rico *[251]* with the variety 'Red Spanish' (Table 48). KCl treated fruit had flesh of an undesirable whitish colour. TEISSON *et al.* *[299]* in the Ivory Coast came to the conclusion that the largest fruit with least highly coloured flesh was obtained by applying a mixture of K_2SO_4 and KCl over the plants shortly before flower induction. Whether applied over the leaves or to the soil, KCl manured fruit contained more acids, expecially ascorbic acid, and were much less highly coloured; but K_2SO_4 produced the larger fruit (Table 49).

Table 47 Effect of form of potash on fruit yield and quality in pineapples *[289]*

•	K_0	KCl	K_2SO_4	P=0.5	P=0.1
Summer fruit set (%)............	96.7	92.0	96.7	2.4	3.5
Total fruit set (%)	98.0	96.0	98.0	—	—
Mean weight of summer fruit (kg)	1.476	1.508	1.553	0.057	n.s.
Summer yield (t/ha)	51.35	49.94	54.02	2.30	3.27
Mean date of ripening	July 28	July 28	July 24	—	—
Peak of ripening	July 27	July 27	July 21	—	—
'Sound flesh' fruits (%)	39.02	27.72	44.50	8.54	12.40

K_2O application = 12 g/plant; before planting: 3 g K_2O/plant

Table 48 Effect of form of potash on yield and chemical composition of pineapples *[251]*

K form*	Yield t/ha	Weight/ fruit kg	Chemical composition of fruit pH	Brix	Invert sugars %	Titratable acidity mg %	Brix: Acidity Ratio
KCl (60%).........	17.5	1.50	4.1	13.4	12.9	463	28.9
K_2SO_4.............	22.7	1.66	4.0	13.4	13.1	584	23.0

* 269 kg K_2O/ha (N:P:K=5:1:4)

Table 49 Effect of form of potash applied to leaves on fruit size, acidity and flesh colour in pineapples *[299]*

K form (10 g/plant)	Acidity me/l	Ascorbic acid μg/l	Colour index	Weight/fruit g
K_2SO_4	74	190	1.7	1409
KCl	97	316	0.5	1340

Avocado *(Persea gratissima)* and **Mango** *(Mangifera indica)* are sensitive to salt concentration and especially to Cl which cause leaf scorch, and the roots are more likely to be damaged than the foliage *[105]*.
The S content of the leaves at 0.32% is relatively high *[134]*. Avocado fruit contain about 30 mg S/100 g fresh weight (Table 46) and the Cl content varies between 10 to 25 mg *[149]*. Much K is contained in the fruit and sufficient K fertilizer should be given to replace this. It seems that the sulphate form should be used for these and other tropical fruit crops whose requirements have not yet been fully investigated.

4.9. Vegetables

Vegetables are grown commercially both extensively, when they are planted in the course of an arable rotation which will include 'agricultural' crops, with or without irrigation, and intensively in specialised vegetable gardens or under glass.

These crops have a high nutrient demand and large amounts of nutrients are removed from the soil in harvested crops. Horticulturists therefore use generous amounts of fertilizer, often in highly concentrated form (FRITZ and VETTER, p. 97 in *[349]*) and, depending on cultural methods, the growing substrate (natural soil or artificial growing medium) and its volume and upon the micro-climatic conditions, problems with salinity will assume greater or lesser proportions. Hence the choice of potash form is an important matter.

Under glass, on account of the interaction between potassium and light, K becoming less efficient as light intensity falls off, the crop's K demand is particularly high and the sulphate forms of potash fertilizer are used exclusively *[86]*. To cover the K needs with chloride fertilizer would, quite apart from any danger of Cl toxicity, raise soil salt concentration to a dangerously high level. For mineral soils, the Cl concentration should not exceed 35–45 mg/100 g. A large proportion of SO_4 ions combines with Ca and thus become less water soluble. The $Ca:SO_4$ ratio should not exceed 1:1.2 in the soil solution or the crop may be damaged *[67]*.

Apart from these general considerations, the choice of potash form is also influenced by the type of crop (botanical family) and the following have to be taken into consideration:

- The great diversity of salt and chloride tolerance among the different kinds of vegetables.
- The great variation in sulphur requirement, even among representatives of the same botanical family.
- Whether the produce is root, shoot, leaf, fruit or seed.
- The relative importance of yield and quality (fresh or dry matter yield, content of nutritionally important constituents).
- The purpose for which the produce is required (fresh vegatables, drying, preservation), behaviour in storage and transportability.

Thus, the *chloride tolerance* of vegetables varies greatly in accordance with botanical characteristics, environmental conditions and the purpose for which the produce is to be used and it is not therefore surprising that it is impossible to group the various crops in a simple way according to their chloride tolerance. The Cl tolerance of the different families, including different species of vegetables, has already been discussed in chapter 2.3.

SCHUPHAN *[264]* considers the leaf vegetables as a whole to be chloride tolerant or neutral in comparison with the root vegetables, the Cl ion favouring the growth of the above ground parts of the plant while it may not favour root growth. High protein crops, in which N metabolism is of great importance, and crops grown for fruit or seed would prefer the sulphate form. The same holds for crops with a high sugar content. So far as properties like transportability and storability are concerned, sulphate usually produces the best results provided Cl is not required for full yield.

GEISSLER *[86]* summarises the behaviour of vegetables in response to Cl or SO_4 as follows:

- Chloride intolerant, *i.e.* definite preference for sulphate: French beans, broad beans, gherkin, melon, onion, all crops under glass.
- Chloride neutral, for which normally SO_4 is preferred: tomato, radish, kohlrabi, cauliflower, spinach, peas.
- Chloride neutral, for which normally Cl is preferred: carrot, black radish, red beet, white cabbage, leek.
- Chloride tolerant with preference for Cl: celery, asparagus, spinach beet.

ANSTETT (p. 57 in *[336]*) classifies the vegetables according to their sulphur requirements (see also chapter 3) on the bases of botanical family and the purpose for which they are grown:

- Families:
  Cruciferae > Umbelliferae (Celery) > Liliaceae > Solanaceae (Tomatoes) > Compositae > Chenopodiaceae > Leguminosae
- Roots:
  Liliaceae > Cruciferae > Compositae > Umbelliferae > Chenopodiaceae
- Leaves and shoots:
  Cruciferae > Umbelliferae > Liliaceae > Compositae > Chenopodiaceae

High sulphur requirement and chloride tolerance are not mutually exclusive (*e.g.* cabbage, celery) and both Cl tolerant and Cl sensitive plants occur in the same family (*e.g.* asparagus, onion) and high Cl contents may be found in chlorophobe plants.

Because sulphate of potash is usually used in vegetable growing and also because organic manures are also used, the S content of vegetable garden soils is usually sufficient to meet the S requirements of the crops. However S deficiency, which appears similar to N deficiency, may occur in spring while S mineralisation is slow. It is therefore important to use sulphate for early spring vegetables.

One further aspect should be taken into consideration and that is the generally high Mg requirement of vegetables, and sulphate of potash magnesia therefore finds wide application in vegetable growing (FRITZ and VETTER, p.117 in *[349]*).

Grain Legumes

The grain legumes, like all members of this family, react positively in yield to sulphur-containing fertilizers. Beans and peas require for protein formation a good supply of S along with N and K *[252a]*. The peak requirement for S occurs about 40 days after emergence and for Mg a little later (Figure 14 by FAUCONNIER, p. 263 in *[343]*). With

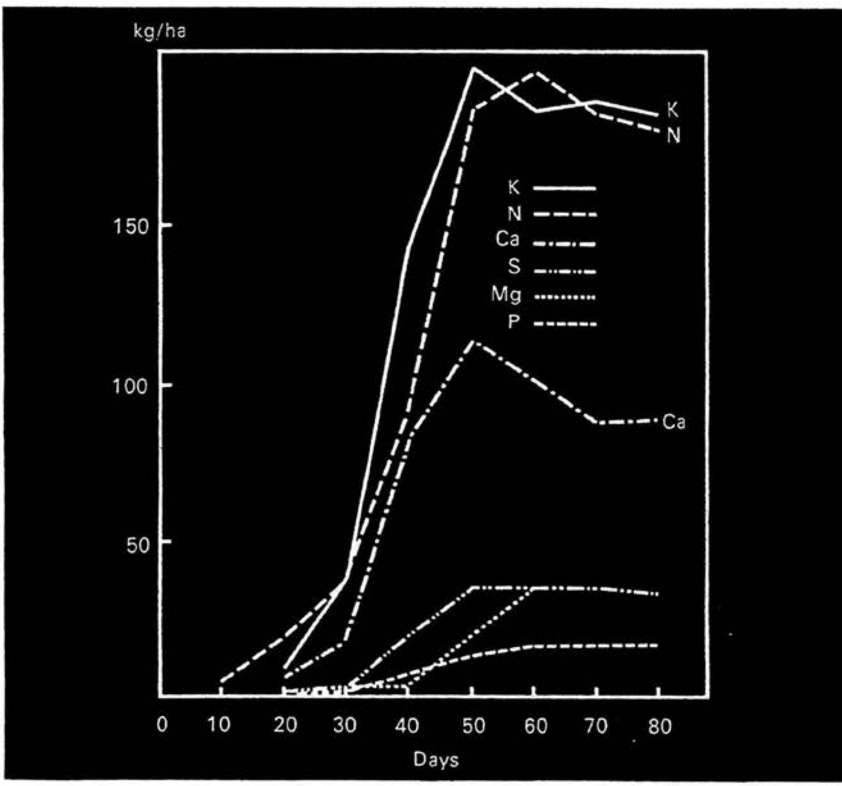

Fig. 14 Uptake of major nutrients by beans (250 000 plants/ha) (FAUCONNIER, p. 263 in *[343]*)

S contents in the leaves of 0.27 *(Phaseolus vulgaris)* and 0.41% *(Pisum sativum)* S uptake is at least 12–15 kg/ha (Anstett, p. 69 in *[336])*.

Cowpea *(Vigna unguiculata)* has been shown to be responsive to S in greenhouse experiments at the *International Institute of Tropical Agriculture (I.I.T.A.)*, Nigeria (Luse *et al.*, p. 197 in *[354]*). Soil solution sulphate was maintained at different levels and the S content of seed remained low and constant over the range <0.2–0.6 ppm S in the soil solution. Above this level there was a distinct increase in seed yield (Figure 15). Seed yields were increased up to 15 fold by applied S. The inference is that S fertilizer will be required for cowpea in many parts of the tropics, where, as for

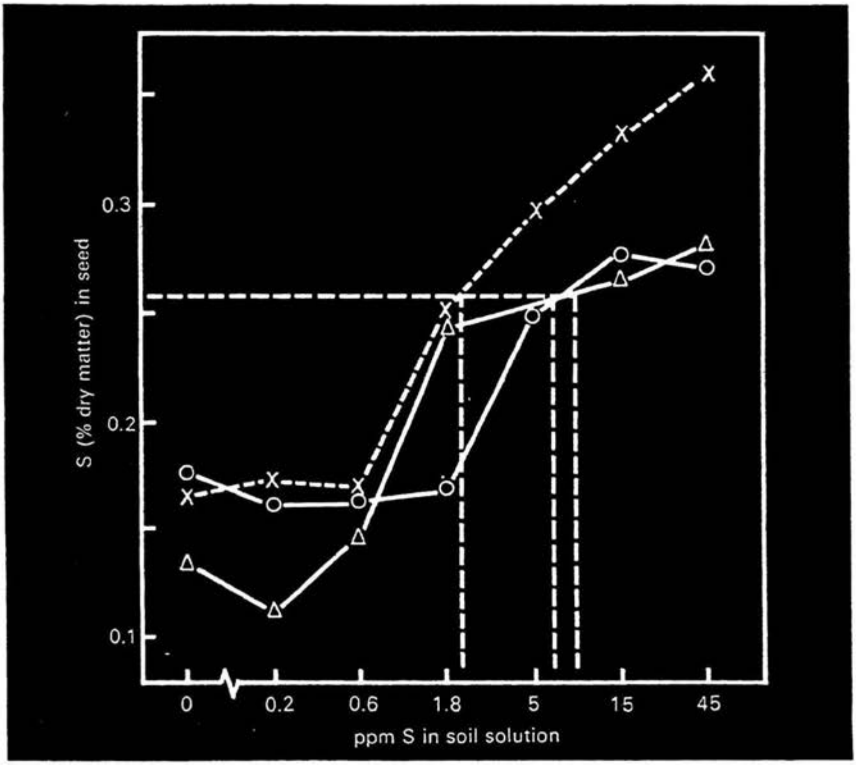

Fig. 15 Effect of soil S on seed S content in cowpea. (Luse et al. p. 199 in *[354])*
× =cv. Sitao Pole, ○=cv. TVu 76-2E, △=cv. TVu 201-1D, '0'=deionized water added. Vertical arrows show soil S level at which near maximum seed yield was obtained.

example in Northern Nigeria, the S content of rainwater is only about 0.2 ppm, quite insufficient to supply the crop's needs.

Sulphate and chloride have contrasting effects on enzyme activities and growth regulating mechanisms in the grain legumes. K affects the functions of saccharose and starch synthetases and the mechanism is further shifted in favour of saccharose and starch at the expense of the reducing sugars *[329]* (Table 50) by the Cl ion.

Table 50 Effects of Cl and SO_4 on carbohydrate content and polysaccharide:monsaccharide ratios in French beans *[329]*

K form	Total Carbohydrate mg/g dry matter	Saccharose / Glucose + Fructose	Starch / Glucose + Fructose
KCl	58.7	20.8	10.6
K_2SO_4	42.5	7.0	7.8

Nitrate reductase activity can be reduced by Cl with resultant reduction in root NO_3 content in peas *[250]*. In **mung beans** *(Phaseolus aureus)* Cl hinders cell elongation of seedlings and roots via stimulation of peroxidase and thus adversely affects yield *[269]*. Cl and SO_4 are concerned in the formation of biologically active peptides having growth control functions and, in this respect, Cl adversely influences the ratio of growth stimulating to growth limiting hormones in pea roots *[230]*.

There are differing opinions as to which form of potash is best suited to **peas** *(Pisum sativum)* and these vary with environmental conditions. In Germany and Austria sulphate of potash and sulphate of potash magnesia are considered best but experiments in England, USA, Switzerland and, recently, in Czechoslovakia *[308]* consider chloride fertilizer equally suitable (cited *[161]*; Lavalleye and Steppe, p. 235 in *[340]*). Experiments in Switzerland with threshing peas from 1957–1964 *[85]* showed a slight advantage in grain yield, keeping quality and profitability in favour of KCl. On the other hand, results from a long term rotational experiment in Germany *[147]* showed vining peas to be Cl sensitive.

Beans *(Phaseolus spp.* and *Vicia faba)* can be regarded as test plants for chloride damage and are affected by quite low Cl concentrations in the soil, and this results in yield reduction *[86, 87]*. In dwarf beans, succulence as a result of increase in leaf thickness and thicker palisade parenchyma is improved by Cl *[329]*.

Pot experiments *[7]* showed that yields of fresh and dry beans were one third lower when 40% KCl was used in place of sulphate of potash magnesia, the effect being seen at both high and low rates of application. Long term field experiments *[120]* showed a 15% yield advantage in favour of K_2SO_4. Opitz *[216]* also obtained the highest bean yields with sulphate of potash and Kiepe *[147]* found that dwarf beans grown in a rotation experiment gave 50% more yield with K_2SO_4 compared with KCl (2.1 and 1.4 kg/kg K_2O).

In summary there is little to choose between Cl and SO_4 fertilizers in that Cl favours fresh weight and SO_4 favours dry matter content so that the end result is the same from both forms *[200]*. Thus fertilizer recommendations include both K_2SO_4 and KCl *[161, 252a]*.

Cabbage and leaf vegetables

The **brassicas** *(Cruciferae)* have a high S requirement and respond to sulphate fertilizers *[15]*. On the other hand cabbages are Cl neutral so that there is advantage in using sulphate only for the finer types of cabbage *[161]*. Thus growers prefer to use sulphate on Brussel sprouts since it gives a higher proportion of high grade small buttons than KCl *[171]*. Cauliflower may show molybdenum deficiency and high NO_3 content when sulphate is used so that a mixture of K_2SO_4 and KCl is often recommended *[212]*.

Evidence as to the Cl tolerance of **spinach** *(Spinacea oler.)* is contradictory and long term experiments indicate no preference for either type *[101]*. Certainly, the reaction to form of fertilizer varies a good deal with weather conditions. According to SCHUPHAN *[264]* the adverse effects of Cl are not as marked in dry years as in wet. It is interesting that leaves from SO_4 fertilized plants showed the lowest moisture loss (loss in weight after 4 days storage: KCl 24%, K_2SO_4 19.2%) and thus had the best keeping quality *[101, 161]*. Higher fresh weight yields are obtained with chloride because of increased water content of the leaves *[256]* but the higher dry matter yields are obtained with K_2SO_4 according to French work *[171]*. Experiments with different forms of N and K gave the highest yield with the combination $KCl + Ca(NO_3)_2$ with very high carotene and vitamin C content *[265]*. A combination of $KCl + K_2SO_4$ seems to be profitable with regard to dry matter yield and contents of carbohydrates, minerals and vitamin C *[212]*.

So far, the form of potash has been found to have no effect on oxalic acid content *[101]* but NO_3 levels are said to be increased by exclusive use of K_2SO_4 *[46, 212]*.

Experience shows that high salt concentration in the soil is damaging to **lettuce** *(Lactuca sativa capitata)* and care should be taken to keep it within limits. Sulphate of potash magnesia is much used. In pot experiments KCl increased fresh yield but K_2SO_4 increased vitamin C and sugar content so that the ideal would appear to be a mixture of the two forms *[212]*.

Root and stem vegetables

Root vegetables are less chlorophile than leaf crops.

In **carrots** *(Daucus carota)* the effects of Cl and SO_4 have been much investigated and it has been found that Cl encourages leaf growth while SO_4 favours the root *[264]*. Some contradictory results have been explained by the fact that the form of N fertilizer and soil moisture content influence the reaction to potash. SCHUPHAN *[264]* found that 'Nantaise' carrots yielded better with K_2SO_4 than KCl when NH_4Cl was used to supply N; with $Ca(NO_3)_2$ both forms were equally effective. When applied with NO_3-N, K_2SO_4 had more effect than KCl in increasing the development of the carotene-containing skin of the root. He also *[265]* confirmed earlier findings of NIEMANN *[211]* that fertilization with sulphatic forms of N and K (+ a little Na_2SO_4) under conditions of good water supply produced the best yields and, in comparison with KCl, led to higher protein content with lower total N and total sugar content in the root. Applying nitrate with KCl gave considerably lower protein and carotene contents and lower yields. The most important quality characteristic of carrots, provitamin A or carotene, is lower when KCl is used *[80, 220, 265]*.

According to SCHARRER and BÜRKE *[253]* the sulphate form of potash gives higher yields, higher dry matter and higher carotene content. GALLAGHER (p. 257 in *[340]*) found from long term experiments in Ireland that carrots were sensitive to high salt concentrations and high rates of KCl, and sulphatic fertilizers gave higher yields than KCl on soils of normal K content. Only on peaty soils did KCl give the best result. Regarding quality, the only effect noted was that K_2SO_4 gave higher carotene content (on mineral soils). Pot experiments on Polish peaty soils *[212]* showed an advantage on both grounds – yield (fresh and dry matter) and quality (vitamin C, sugar, NO_3-content) – in using a mixture of KCl and K_2SO_4.

KCl is to be preferred to K_2SO_4 for **red beet** *(Beta vulg. conditiva)* so far as total yield is concerned, while so far as extrinsic quality is concerned both forms are equally effective; sulphate increases the total N content and particularly NO_3 content and the sugar content *[46, 161, 212]*.

Celery *(Apium graveolens)* is generally regarded as chloride loving. KCl increases the total yield of leaves and stems. SIEGEL and BJARSCH *[271]* investigated effects on chemical composition of celery and found that the Cl ion reduced the content of leaf pigments (chlorophyll, xanthophyll, carotene) but that the difference between Cl and SO_4 was less at high rates of K. Further, Cl reduced dry matter content, glucose, fructose, xylose and raffinose and ascorbic acid. At high levels of leaf K the sugar content of SO_4 treated plants was similarly reduced. Chloride increased the free amino acid content, particularly arginine, of the leaves. Sulphate stimulated protein synthesis giving higher contents of amino acids, other than arginine, in the hydrolysates. The ratio protein : free amino acids was lower with Cl. Small amounts of cysteine were found even in plants grown without sulphur. The amino acid content of the leaf was increased by high K and the effect was more pronounced with the sulphate form of K.

Sulphate increased the root yield of **radish** and **black radish** *(Raphanus spp.)* especially when applied with $Ca(NO_3)_2$ *[161]*. Indian work *[249]* showed no difference due to the anion whatever the rate of K applied. Sulphate of potash magnesia is recommended for **salsify** *(Scorzonera hispanica)*. No adverse effects of KCl have been noted with **horseradish** *(Armoracia lapathifolia)* and **chicory** *(Cichorium intybibus)*.

Asparagus *(Asparagus officinalis)*, with **celery**, belongs to the small group of plants which prefer chloride and have a high magnesium requirement *([161];* FRITZ and VETTER, p. 117 in *[349])*. In deciding whether to use KCl or sulphate of potash magnesia, the Mg content of the soil should be taken into consideration, and, in certain circumstances, it may be advisable to alternate these two forms. Mg-containing KCl fertilizer, *e.g.* available in Germany as 40% 'Kornkali' with 5% MgO, is ideal *[266]*. Depending on the site, sulphatic and chloride fertilizers are equally suitable for **rhubarb** *(Rheum rhabarbarum)* and **artichoke** *(Cynara scolymus [161].)*

Onions, leeks and garlic

The liliaceae to which these *allium species* belong are recognized as having a high sulphur requirement. The high S content from 0.3–0.9% in the various parts of the plant is largely due to the content of leek oils. Harvested crops of onions or leeks remove about 100 kg S/ha from the soil (ANSTETT, p. 60 in *[336]*).
The anatomy of the roots of **onions** *(Allium cepa)* and liability to germination damage make them salt sensitive and sulphatic potash fertilizer is recommended. Cl-containing fertilizer raises the water content of the bulbs and this is to be avoided in main crop onions which are to be stored. Application of sulphur increases the content of the essential S-containing oils, which confer flavour, as well as increasing the yield as experiments in France, Italy, India and the USA have shown *[15, 20, 158]*. In experiments in Czechoslovakia on leached sandy soils *[308]* KCl plots sometimes outyielded K_2SO_4 plots while in other years the reverse was the case, confirming results obtained in the German D.R. *[27]* which showed that in some localities chloride fertilizers were as effective as sulphate. Potash consistently improves the yield and quality of onions, accelerating growth without bolting and improving ripening in the field. When well supplied with K, bulb diameter is large and the dry matter and disaccharide content is higher. K makes the bulb firmer and reduces sprouting of onions in storage increasing the storage life and reducing losses.

The highest yields of **garlic** *(Allium sativum)* have been obtained with K_2SO_4 in Italy *[161]*. H. PESCHUTTER *[225]* found that **leeks** *(Allium porrum)* grown in solution culture contained more allyl sulphur oil when grown with K_2SO_4 (60.1 mg/100 g fresh weight *vs.* 41.7 with KCl). However, in many field experiments there was no great advantage with either form of potash as far as yield was concerned though K_2SO_4 was more consistent, especially when weather conditions were not ideal *[161]*. GEISSLER *[87]* concluded that leeks preferred the chloride, finding higher yields in fresh weight from the Cl-series of treatments but higher dry matter content in the SO_4-series.

Vegetables grown for their fruit

All vegetables of this type can be classified as chlorophobe having a relatively high sulphur requirement. They are exemplified by the **tomato** *(Lycopersicon) [271]*.

Cl-induced yield depressions occur as a rule in conjunction with soil salinity and may occur particularly when saline irrigation water is used. The older leaves are hard, thick and brittle; both vegetative growth and fruit development are reduced (fruit number and weight). The K content of leaves and fruit falls off with increasing Cl content. P uptake is reduced which may be connected with the lowering of pH and appearance of free Al ions in the soil solution (SEATZ, MEYER *et al.*, cited *[139]*). SIEGEL and BJARSCH *[271]* found that chloride reduced the content of leaf pigments, especially of chlorophyll A and gave lower dry matter yield, sugar and ascorbic acid contents while the content of free amino acids, especially arginine, increased so that the protein : free amino acid ratio was lower than when SO_4 was used.

The reaction of tomato to S deficiency in respect of carbohydrate and protein metabolism is similar to that to Cl nutrition as shown in earlier work (cited *[139]*) by SCOTT and COLEMAN. In Russian field experiments by VLASYUK and DOLYA sulphate of potash raised the dry matter, sugar and vitamin C contents and the proportion of marketable fruit. JACOB says that K_2SO_4 improves the flavour compared with KCl by increasing the sugar content. SCHULZ (cited *[161]*) and AMBERGER *[7]* found that as well as increasing yield, sulphate of potash magnesia reduced fruit splitting.

There are very few results in favour of chloride forms of potash with tomato. UEBEL *[308]* obtained higher yields with KCl in field experiments in Czechoslovakia. NURZYNSKI *[212]* recommends a mixture of K_2SO_4 and KCl for tomatoes grown in a peat substrate, KCl increasing the dry matter and sugar content of the fruit and K_2SO_4 the ascorbic acid content.

So far as extrinsic aspects of quality (colour and texture) are concerned, high nutrient concentration in the soil solution seems to be advantageous and potassium is most important in connection with number of fruit, weight and the incidence of ripening disorders. Higher levels of K and N than those needed for maximum yield are needed to produce fruit of the highest quality (WINSOR, p. 303 in *[340]*, ADAMS *et al. [3]*, ZEHLER and FORSTER *[332]*). These necessarily large potash dressings should be applied in the form of sulphate of potash or sulphate of potash magnesia to provide the best conditions for high yield and good quality (LA ROTONDA, p. 185 in *[346]*).

Peppers *(Capsicum annuum spec.)* and **cucumber** *(Cucumis sativus)* prefer the sulphate form according to Czechoslovakian experiments *[308]* and practical experience *[161]*. Treating pepper seedlings with KCl or K_2SO_4 solutions (1–5% K_2O) raised cell sap concentrations and conferred better low temperature resistance, K_2SO_4 being more effective at higher, and KCl more effective at lower rates. Such treatment allowed earlier planting out and earlier harvest *[110]*.

Both these crops require a good supply of potash. K improves the firmness of the fruit allowing it better to withstand transport and to remain in store longer. Cucumbers remain true to shape and are less constricted at the apex of the fruit *[265]*.

Melons *(Cucumis melo)* according to MUCCI (p. 153 in *[349]*) yield better (increased fruit number) and are of better quality (higher sugar content) when sulphate is used.

Increasing the rate of N to some extent reduces the difference between the forms of potash.

4.10. Flowers and ornamentals

There has not, up to date, been a great deal of detailed research on the effect of different forms of potash on the development of flowers and ornamental plants. It is the usual practice of gardeners to use sulphate of potash or sulphate of potash magnesia for intensive growing, and particularly so in the glasshouse. This practise is based on the experience that most ornamentals require generous feeding but are not very tolerant of salt concentration. Usually, and particularly in the case of pot plants, the volume of the growing medium is small so there is always a danger that using fertilizers based on osmotically active salts ($Cl > SO_4$) will cause dangerous levels of salinity. As the discussion of the physico-chemical properties and physiological behaviour of the anions has shown, sulphate is more suitable for use under these conditions than chloride, quite apart from any need to supply the sulphur requirements of the plants.

Salt damage will occur in ornamentals at salt concentrations of more than 0.2–0.7% in the soil solution or nutrient solution. As a rule ornamentals which have a high nutrient requirement are less sensitive to salinity (and vice versa). Depending on the growing medium, the salt tolerance of these plants is approximately as follows *[223]:*

- Very sensitive to salinity and Cl:
  Adiantum, Anturium spp., Asparagus plumosus, Azalea, Erica, Freesia, Gardenia, Lathyrus, Orchidaceae, Primula, Syringa, Vriesea, Bulbs
- Moderately to slightly sensitive to salinity and Cl:
  Gerbera, Cyclamen, Rosa, Asparagus sprengeri, Calla, Convallaria, Dahlia, Dianthus, Euphorbia fulgens and *pulcherrima, Hydrangea, Pelargonium*

LUNT, KOFRANEK *et al.* (cited *[171]*) found that *Azalea* and *Gardenia* died back or suffered severe depression of growth at leaf Cl contents of 0.5 and 0.7% respectively. *Pelargonium, Gladiolus* and *Euphorbia pulcherrima* only suffered ill effects at higher Cl contents (above 2.5%), when they showed highly coloured foliage, marginal necrosis, leaf shedding and root damage.

K_2SO_4 normally improves flower quality with more intensive colour and better lasting properties. Sulphur deficiency may be shown by the production of fewer but larger flowers. Results obtained with *Primula obconica* grown with increasing rates of major nutrients (N 0–210–420 mg, P_2O_5 0–122–244 mg, K_2O 320–640 mg/l soil) in a sandy loam soil are shown in Table 51.

PENNINGSFELD (p. 141 in *[340]*) and PUCCINI (p. 185 in *[340]*), as a result of their investigations in Germany and Italy, favour the exclusive use of sulphate of potash for all ornamentals. It has been found in Holland and Poland that K_2SO_4 increases the yield and improves the quality of tulip bulbs as compared with KCl *[295]*.

Table 51 Effect of form of potash on growth and flowering of *Primula obconica* 3 months after application of fertilizer *

Mean/plant	$N_0P_1K_1$		$N_1P_1K_1$		$N_2P_2K_2$	
	Cl	SO_4	Cl	SO_4	Cl	SO_4
Height (cm)	8.0	8.0	13.1	12.3	12.9	15.0
Diameter of inflorescence	16.9	16.0	23.0	23.5	26.4	27.9
No. of inflorescences	1	1	2	2	3	3
No. of buds	5	4	9	10	20	21
Flower diameter (cm)	4.0	4.4	4.5	4.6	4.8	4.7
No. of individual flowers/infl.	9	10	13	20	24	33
Total flowers	37	37	119	134	211	240

* Reference: Ergebnisse gartenbaulicher Versuche, BELF.
Landwirtschaftsverlag Hiltrup (Westf.)/FRG (1955–1963)

4.11. Forest and ornamental trees

According to Baule and Fricker *[14]* the following affect salt and Cl tolerance and should be taken into consideration in deciding on the form of potash to be used in forest and shrub nurseries and in plantations: amount of rainfall; physical and chemical properties of the forest soil; type and age of plant; rate of fertilizer and date of application.

Basically, the deciduous trees are more salt and Cl tolerant than the evergreens – with the exception of some species – which accumulate salt and Cl in the needles. Especially in more mature plantings, the choice of K form is less important for deciduous trees than for conifers.

According to Penningsfeld *[224]*, Evers *[76]*, Blaser *[24]* and Kreutzer [personal communication] chloride tolerance of the various species is as follows:

- Slightly tolerant:
  Tilia, Acer, Fagus, Carpinus, Pseudotsuga, Picea, Pinus strobus, Larix, Rosaceae, Forsythia, Diervillea, Magnolia
- Fairly tolerant:
  Abies, Populus, Betula, Alnus, Quercus, Fraxinus, Ulmus, Salix, Robinia, Lonicera, Viburnum, Juniperus
- Tolerant:
  Pinus nigra and mugo, Ligustrum, Hippophaea, Symphoricarpus

Age greatly affects tolerance. Thus, young birch and ash are much more Cl sensitive than older trees. The Cl content of young trees should not exceed 1% in the leaf. The tolerance level in one year old needles of conifers is only 0.3%; dying spruce show levels of 0.45–1.05% *[76, 245]*. Young spruce react to low levels of Cl by increased Cl and reduced Fe uptake, producing pale coloured foliage *[303]*. The Cl contents of chlorotic pine needles and branches are higher than average. The effects of Cl will be more marked when fertilizer is placed close to the roots (Fricker, cited *[179]*) as indicated by pot experiments with *Pseudotsuga*, *Picea* and *Abies*.

On the other hand, Benzian *[18]* found no great difference between K_2SO_4 and KCl in English forest nurseries with Sitka spruce. Themlitz *[303]* also reports no difference between KCl and sulphate of potash magnesia with young *Picea excelsa*.

Sandrik (cited *[139]*) in Norway showed that sulphate was better than chloride when applied at 250 kg K_2O/ha to *Picea abies*. The sulphate forms are more effective for *Pseudotsuga* and *Pinus* on the west coast of the USA *[15]*, and for *Pinus maritima* in the French 'Landes' *[191]*; here sulphate of potash magnesia is often used as the light sandy soils are low in S and Mg. Bonneau *[30]* has obtained the best results with sulphate or sulphate of potash magnesia in nurseries and more mature stands of *Picea* and *Pinus* in many experiments at different localities in France. Whilst Trillmich and Uebel *[306]* found KCl better for red oak *(Quercus robur)*, Bruning *et al.* (p. 240 in *[348]*) had particularly good results with high rates of K-Mg fertilizer applied to pine in reafforestation of sandy sites in the German D.R.

The West German potash industry has carried out many experiments recently with K_2SO_4 and sulphate of potash magnesia for spruce and pine in South, West and North Germany (*[14]*; Franz, p. 91, and Zech, p. 250 in *[348]*). On other potash form experiments at Eglofs-Osterwald (F.R. Germany) sulphate of potash magnesia was compared with 40% KCl at 160 kg K_2O/ha for the first five years of growth on peat soils *[284]*. It appeared that KCl increased nutrient uptake, and the higher K contents resulted in reduced frost damage to the leaders with less bifurcation (multiple stems). However, after 16 years tree height and the volume of timber was higher on the K-Mg plots (Table 52).

Russian foresters (cited *[14]*) report no damage from high grade muriate of potash with oak *(Quercus)* and maple *(Acer)* as compared with sulphate of potash. According to Schönnamsgruber *[261]* it is not yet established which form is best for poplar *(Populus)*, though he advises sulphate. French experiments (Viart, cited *[179]*) with poplar indicate a preference for low salt index fertilizer, and K_2SO_4 produced the highest girth increase when applied with superphosphate.

Table 52 Effect of potash form on tree height and timber volume of *Picea excelsa* and *sitchenis* *[284]*

	Relative height		Relative volume
	P. excelsa	P. sitch.	total/ha
K_0	100	100	100
K_2SO_4*	186	191	517
KCl	182	169	425

* Sulphate of potash magnesia

The general impression gained from a perusal of European, American, Japanese and other work is that, though, in principle, there is little evidence to suggest that Cl should not be used, the sulphate form, especially sulphate of potash magnesia, is somewhat better *[14]*.

When high rates of potash are applied to forest nurseries, new plantings and young trees in spring when the rainfall may be insufficient to wash the chloride out of the rooting zone, sulphate fertilizers are recommended in order to avoid any risk of Cl damage (VAN GOOR, ZÖTTL *et al.*, cited in *[14]* and *[30]*). There is also an increased danger of chloride damage when drought supervenes during the growing period. In any case it is advisable to avoid building up locally high Cl concentrations by placing KCl in holes in the rooting zone. In Canada it has been found that increasing salinity reduces frost resistance *[291]*.

The sulphur requirement of forest is normally supplied by the S input from the atmosphere in rain falling on the foliage and it is interesting that twice as much SO_4 was found in percolating water under conifers as under deciduous trees due to the permanent filtering action of the needles. This was shown in balance experiments with spruce and beech *[196]*.

It would not be expected that chloride fertilizers would have any damaging effects on more mature trees in humid climates where the roots explore a considerable volume of soil and, under these conditions, the main objective should be to cover the trees' requirements for K and Mg *[348]*.

4.12. Summary of chapter 4

The majority of agricultural crops have no particular preference for either form of potash when fertilizer is applied in normal amounts and by normal methods, especially in autumn. When very high rates of potash are used continually as in intensive vegetable growing, the use of sulphate incurs less risk of high salt concentration in the soil. Very high salt concentrations occur locally when fertilizer is placed, even though rate per hectare is low.

All crops react favourably to sulphate when natural supplies of **sulphur** are low.

Magnesium in sulphate of potash magnesia and other special K fertilizers is valuable on low Mg soils and especially for grass, sugar beet, hops, vines and ornamentals.

Sodium in some K fertilizers is important, particularly for sugar beet, grassland, asparagus.

- Crops on which it is especially important to use **sulphate** (or to avoid chloride) are:

  Tobacco. There is no doubt that sulphate is superior, Cl affecting quality adversely.

  Potatoes. SO_4 increases dry matter and starch contents giving more evenly sized tubers and is preferred for crisping and dehydration.

Vines. Sulphate gives better quality.

Fruit, particularly soft fruits; for pome fruits chloride can be used if application is correctly timed.

Vegetables. Certain species are Cl sensitive; quality and special purposes of produce require the SO_4 forms.

Flowers. Sulphate gives better colour.

Trees, especially conifers, prefer sulphate of potash magnesia.

Oil crops have a high S requirement, *e.g.* soya and rapeseed.

- Crops for which it is normally preferable to use **chloride:**

  Sugar beet which also requires sodium.

  Coconut and oilpalm, especially on sandy soils away from the sea, which also respond to Cl.

5. Conclusion

This booklet has discussed the special properties of the different potash fertilizers both in general terms in chapters 2 and 3 and as regards their relative efficiencies for individual crops and crop groups in chapter 4. In summary, the choice of potash fertilizer depends upon the following:

- Sulphur is a major plant nutrient and the plant's S requirement is of the same order as that for P. Large areas of soil in non-industrialised countries are low in sulphur and, because of modern measures to reduce pollution, supply of sulphur from the atmosphere is now much less in industrialised countries than was the case a few years ago. Farm crops are receiving less sulphur nowadays because modern fertilizer materials are 'purer' than they used to be, materials like ammonium sulphate and single superphosphate having been superseded by ammonium nitrate, urea, ammonium phosphates and triple superphosphate, the S content of which is negligible. Thus there is now more risk of S deficiency occuring than was the case 15 or 20 years ago. Fertilizers based on sulphate of potash offer a convenient means of supplying S.

- Certain crops are particularly sensitive to chloride – notable examples being tobacco, potatoes, garden beans and some fruits – and for these the use of chloride containing fertilizers should be avoided. Crops are also sensitive to salinity which is a serious problem particularly in arid areas; again, chloride should be avoided in such cases. On the other hand there are other crops, notably sugar beet, which revel in chloride (and sodium) and for these, the chloride based fertilizers should be used. Many crops are indifferent to Cl or SO_4, while chloride may be used on slightly Cl sensitive plants if the fertilizer is applied well before planting, *e.g.* in the autumn before spring planting. When fertilizer is placed close to seed or young seedlings, damage may occur with chloride and sulphate is to be preferred.

- Some potash fertilizers contain auxiliary nutrients: Na, Mg which are valuable under certain circumstances, *e.g.* on soils low in magnesium, or where it is necessary to increase the content of these minerals in animal fodders.

- Particular emphasis has been placed on crop quality which is much affected by the form in which the potassium is combined in the fertilizer. In many cases quality is more important than total yield.

- Finally, the farmer's choice will be influenced by cost and the availability of particular fertilizer materials. Near to the potash mines it may be very attractive to use low grade potash minerals because of their content of auxiliary minerals, while at a greater distance it may be advantageous to use the potash fertilizer with the highest K content and to obtain the other minerals from other sources, because the large freight element in the cost makes the low analysis materials unattractive.

Sulphate of potash fertilizers are more expensive than the chlorides but the extra cost may be well repaid by the higher quality of the resulting produce and consequently higher market price while they may also offer the cheapest and most convenient means of supplying the crop's need for sulphur.

It is hoped that the discussion offered in this book will assist the farmer to make the right choice.

6. Bibliography

1. Abo-Elsaod, I., Momtaz, A., Lashin, H. and Mansor, M.: The response of flax crop to different levels of salinity. Z. Acker- u. Pfl.bau *140*, 255–260 (1975)
2. Achmedov, A.N. and Vyval'ko, I.G.: (Der Einfluss der Kalidüngerformen auf die Synthese und Speicherung der Stärke in Kartoffelknollen auf Moorböden). Ref.: Ldw. Zentralbl. II, *16* (7), Ref. 413 (1971)
3. Adams, P., Davies, J.N. and Winsor, G.W.: Effects of nitrogen, potassium and magnesium on the quality and chemical composition of tomatoes grown in peat. J. hort. Sci. *53*, 115–122 (1978)
4. Aduayi, E.A.: Nutrient composition of white yam *(Dioscorea rotundata)* leaves sampled at various portions on the stakes as influenced by nitrogen fertilization. Comm. Soil Sci. Pl. Analysis *10*, 927–939 (1979)
5. Allaway, W.H. and Thompson, J.F.: Sulfur in the nutrition of plants and animals. Soil Sci. *101*, 240–247 (1966)
6. Altunin, D.A. and Altunina, V.A.: (Die Wirkung verschiedener Kalidüngerformen auf den Ertrag landwirtschaftlicher Kulturen). Ref.: Ldw. Zentralbl. II, *13* (2), Ref. 380 (1968)
7. Amberger, A.: Zur Wirkung des 40%igen Kalisalzes mit 25% Kalimagnesia-Anteil. Kalibriefe (Büntehof), Fachgeb. 10, Folge 2 (1956)
8. Amberger, A. and Gutser, R.: Effect of long-term potassium fertilization on crops and potassium dynamics of a brown-earth (Weihenstephan). Ann. Agron. *27*, 643–657 (1976)
9. *Anonymous:* Foliar fertilization: Most say 'not yet', but allied says 'go'. Farm. Chem. (Ohio) *140* (3), 32–36 (1977)
10. Arnon, I.: Mineral nutrition of maize. Int. Potash Inst., Bern, 1975
11. Aulakh, M.S. and Pasricha, N.S.: Interrelationships between sulphur, magnesium and potassium in rapeseed. I. Yield, concentration and uptake of sulphur. II. Uptake of Mg and K, and their concentration ratio. Indian J. agric. Sci. *47*, 577–581 (1977); *48*, 143–148 (1978)
12. Bailey, L.D.: Alfalfa – 10 tons. A possible in Western Canada. Better Crops (USA) *58*, 23–25/30–31 (1979/80)
13. Balks, R. and Wehrmann, O.: Über den Einfluss verschiedener Kationen auf die Sulfataufnahme von Roggenkeimpflanzen. Bodenkd., Pfl.ernähr. *31*, 129–137 (1943)
14. Baule, H. and Fricker, C.: The fertilizer treatment of forest trees. BLV-Verl., München, 1970
15. Beaton, J.D.: Sulfur requirements of cereals, tree fruits, vegetables and other crops. Soil Sci. *101*, 267–282 (1966)
16. Bellis, E.: Evolution dans les pratiques de fertilisation sur les plantations d'*Hevea Brasiliensis*. Fertilité *38*, 29–43 (1971)
17. Bentley, C.F., Gareau, L. and Renner, R.: Fertilizers and nutritive value of hays. I. Sulphur deficient grey wooded soils. Canad. J. agric. Sci. *36*, 315–325 (1956)
18. Benzian, B.: Cumulative dressings of potassium metaphosphate and soluble PK-fertilizers for seedlings and transplants of *Picea sitchensis* in two English nurseries. Pl. Soil *36*, 243–245 (1972)
19. Bernstein, L.: Effects of salinity and sodicity on plant growth. Ann. Rev. Phytopathol. *13*, 295–312 (1975)
20. Bertrand, D. and Wolf, A. de: Optimum de quantité de soufre pour l'oignon et la pomme de terre. C.R. Acad. Agric. France, No. 12, 1021–1026 (1964)
21. Biar, E.: La fumure des petits fruits. La Potasse, mai-juin, 115–120 (1964)
22. Birkmann, K.H. and Zehler, E.: Zur Kali-Ernährung von Veredelungskartoffeln. Kali-Briefe (Büntehof), Fachgeb. 10, 1. Folge (1975)

23. Blair, G.J., Mamaril, C.P., Pangerang Umar, A., Momuat, E.O. and Momuat, Ch.: S-nutrition of rice. I+II. Agron. J. *71*, 473–480 (1979)
24. Blaser, R.E.: Plants and de-icing salts. American Nurseryman *144*, 8 (1976)
25. Bobkova, L.P.: (Nachwirkung der Düngung auf die Qualität der Kartoffel). Ref.: Ldw. Zentralbl. II, *24* (1), Ref. 413 (1979)
26. Bockelée-Morvan, A.: Efficacité des diverses formes d'apports des éléments minéraux sur l'arachide. Oléagineux *21*, 163–166 (1966)
27. Böttcher, H. and Kolbe, G.: Neue Ergebnisse zur Mineraldüngung von Dauerzwiebeln. Feldwirtsch. *15*, 556–560 (1974)
28. Bolle-Jones, E.W.: Incidence of sulphur deficiency in Africa. A review. Emp. J. exp. Agric. *32*, 241–248 (1964)
29. Bonjour, R.A.: Wirkung des Natriums bei der Düngung von Zuckerrüben. Schweiz. landw. Forsch. *10*, 216–223 (1971)
30. Bonneau, M.: La fertilisation en sylviculture. Rev. forest. franç. *21*, 429–439 (1969)
31. Book, O.J., Catani, R.A. and Freire, E.S.: Adubação da batatinha. Experiencias com leucita, sulfato e cloreto de potassio. Bragantia *19*, 811–828 (1960)
32. Boresch, K.: Weitere Untersuchungen über durch Chloride hervorgerufene Blattkrankheiten bei Johannisbeere. Bodenkd., Pfl.ernähr. *14*, 230 (1939)
33. Brook, R.H.: Sulphur in agriculture. Abstr. Trop. Agric. *5* (9), 9–15 (1979)
34. Bruchholz, H.: Auswirkungen differenzierter Kalidüngung auf den Ertrag landwirtschaftlicher Kulturpflanzen (Ergebnisse von 50 Feldversuchen in der DDR und CSSR). Kali-Mitteilungen (VEB Kombinat Kali, Sondershausen) B-3, 4–14 (1970)
35. Bruchholz, H.: Der Einfluss der Düngung mit verschiedenen Kalidüngemitteln auf die Ertragsleistung einer Fruchtfolge auf einem sauren, kali- und magnesiumarmen Sandboden. Kali-Mitteilungen (VEB Kombinat Kali, Sondershausen) B-3, 24–28 (1970)
36. Bruchholz, H.: Die Wirkung langjähriger Düngung mit unterschiedlichen Kalidüngermengen und verschiedenen Kalidüngerformen in der CSSR. Kali-Mitteilungen (VEB Kombinat Kali, Sondershausen), Sdh. 2, 1–20 (1974)
37. Bruchholz, H.: Einfluss langjähriger Kalidüngung auf Boden und Pflanze. Kali-Mitteilungen (VEB Kombinat Kali, Sondershausen), Sdh. *21* (1), (1976)
38. Bruchholz, H. and Fiedler, W.: Untersuchungen über den Einfluss langjähriger Düngung mit verschiedenen Kalidüngemitteln sowie unterschiedlichen Stickstoff- und Kalimengen auf Leistungsmerkmale von Apfelniederstammanlagen an verschiedenen Standorten der DDR. I. Ertrag und Nährstoffgehalt des Bodens. II. Kronenvolumen, Ertrag/m³ Kronenvolumen, Blattinhaltsstoffe und Lagerverhalten der Früchte. Beitr. Kalidüngg. Land-Forstwirtsch. (VEB Kali, DDR) *1* (3), 9–27/28–29 (1977)
39. Bruchholz, H. and Ramanathan, K.M.: The effect of nitrogen and potassium fertilisation on the yield and the nutrient content of the soil in a crop rotation at Tamil Nadu. First test series 1976–1978. Part 2: Nutrient content of the soil, nutrient balance, quality of the crop products and economic effect. Beitr. Kalidüngg. Land-Forstwirtsch. (VEB Kali, DDR) *3* (2), 20–26 (1979)
40. Bucher, R.: Die Magnesiumbevorratung von Weinbergböden; ihre Bedeutung für den Qualitätsweinbau und ihre Abhängigkeit von der Bodenbildung. Weinberg u. Keller *25*, 197–203 (1978)
41. Bünemann, G. and Gruppe, W.: Untersuchungen zur mineralischen Ernährung von Erdbeeren. III. Qualitätsmerkmale und Mineralstoffgehalte der Früchte in Abhängigkeit von der Versorgung mit Makronährstoffen. Gartenbauwiss. *27*, 166–182 (1962)
42. Bugaev, V.P. and Khlystovskii, A.D.: (Effectiviness of various forms of potassium fertilizers on sod-podzolic soil.) Ref.: Fertil. Abstr. *5*, Ref. 1946 (1972)
43. Burghardt, H.: Über die Bedeutung des Chlors für die Pflanzenernährung unter besonderer Berücksichtigung des Chlorid/Sulfat-Problems. Angew. Bot. *36*, 203–257 (1962)
44. Burkersroda, K.W. von: Fertilizing maize in Rhodesia. World Crops *16*, 75–79 (1964)

45. BYERS, M. and BOLTON, J.: Effects of nitrogen and sulphur fertilisers on the yield, N and S content, and amino acid composition on the grain of spring wheat. J. Sci. Fd. Agric. *30*, 251–263 (1979)
46. CANTLIFFE, D.J.: Nitrate accumulation in table beets and spinach as affected by nitrogen, phosphorus, and potassium nutrition and light intensity. Agron. J. *65*, 563–565 (1973)
47. CATANI, R.A. *et al.:* Uptake of N, P, K, Ca, Mg, S and Si by sugarcane as affected by fertilization. Escola Agric. *16*, 168–190 (1959).
48. CHAPIN, J.S. and SMITH, F.W.: Germination of wheat at various levels of soil moisture as affected by applications of ammonium nitrate and muriate of potash. Soil Sci. *89*, 322–327 (1960)
49. CHISCI, G.: La concimazione al medicaio asciutto. L'Informatore Agrario de Verona (1957)
50. CHOPRA, S.L. and KANWAR, J.S.: Effect of sulphur fertilization on the chemical composition and nutrient uptake by legumes. J. Indian Soc. Soil Sci. *14*, 69–76 (1966)
51. CHOUTEAU, J.: Incidence des chlorures sur l'équilibre acides-bases de la composition chimique des feuilles. Relation avec la combustibilité. Communicat. 4th Congr. Scient. Int. Tabac, Athènes, 1966
52. CHOUTEAU, J. *et al.:* Influence de la fertilisation potassique sur le rendement et les caractéristiques physiques et chimiques de tabacs noirs. Ann. S.E.I.T.A., Sect. *2* (7), 21–43 (1970)
53. COÏC, Y.: La nutrition en soufre de nos cultures, perspectives de déficience en cet élément. Bull. Doc. Ass. int. Fabr. Superph., No. 29, 1–13 (1961)
54. COLEMAN, R.G.: The importance of sulfur as a plant nutrient in world crop production. Soil Sci. *101*, 230–239 (1966)
55. COLLIVER, G.W.: Effects of potassium sources and nitrogen on soybeans grown in two low K soils in the greenhouse. Agron. Abstr., Ann. Meet. Amer. Soc. Agron., 136 (1975)
56. *Consulentschap v. Bodemaangel i. d. Landbouw, Bemesting van bouwland:* Vlugschrift v. d. Landbouw, Wageningen, No. 253, 1–12 (1978)
57. COUSINS, L.T.V.: The effects of nitrogen, phosphate and potash fertilization on yield and quality of oriental tobacco in Rhodesia. Communicat. 4th Congr. Scient. Int. Tabac, Athènes, 1966
58. CRABTREE, R.J.: Effects of rates and sources of potassium on yields and mineral content of potatoes and evaluation of potassium quantity intensity relationships of selected Michigan soils. Diss. Michigan State Univ., East Lansing, Abstr. Int. *30* (4), 1454B, 1969
59. CRITTENDEN, H.W. and SVEC, L.V.: Soybean *(Glycine max. [*L.*] Merr.)* yield and disease incidence with potassium fertilization. Commun. Soil Sci. Pl. Analysis 7, 727–741 (1976)
60. DAS, S.K. and DATTA, N.P.: Sulphur fertilisation for increased production and grain quality. Fert. News (India) *18* (9), 3–10 (1973)
61. DHILLON, N.S. and DEV, G.: Effect of elemental sulphur on soybean *(Glycine max. [*L.*] Merr.)*. J. Indian Soc. Soil Sci. *26*, 55–57 (1978)
62. DICKINS, J.C., HARRAP, F.E. and HOLMES, M.R.: Field experiments comparing the effect of muriate and sulphate of potash on potato yield and quality. J. agric. Sci. *59*, 319–326 (1962)
63. DILLEY, D.R., KENWORTHY, A.L. and BENNE, E.J.: Growth and nutrient absorption of apple, cherry, peach, and grape plants as influenced by various levels of chloride and sulphate. Proc. Amer. Soc. hort. Sci. *72*, 64–73 (1958)
64. DRAYCOTT, A.P.: Sugarbeet nutrition. Appl. Sci. Publ., London, 1972
65. DRAYCOTT, A.P. and DURRANT, M.J.: Response by sugar beet to potassium and sodium fertilizers, particularly in relation to soils containing little exchangeable potassium. J. agric. Sci. *87*, 105–112 (1976)
66. DRAYCOTT, A.P. and DURRANT, M.J.: Sodium and potassium fertilizer in relation to soil physical properties and sugarbeet yield. J. agric. Sci. *87*, 633–642 (1976)

67. DREWS, M.: Die Auswirkung von Chlorid, Natrium und Sulfat auf die Bodenfruchtbarkeit von Böden und Erden im Gemüsebau unter Glas und Plasten. Arch. Gartenbau *22*, 27–39 (1974)
68. DUKE, ST.H., COLLINS, M. and SOBERALSKE, R.M.: Effects of potassium fertilization on nitrogen fixation and nodule enzymes of nitrogen metabolism in alfalfa. Crop Sci. *20*, 213–219 (1980)
69. DURRANT, M.J., DRAYCOTT, A.P. and MILFORD, G.F.J.: Effect of sodium fertilizer on water status and yield of sugar beet. Ann. Appl. Biol. *88*, 321–328 (1978)
70. DWELLE, R.B., STALLKNECHT, G.F., McDOLE, E.R. and PAVEK, J.J.: Effects of soil potash treatment and storage temperature on blackspot bruise development in tubers of four *Solanum tuberosum* cultivars. Amer. Potato J. *54*, 137–146 (1977)
71. EDELBAUER, A.: Traubenertrag, Mineralstoffgehalt von Blättern und einjährigen Trieben sowie Frostanfälligkeit der Knospen von *Vitis vinifera* L. bei verschiedenen Cl/SO_4-Relationen. Z. Pfl.ernähr., Bodenkd. *141*, 83–94 (1978)
72. EDELBAUER, A.: Investigations on the influence of varied KCl/K_2SO_4 ratios on yield of grapes, and on quality of grape juice and its aminoacid pattern, of *Vitis vinifera* in nutrient solution culture. Potash Rev. (IPI), Subj. 29, 10th suite (1979)
73. ELLIOT, J.M. and BACK, M.E.: Effects of potassium and chlorine on the production of tabacco seedlings. Canad. J. Soil Sci. *43*, 268–274 (1963)
74. EL-NENNAH, M. and ABDOU, F.M.: Effect of salts on the uptake of P by alfalfa from both soil and labelled fertilizer. Isotope a. Radiation Res. *9*, 79–84 (1977)
75. ENSMINGER, L.E. and FRENEY, J.R.: Diagnostic techniques for determining sulfur deficiencies in crops and soils. Soil Sci. *101*, 283–290 (1966)
76. EVERS, F.H.: Fernwirkung abgeschwemmter Auftausalze im Innern von Waldbeständen. Europ. J. Forest Pathology *4*, 46–48 (1974)
77. FORESTIER, J. and BELEY, J.: Teneurs en soufre et en oligoéléments des feuilles du caféïer *robusta* en Lobaye (R.C.A.). Café, Cacao, Thé *10*, 17–27 (1966)
78. FOUCHE, P.S., BESTER, D.H. and VELDMAN, G.H.: Influence of potassium applications and nematocides on the potassium nutrition of Valencia orange trees on replant citrus soil. J. Amer. Soc. hort. Sci. *102*, 546–547 (1977)
79. FOX, R.L., Kang, B.T. and WILSON, G.F.: A comparative study of the sulfur nutrition of banana and plantain. Fruits d'outre-mer *34*, 525–534 (1979)
80. FREEMAN, J.A. and HARRIS, G.H.: The effect of nitrogen, phosphorus, potassium and chlorine on the carotene content of the carrot. Sci. Agric. *31*, 207–211 (1951)
81. FRENEY, J.R. and STEVENSON, F.J.: Organic sulfur transformations in soils. Soil Sci. *101*, 307–316 (1966)
82. FRITZSCHE, B. and WIRTH, A.: Düngung der Obstbäume. Schweiz. Z. Obst- u. Weinbau *72*, 101–108 (1963)
83. FURLANI, A.M.C. *et al.:* (Effects of potassium chloride and of potassium sulfate on coffee plants). Ref.: Fertil. Abstr. *11*, Ref. 913 (1978)
84. GARIN, N.A.: (Comparative effect of different forms of potassium fertilizers on yield and marketable quality of potatoes) Ref.: Soils Fertil. *42*, Ref. 3436 (1979)
85. GEERING, J.: Über die Düngungsansprüche der Drescherbsen, insbesondere an P_2O_5 und K_2O. Schweiz. Landw. Forsch. *5*, 20–55 (1966)
86. GEISSLER, TH.: Über die Wirkung chlorid- und sulfathaltiger Düngemittel auf den Ertrag einiger Gemüsearten unter verschiedenen Umweltverhältnissen. Arch. Gartenbau *1*, 233–342 (1953)
87. GEISSLER, TH.: Einige Untersuchungen über die Chloridverträglichkeit verschiedener Gemüsearten. Arch. Gartenbau *3*, 316–325 (1955)
88. GERRITSEN, J.D.: Problems of potassic nutrition in the experimental orchard at Geldermalsen (Holland). Potash Rev. (IPI), Subj. 8, 10th suite (1957)

89. GETHING, P.A., LEWIS, B.M. and McDONALD, M.G.: Comparison of potassium sulphate and potassium chloride manuring of potatoes. Irish J. agric. Res. *3*, 119–122 (1964)
90. GETHING, P.A.: The effect of form of potash and method of application of compound fertilizer on fertilizer response by potatoes. Exper. Husbandry *16*, 51–62 (1968)
91. GISIGER, L.: Die Schwefeldüngung im Lichte der Ergebnisse neuerer Düngungsversuche. Mitt. schweiz. Landw. *10*, 1–9 (1962)
92. GISQUET, P. and HITIER, H.: La production du tabac. Principes et méthodes. Ballière et Fils Edit., Paris, 1961
93. GLANDER, H. and PETER, A. VON: Discoveries and experience of manuring rice. Green Bull. No. 6, Verlagsges. Ackerbau, Hannover, 1962
94. GLANDER, H. and TEIWES, G.: The supply of nutrients to cotton with special reference to potash. Green Bull. No. 4, Verlagsges. Ackerbau, Hannover, 1962
95 GÖRLITZ, H.: Untersuchungen über den Einfluss der Mineraldüngung auf die Korngrösse der Kartoffelstärke. Thaer-Arch. *11*, 921–930 (1967)
96. GOLDWORTHY, P.R. and HEATHCOTE, R.: Fertilizer trials with soya beans in Northern Nigeria. Emp. J. exp. Agric. *32*, 257–262 (1964)
97. GONCARIK, M.N. and TALANOVA, K.S.: (Einfluss chlorhaltiger Dünger auf die Verwertung von Stickstoff, Phosphor und Kali durch Kartoffeln). Ref.: Ldw. Zentralbl. II, *14*, (6), Ref. 385 (1969)
98. GROOM, J.L. and DARLEY, E.C.: Managing lucerne stands. Queensland agric. J. *78*, 133–140 (1954)
99. GRÜNEBERG, F.: Nutrition and manuring of maize. Green Bull. No. 9, Verlagsges. Ackerbau, Hannover, 1959
100. GRÜNEBERG, F.: Potash fertilizers for sugarcane (Abstracts). Green Bul. No. 12, Verlagsges. Ackerbau, Hannover, 1961
101. GRÜTZ, W.: Ertragsunterschiede zwischen chloridhaltiger und sulfathaltiger mineralischer Düngung beim Spinatbau. Z. Pfl.ernähr., Düngg., Bodenkd. *62*, 239–243 (1953)
102. GRUNER, G.: The manuring of potatoes. Green Bull. No. 17, Verlagsges. Ackerbau, Hannover, 1963
103. GRUPPE, W.: Bodenuntersuchung und Düngung im Obstbau. Erwerbsobstbau *2*, 110–113 (1960)
104. GUTSTEIN, Y.: Differential cotton cultivar responses to levels of K availability. Qual. Plant. Mater. Veg. *22*, 107–118 (1972)
105. HAAS, A.R.C. and BRUSCA, J.N.: Chloride toxicity in avocados. Calif. Agric. *9*, 12–14 (1955)
106. HABRAN, R. and LEMAITRE, R.: Comment obtenir de belles fraises? DUP, 2e édit., Liège, 1958
107. HAEDER, H.E.: Einfluss chloridischer und sulfatischer Ernährung auf Assimilation und Assimilatverteilung in Kartoffelpflanzen. Landw. Forsch., Sdh. 32/I, 122–131 (1976)
108. HAHLIN, M. and JOHANNSSON, O.: (Phosphorus and potassium fertilization to food potatoes). Landbr.högsk. meddn. Uppsala, A, No. 192 (1973)
109. HAMPE, TH.: Bedeutung von Natrium für die unterschiedliche Resistenz von Buschbohnen *(Phaseolus vulg.)* und Zuckerrüben *(Beta vulg.)* gegenüber Salz- und Trockenstress. Diss. Techn. Univ. Berlin, Inst. f. Nutzpfl.forschg., 1979
110. HARASZTY, J.: (The effect of potassium treatment on the low temperature resistance of capsicum transplants). Ref.: Hort. Abstr. *45*, Ref. 3247 (1975)
111. HARDING, R.B., MILLER, M.P. and FIREMAN, M.: Absorption of salts by citrus leaves during sprinkling with water suitable for surface irrigation. Proc. Amer. Soc. hort. Sci. *71*, 248–251 (1958)
112. HART, T.G. and SMITH, O.: Effect of levels and sources of potassium on absorption of phosphorus by potato plants. Amer. Potato J. *43*, 217–235 (1966)

113. HASCHEMI, H.: Die Wirkung verschiedener K- und N-Formen auf Boden und Pflanze unter Berücksichtigung der Witterungsverhältnisse, dargestellt am Dauerdüngungsversuch Poppelsdorf. Diss. Univ. Bonn, Landw. Fak., 1971
114. HASLER, A. and SCHNETZER, H.L.: Beitrag zur Pflanzenernährung durch Schwefeldüngung. Mitt. schweiz. Landw. *14*, 93–100 (1966)
115. HAUCK, F.W.: Science and practice of the use of potash in tobacco culture. Green Bull. No. 7, Verlagsges. Ackerbau, Hannover, 1958
116. HAYWARD, H.E.: Factors affecting the salt tolerance of horticultural crops. Report 14th Internat. Hortic. Congr., Wageningen *1*, 385–399, 1955
117. HENDERSON, R.: Effect of type of potash and rates of nitrogen, phosphate and potassium in fertilizers on growth, yield and quality of potato crops. J. Sci. Fd. Agric. *16*, 480–488 (1955)
118. HOANG THI HA: Die Wirkung unterschiedlicher Kaliumdüngung auf die Wasserabgabe, den Chlorophyllgehalt, die Bildung von Pflanzenmasse und andere Parameter von Mais- und Reispflanzen. Beitr. trop. Landw. Veterinärmed. *12*, 275–286 (1974)
119. HOEFT, R.G. and WALSH, L.M.: Alfalfa and corn response to sulfur. Better Crops (USA) *54* (2), 28–31 (1970)
120. HOFMANN, E., BUCHNER, A. and SCHULZ-SCHOMBURGK, E.: Die Wirkung der Kalidüngung auf Boden und Pflanze nach den Ergebnissen eines 35jährigen Feldversuches. Z. Pfl.bau, Pfl.schutz *1*, 212–228 (1950)
121. HOFMANN, E.: Das Sulfatproblem als Folge der veränderten Düngewirtschaft. Bayer. landw. Jb. *34*,, Sdh. 1, 19–26 (1957)
122. HOFMANN, E. and MATTHES, F.: Verschiedene Kalidüngung und ihre Auswirkung auf den Boden. Bayer. landw. Jb. *35*, 570–581 (1958)
123. HØJMARK, J.: (Effect of increasing rates of $KCl + K_2SO_4$ on potato yield, cooking quality and chip colour). Tidsskr. Planteavl. *81*, 68–80 (1977)
124. HOLMES, M.R.J., PEAKE, H.V. and STEVENS, M.T.: Optimum fertilizer requirements for potatoes in relation to tuber size and price. Expl. Husbandry *23*, 1–9 (1973)
125. HUNNIUS, W.: Mineraldüngung zu Kartoffeln als Rohstoff für die Veredelungsindustrie. Kartoffelbau *24*, 70–72 (1973)
126. HUNNIUS, W., MUNZERT, M., SCHWEIGER, S. and SIEBOLD, M.: Wirkung gesteigerter Magnesiumgaben bei Kartoffeln. Kali-Briefe (Büntehof), Fachgeb. 8, 4. Folge (1977)
127. HUNNIUS, W. and MÜLLER, K.: Düngung und Kartoffelqualität. Neuere Ergebnisse zu Fragen der Kartoffeldüngung. Kartoffelbau *30*, 140–142, 142–143 (1979)
128. ISAKOVA, A. and CHKONIA, T.: (The influence of Cl and SO_4 anions on the development, physiological functions and fibre quality of white Ramie *(Boehmeria nivea)*). Ref.: Bibliogr. Minor Elements 246 (1939)
129. ISMUNADJI, M. and ZULKARNAINI, I.: Sulphur deficiency in lowland rice in Indonesia. Proc. Internat. Seminar Soil Environm. a. Fertility Managem. in intensive Agriculture, Tokyo, 647–652, 1977
130. IVANOV, N.P., BORODICH, V.I. and IVAKHNENKO, N.N.: (Effectiveness of chlorine-containing potassium fertilizer applied to potatoes at different times). Ref.: Fertil. Abstr. *6*, Ref. 1787 (1973)
131. IVANOV, N.P., KULIKOV, Y.K. and MASNYI, M.N.: (Effect of potassium nutrition on the biological value of barley grain). Ref.: Fertil. Abstr. *12*, Ref. 1743 (1979)
132. IVANOVA, T.I., ZHUKOV, S.N. and KOVALENKO, A.A.: (Zusammenhang zwischen Ertrag und Stärkegehalt der Knollen mit dem Nährstoffgehalt in den Blattstielen bei der Kartoffel). Ref.: Ldw. Zentralbl. II, *23* (6), Ref. 399 (1978)
133. JACOB, A. and ALTEN, F.: Faserausbeute und Nährstoffentzug des Sisals bei unterschiedlicher Düngung. Arbeiten über Kalidüngg., III. Reihe, 388–395, Verlagsges. Ackerbau, Berlin, 1942

134. JACOB, A. and UEXKÜLL, H. VON: Fertilizer use. Nutrition and manuring of tropical crops. Verlagsges. Ackerbau, Hannover, 3rd ed., 1963
135. JAMES, D.W., KIDMAN, D.C., WEAVER, W.H. and REEDER, R.L.: Factors affecting chloride uptake and implications of the chloride-nitrate antagonism in sugar beet mineral nutrition. J. Amer. Soc. Sugar Beet Tech. *15*, 647–656 (1970)
136. JONES, R.M.: Seedling death of *Desmodium intortum* in the Queensland Wallum with special reference to potassium chloride fertilizer. Ref.: Herb. Abstr. *44*, Ref. 2698 (1974)
137. JORDAN, H.V. and ENSMINGER, L.E.: The role of sulfur in soil fertility. Adv. Agron. *10*, 408–434 (1958)
138. JUKOV, M.S. and REPIAKH, I.I.: The effects of chlorides and sulphates on hemp. Potash Rev. (IPI), Subj. 12, 17th suite (1967)
139. KÄMPFER, M. and ZEHLER, E.: Die Bedeutung der sulfatischen Düngemittel für die Ertragserhöhung und Qualitätsverbesserung landwirtschaftlicher, gartenbaulicher und forstlicher Kulturen. Int. Potash Inst., Bern, May/June 1967
140. KAFKAFI, U., GILAT, R., YOLES, D. and NOY, Y.: Studies on fertilization of field-grown irrigated alfalfa. I. Effect of potassium source and time of application. Pl. Soil *46*, 165–173 (1977)
141. KHALIL, M.M., ANTAR, J., BAKHATI, H. and ISMAIL, A.: Effect of total and specific salinity of irrigation water on salt tolerance and red leaf phenomenon in cotton plant. Agric. Res. Rev. (Cairo) *55* (5), 41–48 (1977)
142. KALINOWSKA-ZDUN, M.: (Blattdüngung und Bewässerung von Tabak). Ref.: Ldw. Zentralbl. II, *16* (11), Ref. 471 (1971)
143. KAMESWARARAO, B.V., RAMAKRISCHNAYYA, B.V. and SASTRY, A.S.: Effect of chlorides on the yield and quality of Indian flue-cured tobacco. Indian J. agric. Sci. *34*, 78–86 (1964)
144. KELTJENS, W.G.: Factors affecting absorption and transport of potassium in maize roots. Diss. Wageningen, Versl. landbouwk. Onderz. No. 876, 1978
145. KEMMLER, C.: Results of recent investigations on potash as a nutrient for the tea bush. Green Bull. No. 2, Verlagsges. Ackerbau, Hannover, 1956
146. KICK, H. and POLETSCHNY, H.: Kaliumhaushalt und Ertragsleistung bei einem langjährigen Kaliformenversuch. Landw. Forsch., Sdh. 31/I, 59–68 (1975)
147. KIEPE, H.: 38jähriger Wirkungsvergleich zwischen verschiedenen Kali- und Stickstoffdüngerformen im Dauerdüngungsversuch Poppelsdorf (1906 bis 1944). Diss. Univ. Bonn, Landw. Fak., 1950
148. KLAPP, E.: Einfluss der Kalidüngung auf den Zustand und die botanische Zusammensetzung des Grünlandes. Proc. 4th Congr., Int. Potash Inst., Wien, 101–111, 1957
149. KODIA, A.A., IRIGARAY, J.L. and DÉJOU, J.: Recherche analytique d'éléments majeurs et d'oligoéléments dans la banane, l'avocat, l'igname et l'attiéké de Côte d'Ivoire, par radioactivation avec des neutrons de 14 MeV. Fruits d'outre-mer *34*, 743–749 (1979)
150. KONDRAT'EV, I.G. and PODKOLZINA, G.V.: (Effect of type of potassium fertilizer on yield of agricultural crops). Ref.: Soils Fertil. *31*, Ref. 3539 (1968)
151. KOO, R.C.J. and REESE, R.L.: The effects of omitting single nutrient elements from fertilizer on growth and performance of 'Pineapple' orange. Potash Rev. (IPI), Subj. 27, 58th suite (1972)
152. KOO, R.C.J. and REESE, R.L.: A comparison of potash sources and rates for citrus. Potash Rev. (IPI), Subj. 8, 24th suite (1973)
153. KOVANCI, I.: Fertilizer practice and some research abstracts in Aegean region. Spec. Bull., 12th Coll., Int. Potash Inst., Izmir, 1–26 (1976)
154. KOVERGA, E.L.: (The causes of chlorosis in citrus in the Crimea). Ref.: Hort. Abstr. *28*, Ref. 4012 (1958)
155. KREEB, K.: Salzschädigungen bei Kulturpflanzen. Z. Pfl.krankheit. *67*, 385–399 (1960)
156. KRETSCHMER, A.E., TOTH, G.J. and BEAR, F.E.: Effect of chloride versus sulfate ions on nutrient ion absorption by plants. Soil Sci. *76*, 193–199 (1953)

157. KUBADINOW, N. and FORSTHUBER, J.: Zur Bestimmung von Schwefel und Chlor in Zuckerrübenpflanzen und Produkten der Rübenzuckergewinnung. Zuckerind. *104*, 1019–1021 (1979)
158. KUMAR, K. and SAVAY, R.K.: Effect of sulphur fertilization on the pungency of onion. Curr. Sci. *23*, 368–369 (1954)
159. KURMIES, B.: Über den Schwefelhaushalt des Bodens. Phosphorsäure *17*, 258–278 (1957)
160. LAM, H. and MCLEAN, E.O.: Effects of salts on DM yield and N and P contents of rice plants. Commun. Soil Sci. Pl. Analysis *10*, 969–979 (1979)
161. LASKE, P.: The manuring of vegetables in field cultivation. Green Bull. No. 16, Verlagsges. Ackerbau, Hannover, 1962
162. LÁSZTITY, B.: (The effects of various potassium fertilizers on maize yields on a calcareous sandy soil). Ref.: Abstr. Trop. Agric. *3*, Ref. 13457 (1977))
163. LATZKO, E.: Beziehungen zwischen Cl- und SO_4-Ernährung, Assimilationsintensität, Enzymaktivität, Kohlenhydratstoffwechsel und Qualität bei Kartoffeln. Z. Pfl.ernähr., Düngg., Bodenkd. *68*, 49–55 (1965)
164. LAUGHLIN, W.M.: Spray concentrations of KCl and K_2SO_4 affect potato growth, yields and chemical composition. Amer. Potato J. *39*, 100–106 (1962)
165. LAWRIE, J.J.: The fertilization of tobacco. Chilean Nitrate Agric. Serv. Inform., No. 141, 1–21 (1979)
166. LEMPITSKAYA, V.K.: The influence of different potassium salts on carbohydrate accumulation in the potato. Potash Rev. (IPI), Subj. 11, 12th suite (1960)
167. LIN, C.F.: A dismission on the potash fertilization for the production of tea in Taiwan. Soils a. Fert. Taiwan, 17–28 (1958/59)
168. LIN, T.C.: Report on Irish potato K test. Potash Rev. (IPI), Subj. 16, 36th suite (1966)
169. LINTNER, J.: Fertiliser investigations on potatoes in the Transvaal, Republic of South Africa. Potash Rev. (IPI), Subj. 11, 20th suite (1968)
170. LOTT, W.L., MCCLUNG, A.C. and MEDCALF, J.C.: Sulfur deficiency in coffee. IBEC-Res. Inst. Bull. 22, 1960
171. LOUÉ, A.: Le sulfate de potasse. Au service de l'agriculture (SCPA, Mulhouse) No. 2, 1978 – Dossier K_2O, No. 11 (1978)
172. LUDWICK, A.E., GILBERT, W.A. and WESTFALL, D.G.: Sugarbeet quality as related to KCl fertilization. Agron. J. *72*, 453–456 (1980)
173. LUNDEN, A.P.: (Pot experiments on the action of potassium chloride and sulfate on the growth of clover and timothy). Meldinger Norg. Landbrukshogsk. *25*, 71–100 (1945)
174. MCNEE, D.A.K. and SKERMAN, P.J.: Distribution of chlorides in the waters of catchment of Macintyre Brook, Southern Queensland, and their effect on tobacco production. Queensld. J. Agric. Anim. Sci. *22*, 39–47 (1965)
175. MAGAT, S.S., MARGATE, R.Z. and PRUDENTE, R.L.: Utilization of common salt (sodium chloride) as a fertilizer and for the control of leaf spot disease of coconut seedlings. Ref.: Oléagineux *33* (2), Ref. 78–279 (1978)
176. MAJKOWSKI, K.: (The influence of mineral nutrition in combination with technical ligniu on flax yield and its structure). Ref.: Soils Fertil. *34*, Ref. 626 (1971)
177. MALAVOLTA, E., HAAG, H.P., MELLO, F.A.F. and BRASIL SOBR°, M.O.C.: On the mineral nutrition of some tropical crops. Int. Potash Inst., Bern, 1962
178. MANCIOT, R., OLLAGNIER, M. and OCHS, R.: Mineral nutrition and fertilization of the coconut around the world. Oléagineux *34*, 499–515, 563–580 (1979)
179. MANDAL, A.K. and DOHAREY, A.K.: Jute Agricultural Research Institute – Work done on crop production and fertiliser use. Fert. News *23* (9), 57–64 (1978)
180. MAPLES, R. and KEOGH, J.L.: Fertilization of cotton with potassium, magnesium, and sulfur on certain delta soils: Alfisols formed from Mississippi river valley alluvium. Agric. Exp. Stat., Univ. Arkansas, Bull. 787, 1974

181. MAPPES, F.: Der einjährige Erdbeerbau. Dt. Gartenbauwiss. *7*, 140 (1961)
182. MARABY, J.: Rape crops shows sulphur deficiency in France. Sulphur Inst. J. *4* (2), 2–4 (1968)
183. MARGATE, R.Z., MAGAT, S.S., ALFORJA, L.M. and HABANA, J.A.: A long-term KCl fertilization study of bearing coconuts in an inland-upland area of Davao (Philipp.). Oléagineux *34*, 235–240 (1979)
184. MARSCHNER, H. and KRAUSS, A.: Beziehung zwischen Kaliumgehalt und Qualität von Kartoffeln. Kartoffelbau *31*, 65–67 (1980)
185. MARTEL, Y.A. and ZIZKA, J.: Yield and quality of alfalfa as influenced by additions of S to P and K fertilizations under greenhouse conditions. Agron. J. *69*, 531–535 (1977)
186. MARTIN, W.E. and WALKER, T.E.: Sulfur requirements and fertilization of pasture and forage crops. Soil Sci. *101*, 248–257 (1966)
187. MASAEVA, M.: Zur Chlorophobie der Pflanzen. Bodenkd., Pfl.ernähr. *1*, 39–56 (1936)
188. MATZNER, F.: Der Einfluss einer Volldüngung mit Sulfaten und Chloriden auf Ertrag und Zusammensetzung der Erdbeersorten 'Dresden' und 'Sachsen'. Arch. Gartenbau *4*, 320–338 (1956)
189. MATZNER, F.: Einfluss steigender Stickstoffgaben auf die Frosthärte einjähriger Triebe der 'Schattenmorelle'. Gartenbauwiss. *39*, 225–240 (1974)
190. MATZNER, F. and MAURER, E.: Der Einfluss steigender Stickstoffgaben auf das Platzen von Früchten der 'Schattenmorelle'. Erwerbsobstbau *17*, 129–134 (1975)
191. MAUGÉ, J.P.: Effets d'un apport d'azote et de soufre sur pin maritime en ligniculture. FAO/IUFRO Symp. Internat. Fertilis. Forest., Paris, 1973
192. MAYS, D.A.: Forage fertilization. Symp. Muscle Shoals, Alab., 19.–21. 7. 72. Amer. Soc. Agron., 1974
193. MCCORMICK, R.W. and WOLF, D.C.: Effect of sodium chloride on CO_2 evolution, ammonification, and nitrification in a sassafras sandy loam. Soil Biol. Biochem. *12*, 153–157 (1980)
194. MCDOLE, R.E.: Potassium fertilizer trials with potatoes on coarse-textured soils in Southeastern Idaho. Amer. Potato J. *55*, 161–170 (1978)
195. MCDOLE, R.E., STALLKNECHT, G.F., DWELLE, R.B. and PAVEK, J.J.: Response of four potato varieties to potassium fertilization in a seed growing area of Eastern Idaho. Amer. Potato J. *55*, 495–504 (1978)
196. MEIWES, K.-J., HEINRICHS, H. and KHANNA, P.K.: Schwefel in Waldböden Nordwest-Deutschlands und seine vegetationsabhängige Akkumulation. Pl. Soil *54*, 173–183 (1980)
197. MENEELY, G.R.: A review of sources of and the toxic effects of excess NaCl and the protective effect of extra K in the diet. Qual. Plant. Pl. Fds. hum. Nutr. *23* (1/3), 3–31 (1973)
198. MENGEL, K.: Das Kationen-Anionen-Gleichgewicht in Wurzeln, Stengel und Blatt von *Helianthus annuus* bei K-Chlorid- und K-Sulfat-Ernährung. Planta *65*, 358–368 (1965)
199. MENGEL, K. and KIRKBY, E.A.: Principles of plant nutrition. Int. Potash Inst., Bern, 1978
200. MERKLE, F.G. and KUNKLE, E.C.: Soluble salt content of greenhouse soils as a diagnostic aid. J. Amer. Soc. Agron. *36*, 10–19 (1944)
201. MIRANDA, E. RUY DE and MORAIS, F.D. DE O.: (Effect of the calcium, magnesium and potassium balance on cacao growth). Rvta. Theobroma *1* (3), 21–32 (1971)
202. MÜLLER, K.: Veränderungen wertgebender Inhaltsstoffe in der Kartoffelpflanze und -knolle im Verlauf von Vegetation und Lagerung, ihre Bedeutung für die Qualität der Knolle. Habil.schrift Univ. Göttingen 1974; Hefte f.d. Kartoffelb. No. 17, 1975
203. MÜLLER, K.: Chemisch und physiologisch bedingte Ursachen von Blaufleckigkeit, Rohbreiverfärbung und Kochdunkelung der Kartoffel. Kartoffelbau *30*, 404–407 (1979)
204. MÜLLER, K.: Kritische Anmerkungen zur Düngung der Kartoffel. Kartoffelbau *30*, 106–109 (1979)

205. MURARKA, I.P., JACKSON, T.L. and MOORE, D.P.: Effects of N, K, and Cl on nitrogen components of Russet Burbank potato plants *(Solanum tuberosum* L.*)*. Agron. J. *65*, 868–870 (1973)
206. MURPHY, H.J. and GOVEN, M.J.: The last decade in 38 years of potash studies for potato fertilizers in Maine. Amer. Potato J. *43*, 122–127 (1966)
207. NALIVAJKO, G.S.: (Effect of various potash fertilizers on the yield and quality of hop cones). Ref.: Hort. Abstr. *40*, Ref. 4637 (1970)
208. NELSON, L.B.: Changing patterns in fertilizer use. Proc. Symp., Chicago, 14.–15. 2. 68, Soil Sci. Soc. Amer. (1968)
209. NGONGI, A.G.N., HOWELER, R. and MCDONALD, H.A.: Effect of potassium and sulfur on growth, yield, and composition of cassava. Proc. 4th Symp. Int. Soc. Trop. Root Crops, Cali/Columbia, 1.–7. 8. 76; Internat. Devel. Res. Centre (Edit. COCK, J. *et al.*) Ottawa, 107–113, 1977
210. NIELSON, F.E., CARSON, R.B. and HOFFMAN, I.: A study of the ion interactions in the uptake of nitrogen, phosphorus, potassium, calcium, chlorine and sulfur by corn. Soil Sci. *95*, 315–321 (1963)
211. NIEMANN, J.: Ein Beitrag zur Ernährung der Gartenmöhre unter besonderer Berücksichtigung des Wasserhaushalts. Z. Pfl.ernähr., Düngg., Bodenkd. *7*, 19–33 (1955)
212. NURZYNSKI, J.: (The effect of chloride and sulphate of potassium on the quantify and quality of yields of some vegetable crops grown on garden peat). Ref.: Hort. Abstr. *48*, Ref. 1494 (1978)
213. OBIGBESAN, G.O., AGBOOLA, A.A. and FAYEMI, A.A.A.: Effect of potassium on tuber yield and nutrient uptake of yams. Proc. 4th Symp. Int. Soc. Trop. Root Crops, Cali/Columbia, 1.–7. 8. 76; Internat. Devel. Res. Centre (Edit. COCK, J. *et al.*) Ottawa, 104–107, 1977
214. OGUIS, L.G., MAGAT, S.S. and MARGATE, R.Z.: The effect of chlorine sources and ammonium sulfate on the growth of coconut seedlings. Philip. J. Coco. Stud. *IV* (3), 25–38 (1979)
215. OLLAGNIER, M., OCHS, R. and DANIEL, C.: The chlorine nutrition of oil palm and coconut application to fertilization. Inst. Rech. Huiles Oléagineux, Paris, Doc. No. 1297, 1976
216. OPITZ, K. and RATHSACK, K.H.: Untersuchungen über Kalidüngung der Leguminosen. Ernährung d. Pfl. *28*, 229–239, 249–256 (1932)
217. OPITZ VON BOBERFELD, W.: Sachgerechte Grünlanddüngung. Kali-Briefe (Büntehof), Fachgeb. 4, 4. Folge (1976)
218. OPITZ VON BOBERFELD, W.: Auswirkungen verschiedener K-Salze auf einige Eigenschaften des Aufwuchses und des Bodens in Abhängigkeit vom K- und N-Aufwand bei Mähweiden. Z. Acker- u. Pfl.bau *149*, 58–74 (1980)
219. OSCHATZ, H.: Recent findings and experiences with the fertilizer treatment of the banana. Green Bull. No. 14, Verlagsges. Ackerbau, Hannover, 1962
220. OTT, M.: Über den Gehalt von Feld- und Gartenfrüchten an Vitamin C und Karotin bei verschiedener Düngung. Angew. Chem. *50*, 75–77 (1937)
221. PAL, N.L., BANGARAYA, M. and NARASIMHMURTY, J.C.: Interrelation of potassium and chlorine supply on the burn of flue-cured tobacco. Soil Sci. *102*, 346–352 (1966)
222. PAPP, J.: NPK status in raspberry, KCl and K_2SO_4. Comparative fertilization test in sand culture. Comptes-Rendus 3e Colloq. Europ. Mediterr. Budapest, 4.–7. 9. 72; Akadémiai Kiadó, Budapest, Vol. II, 957–963, 1975
223. PENNINGSFELD, F.: Die Ernährung im Blumen- und Zierpflanzenbau. Ihr Einfluss auf Wuchsbild, Nährstoffaufnahme, Ertragshöhe und Qualität. Parey Verl., Hamburg, 2. Aufl., 1962
224. PENNINGSFELD, F.: Düngungsversuche mit Baumschulgehölzen. Gartenwelt *64*, 450–452 (1964)

225. PESCHUTTER, G.: Der Einfluss von Ernährung und Witterung auf den Ertrag und den Gehalt an ätherischem Öl bei Porree. Diss., Univ. München, Landw. Fak., 1948
226. PETTERSON, L.A. and TIBBITTSS, T.W.: Chemical composition of tobacco in relation to leaf burn and quality. Agron. J. *55*, 114–117 (1963)
227. PETTINGER, N.A.: Effect of fertilizers on the chlorine content of the sap of corn plants. J. agric. Res. *44*, 919–931 (1932)
228. POLETSCHNY, H. and KICK, H.: Der Einfluss verschiedener Kaliformen und -mengen auf die Mineralstoffgehalte in Kartoffellaub und Kartoffeln sowie auf die Chipsqualität. Landw. Forsch., Sdh. *35*, 586–593 (1979)
229. PRÉVOT, P. and OLLAGNIER, M.: Sulfur deficiency of peanuts in Africa. Agrochimica *8*, 211–221 (1964)
230. PRIKHOD'KO, L.S., KLYSHEV, L.K. and DARDYKINA, O,N.: (Durch Salze hervorgerufene Veränderungen der Peptidzusammensetzung von Erbsenwurzeln). Ref.: Ldw. Zentralbl. II, *24* (1), Ref. 222 (1979)
231. PROTASHCHIK, P.N. and DMITRIEVA, Z.A.: (Effect of fertilizers on yield and quality of table potatoes). Ref.: Fld. Crop Abstr. *30*, Ref. 2884 (1977)
232. PRUDENTE, R.L. and MENDOZA, A.M.R.: The effect of NPK fertilizers on coconut from transplanting to full bearing. Potash Rev. (IPI), Subj. 27, 88th suite (1979)
233. PRUMMEL, J.: Kalibemesting bij aardappelen. Stikstof, No. 11, 367–371 (1956)
234. PUTZ, B., ROEBERS, F. and WETZOLD, P.: Veredlung der Kartoffel – Ein Neubeginn. Landw. Schriftenreihe 'Boden u. Pflanze', Parey-Verl., Hamburg, Heft 17, 1976
235. PUMPHREY, F.V. and MOORE, D.P.: S and N content of alfalfa herbage during growth. Agron. J. *57*, 237–239 (1965)
236. QUELLETTE, G. and GLANDER, H.: Potash fertilization of the potato. Potash Rev. (IPI), Subj. 11, 19th suite (1964)
237. RADER, L.F., WHITE, L.M. and WHITTAKER, C.S.: The salt index – A measure of the effect of fertilizers on the concentration of the soil solution. Soil Sci. *55*, 201–218 (1943)
238. RADET, E.: La fumure du colza. La Potasse (SCPA Mulhouse), No. 217, 129–132 (1954)
239. RATHJE, W.: Zur Physiologie des Chlors. Z. Pfl.ernähr., Düngg., Bodenkd. *57*, 163–168 (1952)
240. RAY, B.K.: Observation of potassium in tea. Assam Rev. a. Tea News *68* (4), 15–16 (1979)
241. ROLLIER, M. and FERRIF, J.P.: Le colza et le soufre. Oléagineux *24*, 491–496 (1969)
242. ROWBERRY, R.G., SHERRELL, C.G. and JOHNSTON, G.R.: Influence of rates of fertilizer and source of K on the yield, specific gravity and cooking quality of Katahdin potatoes. Amer. Potato J. *40*, 177–181 (1963)
243. ROWBERYY, R.G. and KETCHESON, J.W.: Source of potassium in potato fertilizer and times of application. Canad. J. Plant Sci. *58*, 779–782 (1978)
244. RUBIN, S.S.: Langfristige Düngungsversuche in Obstanlagen. Arch. Gartenbau *24*, 69–106 (1976)
245. RUGE, U.: Physiologische Schäden durch Umweltfaktoren. 5. Auftausalze. In: MEYER, F.H. *et al.*: Bäume in der Stadt. Ulmer-Verl., Stuttgart, 152–181, 1978
246. RUSSEL, G.E.: Some effects of applied sodium and potassium chloride on yellow rust in winter wheat. Ann. appl. Biol. *90*, 163–168 (1978)
247. SAALBACH, E.: The influence of sulphur on the yield of forage crops in West Germany. Sulphur Inst. J. *1* (2), 7–9 (1965–66)
248. SABOURIN, L. and BONNET, R.: A chloride-sulphate comparison in the potassium manuring of tobacco. Potash Rev. (IPI), Subj. 12, 16th suite (1967)
249. SADAPHAL, M.N.: A note on evaluation of potassic fertilizers: 1. Effect of sources and rates of potassic fertilizers on radish (Japanese white). Indian J. Agron. *18*, 88–89 (1973)
250. SAHULKA, J.: (The effect of chloride on nitrate reductase level, on anaerobic nitrite production, and on nitrate content in excised *Pisum sativum* L. roots). Ref.: Ldw. Zentralbl. II, *24* (4), Ref. 243 (1979)

251. SAMUELS, G. and GANDIA DIAZ, H.: Effects of potassium chloride and sulfate on pineapple yields and quality. J. Agric. Univ. Puerto Rico *44*, 16–20 (1960)

252. SAN VALENTIN, G.O., ROBERTSON, W.K., JOHNSON, J.T. and WEEKS, W.W.: Effect of slow release fertilizer on yield and composition of flue-cured tobacco and fertilizer residues. Agron. J. *70*, 345–348 (1978)

252a. SCHÄFER, P.: The manuring of pulses. Green Bull. No. 20, Verlagsges. Ackerbau, Hannover, 1967

253. SCHARRER, K. and BÜRKE, R.: Der Einfluss der Ernährung auf die Provitamin-A-(Carotin)-Bildung in landwirtschaftlichen Nutzpflanzen. Z. Pfl.ernähr., Düngg., Bodenkd. *62*, 244–262 (1953)

254. SCHEFFER, P. and SCHACHTSCHABEL, P.: Lehrbuch der Bodenkunde. Enke-Verl., Stuttgart, 10. Aufl., 1979

255. SCHILLING, R. and HIRSCH, P.-J.: Chlorine nutrition of peanuts in Senegal. Oléagineux *29*, 85–90 (1974)

256. SCHMALFUSS, K. and REINICKE, J.: Über die Wirkung gestaffelter K-Gaben als KCl und K_2SO_4 auf Ertrag und Gehalt an Wasser, N-Verbindungen, K, Cl und S-Fraktionen von Spinatpflanzen im Gefässversuch. Z. Pfl.ernähr., Düngg., Bodenkd. *91*, 21–29 (1960)

257. SCHMALFUSS, K.: Zur Kenntnis der Schwefelernährung der Pflanze. Z.Pfl.ernähr., Düngg., Bodenkd. *105*, 116–127 (1964)

258. SCHMALFUSS, K. and SCHULZE, W.: Untersuchungen über Inhaltsstoffe (Carotin, Vitamine) von Pflanzen unter dem Einfluss verschiedener Mineraldüngung an Hand von Gefäss- und Felddüngungsversuchen. Besondere Berücksichtigung der L-Ascorbinsäure. Ref.: Ldw. Zentralbl. II, *13* (9), Ref. 345 (1968)

259. SCHMITT, L. and BRAUER, A.: 75 Jahre Darmstädter Wiesendüngungsversuche. Sauerländer Verl., Frankfurt, 1979

260. SCHNEIDER, C.B.H.: Beregning in de landbouw en de kwaliteit van het water. Bedrijfsontw. *6*, 375–380 (1975)

261. SCHÖNNAMSGRUBER, H.: Neuere Untersuchungen über die Kalidüngung von Pappeln in Holland. Allg. Forstz. *20* (16/17), (1965)

262. SCHREIBER, R.: Über die Wirkung des Magnesiums auf den Ertrag und die Nährstoffaufnahme von K_2O und MgO bei den Getreidearten. Z. Pfl.ernähr., Düngg., Bodenkd. *48*, 37–64 (1950)

263. SCHULTE-KELLINGHAUS, W.: The manuring of apples and pears. Green Bull. No. 11, Verlagsges. Ackerbau, Hannover, 1960

264. SCHUPHAN, W.: Über den Einfluss der Chlorid- und Sulfatdüngung auf Ertrag, Marktgängigkeit und biologischen Wert verschiedener Gemüse unter Berücksichtigung edaphischer und klimatischer Faktoren. Bodenkd., Pfl.ernähr. *19*, 265–315 (1940)

265. SCHUPHAN, W.: Der Einfluss des Kaliums auf die Qualität der Nahrungspflanzen unter besonderer Berücksichtigung des biologischen Wertes. Proc. 3rd Congr. Int. Potash Inst., London, 155–178 (1956)

266. SEITZ, P.: Zur Düngung der Spargelanlagen. Bad. Obst- u. Gartenbauer, 277–278 (1963)

267. SHARMA, R.C., SINGH, M. and SUD, K.C.: Relative response of the potato to three sources of potassium. Indian J. Agron. *21*, 341–348 (1976)

268. SHELDON, V.L., BLUE, W.G. and ALBRECHT, W.A.: Biosynthesis of amino acids according to soil fertility. II. Methionine content of plants and the sulfur applied. Pl. Soil *3*, 361–365 (1951)

269. SHEORAN, I.S. and GARG, O.P.: Effect of salinity on the activities of RNase, DNase and protease during germination and early seedling growth of mung bean. Physiologia Pl. *44*, 171–174 (1978)

270. SHUGLYA, N.V., SHUGLYA, Z.M. and BABUL', A.A.: (Effect of forms of potassium fertilizer on yield and quality of potatoes). Ref.: Fld. Crop Abstr. *27*, Ref. 5841 (1974)

271. SIEGEL, O. and BJARSCH, H.-J.: Über die Wirkung von Chlorid- und Sulfationen auf den Stoffwechsel von Tomaten, Sellerie und Reben. I. Der Einfluss auf den Gehalt an Chlorophyll a und b, Xanthophyll und Karotin. II. Der Einfluss auf die Trockensubstanz- und Kohlenhydratbildung sowie den Ascorbinsäuregehalt. III. Der Einfluss auf die freien Aminosäuren sowie auf die Zusammensetzung des Eiweisses. Gartenbauwiss. *27*, 15–26, 103–118, 437–446 (1962)
272. SINGH, C. and JACOBSON, L.: The accumulation and transport of calcium in barley roots. Physiologia Pl. *45*, 443–447 (1979)
273. SINGH, M., NARWAL, R.P. and SINGH, J.P.: Effect of selenium and sulfur compounds on the growth and chemical composition of forage cowpea. J. Indian Soc. Soil Sci. *27*, 65–69 (1979)
274. SITHANANTHAM, S. and SRINIVASAN, T.R.: Sources of potassium in foliar spray with endrins influencing the quality and yield of sugarcane. Indian Sugar *23*, 329–333 (1973)
275. SIVANADYAN, K.: Lysimeter studies on the efficiency of some potassium and nitrogenous fertilizers on two common soils in West Malaysia. Proc. 2nd Asian Soil Conf., 17.–29.7.72, Djakarta, 1972
276. SMITH, D.: Levels and sources of potassium for alfalfa as influenced by temperature. Agron. J. *63*, 497–500 (1971)
277. SMITH, D.: Effect of K top dressing a low fertility silt loam soil on alfalfa herbage yields and composition and on soil K values. Agron. J. *67*, 60–64 (1975)
278. SMITH, D.E. and WARREN, G.F.: Studies of soluble salts in greenhouse soils. Proc. Amer. Soc. hort. Sci. *70*, 501–511 (1957)
279. SORENSEN, R.C., PENAS, E.J. and ALEXANDER, U.U.: Sulfur content and yield of alfalfa in relation to plant nitrogen and sulfur fertilization. Agron. J. *60*, 20–22 (1968)
280. SOUTHERN, P.J.: S deficiency in coconut. Oléagineux *24*, 211–220 (1969)
281. STANFORD, G. and JORDAN, H.V.: Sulfur requirements of sugar, fiber and oil crops. Soil Sci. *101*, 258–266 (1966)
282. STARKEY, R.L.: Oxidation and reduction of sulfur compounds in soils. Soil Sci. *101*, 297–306 (1966)
283. STASSEN, J.G.H.: Fruitbemestingsproef met kali op zware rivierklei te Nederhemert. Kali (NKIM Amsterdam) *4*, 197–200 (1958)
284. STRAUCH, A.: Die Kali-Düngungsversuche Eglofs-Osterwald und Bodenwöhr. Bericht über die bisherigen ertragskundlichen Ergebnisse. Dipl.-Arb. Fachber. Forstwiss., Univ. München, 1978
285. STRICKER, H.W.: Zur mineralischen Düngung im Zuckerrübenbau bei Verwendung von Monogermsaatgut. Kali-Briefe (Büntehof), Fachgeb. 8, 4. Folge (1962)
286. STRICKER, H.W.: Über die Bedeutung der Kaliform in der Pflanzguterzeugung unter besonderer Berücksichtigung der Frührodung. Kali-Briefe (Büntehof), Fachgeb. 10, 1. Folge (1963)
287. STRICKER, H.W.: Zusammenhänge zwischen der Düngung und dem Verarbeitungswert von Kartoffeln unter besonderer Berücksichtigung des Qualitätsmerkmales 'reduzierender Zucker'. Landw. Forsch., Sdh. 26/II, 11–20 (1971)
288. STURM, H.: Untersuchungen über das Auftreten von echtem Mehltau an Kleearten bei verschiedenen Umweltverhältnissen. Z. Acker- u. Pfl.bau *107*, 203–240 (1959)
289. SU, N.R.: Response of pineapples to potash in Taiwan. Soils Fertil. Taiwan, 29–38 (1958–59)
290. SU, N.R. and LI, C.Y.: Comparison of two potassium salts as regards their effects on yield and quality of pineapple fruits. Soils Fertil. Taiwan, 82–83 (1962)
291. SUCOFF, E. and HONG, S.G.: Effect of NaCl on cold hardiness of *Malus spp.* und *Syringa vulgaris*. Canad. J. Bot. *54*, 2816–2819 (1976)
292. SUGIHARA, S., ISHII, K. and SASAKI, K.: (Effect of chloride fertilizers on pasture soils). Ref.: Fertil. Abstr. *9*, Ref. 1869 (1976)

293. SUMBAK, J.H. and BEST, E.: Fertilizer response with coconuts in coastal Papua. 4th Sess. FAO Techn. Work. Party Coconut Prod., Protect., Process., 14.–29. 9. 75, Kingston. FAO-Doc. No. 30002, 1975
294. SYS, C.: The pedology of rubber. FAO World Soil Resources Rep., No. 45, 59–79, 1975
295. SZLACHETKA, W.: (Die Wirkung der Dünger Kaliumchlorid und Kaliumsulfat auf den Ertrag von Tulpenzwiebeln der Sorte 'Apeldoorn'). Ref.: Ldw. Zentralbl. II, *23* (6), Ref. 591 (1978)
296. TAY, T.H.: Comparative study of different types of fertilizer as sources of nitrogen, phosphorus and potassium in pineapple cultivation. Trop. Agric. *49*, 51–59 (1972)
297. TAY, T.H.: Effect of potassium and magnesium application on the yield and quality of pineapple. MARDI Res. Bull. *2*, 43–45 (1974)
298. TAY, T.H.: Effects of nitrogen and potassium on the growth, mean fruit weight and fruit quality of pineapple. MARDI Res. Bull. *3*, 1–14 (1975)
299. TEISSON, C., LACOEUILHE, J.J. and COMBRES, J.C.: Le brunissement interne de l'ananas. V. Recherches des moyens de lutte. Fruits d'outre-mer *34*, 399–415 (1979)
300. TEIWES, G.: Nutrition and manuring of coconut palms. Green Bull. No. 15, Verlagsges. Ackerbau, Hannover, 1962
301. TEIWES, G. and GRÜNEBERG, F.: Science and practice in the manuring of pineapples. Green Bull. No. 3, Verlagsges. Ackerbau, Hannover, 1963
302. TERMAN, G.L.: Atmospheric sulphur – the agronomic aspects. Techn. Bull. Sulphur Inst., No. 23, 1–15 (1978)
303. THEMLITZ, R.: Einfluss sulfatischer und chloridischer Kalium- und Magnesiumsalze auf das Wachstum und die Nährstoffaufnahme junger Fichten. Kali-Briefe (Büntehof), Fachgeb. 6, 5. Folge (1961)
304. TISDALE, S.L.: Sulphur in forage quality and ruminant nutrition. Techn. Bull. Sulphur Inst., No. 22, 1977
305. TOBLER, F.: Die Düngerwirkung einzelner anorganischer Stoffe auf die Faserpflanzen. Faserforschg. *10*, 10–20 (1932/33)
306. TRILLMICH, H.-D. and UEBEL, E.: Zum Einfluss der Düngung auf Ernährung und Wachstum der Roteiche auf verschiedenen Sandstandorten. Beitr. Kalidüngg. Land-, Forstwirtsch. (VEB Kali, DDR) *3* (1), 19–28 (1979)
307. TSAI, C.F. and LIN, J.Y.: (Effects of sulphate supply on ionic elements content and their cation-anion equilibrium in flue-cured tobacco). Ref.: Fld. Crop Abstr. *25*, Ref. 927 (1972)
308. UEBEL, E.: Einfluss unterschiedlicher Kalidüngermengen und -formen auf Ertrag und ökonomisches Ergebnis 5jähriger Feldgemüsefruchtfolgen in der CSSR. Beitr. Kalidüngg. Landw.-, Forstwirtsch. (VEB Kali, DDR) *3*, 1–11 (1979)
309. UEXKÜLL, H.R. VON and KÄMPFER, M.: Science and practice in the manuring of citrus. Green Bull. No. 1, Verlagsges. Ackerbau, Hannover, 1966
310. UEXKÜLL, H.R. VON: Response of coconuts to (potassium) chloride in the Philippines. Oléagineux *27* (1), 13–19 (1972)
311. ULONSKA, E.: Neuere Erkenntnisse über Braugersteanbau. Kali-Briefe (Büntehof), Fachgeb. 11, 1. Folge (1966)
312. UNGER, J.: Zur Salztoleranz landwirtschaftlicher Nutzpflanzen. Beitr. trop. Landw., Veterinärmedizin *12*, 17–32 (1974)
313. VENEMA, K.C.W.: Some notes regarding the cultivation and fertilization of matting grass *(Juncus effusus* L. var. *decipiens* F.B.*)*. Potash a. Trop. agric. *2* (2), (1959)
314. VENEMA, K.C.W.: The importance of the sulphate anion in the fertilizer treatment of oil palms *(Elaeis guineensis)*. Potash Rev. (IPI), Subj. 27, 27th suite (1959)
315. VENEMA, K.C.W.: Some notes regarding the function of the sulphate-anion in the metabolism of oil producing plants, especially oil palms. Potash a. Trop. agric. *5* (3) and (4), (1962); *6* (1) and (2), (1963)

316. Vlasyuk, P.A.: (The effect of various forms of potassium fertilizers on the phosphorus and protein metabolism of plants). Ref.: Soils Fertil. *18*, Ref. 1297 (1955)
317. Vlasyuk, P.A. and Klimovitskaya, Z.M.: (The effect of various forms of potassium fertilizers on the oxidation-reduction properties and the yield of plants). Ref.: Soils Fertil. *18*, Ref. 2227 (1955)
318. Volynskaya, U.M.: (The effect of various forms of potash fertilizers on the seed yield and the quality of fodder lupin). Ref.: Soils Fertil. *22*, Ref. 899 (1959)
319. Vries, J.S. de: Proef met verschielende kaligiften en zes kalimeststoffen op suikerbieten. Kali (NKIM Amsterdam) *35*, 175–178 (1958)
320. Walker, D.R. and Bentley, C.F.: Sulphur fractions of legumes as indicators of sulphur deficiency. Canad. J. Soil Sci. *41*, 164–168 (1961)
321. Walker, T.W.: Sulphur responses on pastures. Proc. 9th Conf. New Zealand Grassl. Assoc., 117–124, 1957
322. Walker, T.W. and Adams, A.F.R.: Competition for sulphur in a grass clover association. Pl. Soil *9*, 353–366 (1958)
323. Wang, C.H.: Sulphur fertilization of rice – diagnostic techniques. Sulphur in Agric. *2*, 13–16 (1978); *3*, 12–15/18 (1979)
324. Wegener, J., Ziegler, G. and Sternkopf, G.: 1. Untersuchungen zur Schwarzfleckigkeit von Kartoffelknollen in Abhängigkeit von Stickstoff-, Stallmist- und Kalidüngung sowie Zusatzberegnung und Reifegrad der Knollen. 2. Über Zusammenhänge der Schwarzfleckigkeit von Kartoffelknollen mit dem Trockenmassegehalt und den Inhaltsstoffkonzentrationen sowie mit der Düngung. Arch. Acker-, Pfl.bau, Bodenkd. *23*, 297–303, 305 – 314 (1979)
325. Welte, E. and Dianati, M.: Untersuchungen über die Verlagerung von Chlorid und Sulfat in verschiedenen Böden mit Hilfe der Radioisotope ^{36}Cl und ^{35}S. Kali-Briefe (Büntehof) *14*, 791–808 (1979)
326. Werkhoven, J.: The manuring of the oilpalm. Green Bull. No. 18, Verlagsges. Ackerbau, Hannover, 1965
327. Wilcox, G.: Effect of chloride and sulphate sources and rates of potassium on potato growth and tuber quality. Amer. Potato J. *38*, 215–220 (1961)
328. Willigen, A.H.A. de: Viskositeit van aardappelmeel en de bemesting van de aardappel. Kali (NKIM Amsterdam) *4* (33), 91–96 (1957)
329. Witt, J.: Wirkung inverser K/Na-Relationen bei hoher K + Na-Gesamtkonzentration auf Mineralstoffwechsel sowie auf Saccharose und Stärkesynthese und unterschiedlich salztoleranter Pflanzenarten. Diss. Techn. Univ. Berlin, Inst. f. Nutzpfl.forschg., 1978
330. Wutscher, H.K. and Hardesty, C.A.: Ammonium, nitrite, and nitrate nitrogen levels in the soil under blight-affected and healthy citrus trees. Commun. Soil Sci. Pl. Analysis *10*, 1495–1503 (1979)
331. Younts, S.E. and Musgrave, R.B.: Growth, maturity and yield of corn as affected by Cl in K fertilizer. Agron. J. *50*, 423–426 (1958)
332. Zehler, E. and Forster, H.: Yield potential of tomatoes in relation to potassium nutrition. Potash Rev. (IPI), Subj. 8, 22nd suite (1972)
333. Ziegler, G.: P-K-Düngung nach Verwertungsrichtungen in der Kartoffelproduktion. Feldwirtschaft *9*, 363–365 (1968)
334. Ziegler, G.: Zur Chloridempfindlichkeit der Kartoffel unter Feldbedingungen bei hohem N-Angebot. Thaer-Arch. *13*, 985–1000 (1969)
335. Zuk, L.J. and Gupalo, P.I.: Einfluss der Mineraldünger auf die Speisequalität der Kartoffel. Agrohimija (Moscow), No. 9, 81–86 (1970)

336. *Association Française pour l'Etude du Sol/Sulphur Institute (London):* Symposium international sur le soufre en agriculture. Versailles, 1970. Ann. Agron., No. hors série (1972)
337. *Association des Ingénieurs Agronomes de la Suisse romande:* La fumure de la vigne. Normes pour la Suisse romande. Revue Suisse Vitic. Arboric. *II*, 127–131 (1970)
338. *British Sulphur Corporation (London):* World potassium sulphate supply – an overview. Phosphorus a. Potassium, No. 106, 24–25+28 (1980)
339. *Centro Internacional de Agricultura Tropical (CIAT), Cali/Colombia:* Cassava: Soils. Ann. Rep., 92–94 (1974)

International Potash Institute, Bern (Congresses and Colloquia since 1963):

340. Potassium and the quality of agricultural products.
Proc. 8th Congr. Brussels (1966)
341. Role of fertilization in the intensification of agricultural production.
Proc. 9th Congr. Antibes (1970)
342. Potassium research and agricultural production.
Proc. 10th Congr. Budapest (1974)
343. Potassium research – Review and trends.
Proc. 11th Congr. Bern (1978)
344. Potassium in relation to grassland production.
Proc. 1st Coll. Wexford (1963)
345. Das Kalium und die Qualität landwirtschaftlicher Produkte: Grünfutter, Stein- und Kernobst, Kartoffeln.
Proc. 2nd Coll. Murten (1964)
346. Le potassium et la qualité des produits agricoles: raisins de table et vins, olive et huile d'olive, tomates, liège.
Proc. 3rd Coll. Lisbon (1965)
347. Das Kalium und die Qualität landwirtschaftlicher Produkte: Weizen, Mais, Hopfen, Gerste.
Proc. 4th Coll. Belgrade (1965)
348. Forest fertilization.
Proc. 5th Coll. Jyväskylä (1967)
349. Fertilization of protected crops.
Proc. 6th Coll. Florence (1968)
350. Transition from extensive to intensive agriculture with fertilizers.
Proc. 7th Coll. Israel (1969)
351. Potassium in biochemistry and physiology.
Proc. 8th Coll. Uppsala (1971)
352. Potassium in soil.
Proc. 9th Coll. Landshut (1972)
353. Potassium in tropical crops and soils.
Proc. 10th Coll. Abidjan (1973)
354. Fertilizer use and protein production.
Proc. 11th Coll. Rønne-Bornholm (1975)
355. Fertilizer use and plant health.
Proc. 12th Coll. Izmir (1976)
356. Fertilizer use and production of carbohydrates and lipids.
Proc. 13th Coll. York (1977)
357. Soils in Mediterranean type climates and their yield potential.
Proc. 14th Coll. Seville (1979)

Sulphur Institute, Washington/London:

358. Sulphur, the essential plant nutrient, 1964
359. Sulphur and sulphates in blueberry culture.
Sulphur Inst. J. *1*, 20 (1965)
360. S in fertilizers in the EEC countries.
Proc. Symp., 16. 11. 73, Brussels (1973)
361. Marketing of S-containing fertilizers.
Proc. Symp., 3. 12. 74, Paris (1974)
362. The use of S-containing products in agriculture.
Proc. Symp., 17./18. 5. 78, Seville (1978)
363. Sulfur in the tropics.
Techn. Bull. IFDC, Muscle Shoals, Alab., T 12, 1979

364. *Victorias Milline Company/USA:*
Potash fertilization.
Exp. Stat. Bull. *2* (10), 7 (1960)