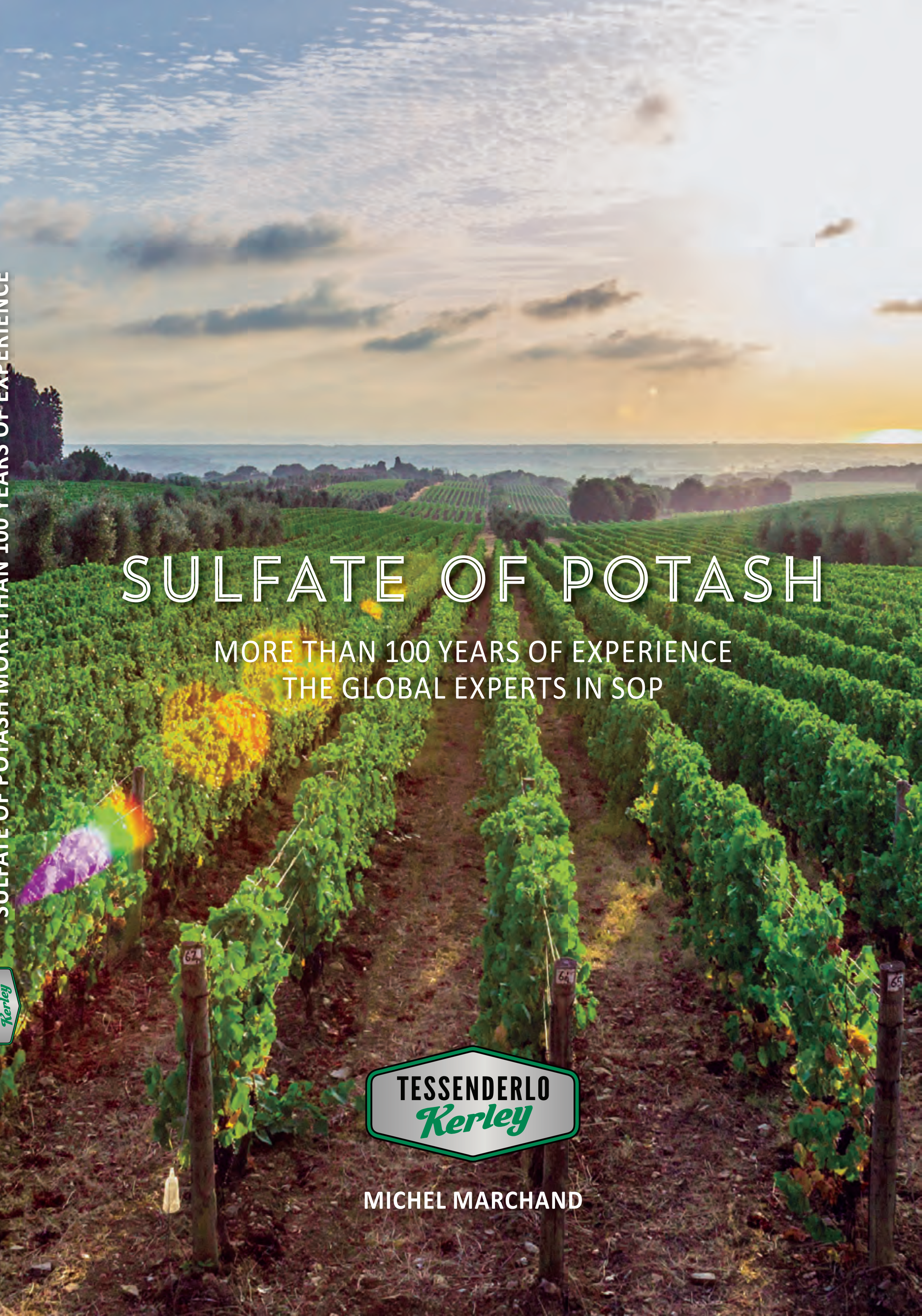

SULFATE OF POTASH

MORE THAN 100 YEARS OF EXPERIENCE
THE GLOBAL EXPERTS IN SOP

TESSENDERLO Kerley

MICHEL MARCHAND

FOREWORD

This book reflects more than 100 years of expertise in sulfate of potassium uses in agriculture, involving many agronomists and field technicians working for the Société Commerciale des Potasses et de L'Azote (SCPA) and later on for Tessenderlo Group.

The use of fertilizers seems to be easy and to be a part of the day-to-day farmer's job. This is ignoring that good agricultural practice in fertilizer use means to properly manage soil science, plant nutrition, plant physiology and application techniques. Farmers cannot be specialists in all these scopes; this is the reason why communication is essential to deliver a clear message for the benefit of a better productivity, a better quality and finally a better income for growers.

In the fertilizer world, potassium is sometimes called the "forgotten element" as its use is often neglected compared to nitrogen and phosphorus among the three main mineral elements. So the first step for a balanced fertilization is to make farmers aware of the benefit of potassium in combination with other elements. Talking about potassium sulfate, it must be kept in mind the reason why this potash source was produced: to have a potash fertilizer without chloride that can be used on chloride sensitive crops or in saline conditions. It is worth saying that those specific uses make the potassium sulfate market, a niche market, in which communication is even more difficult.

I hope that the information given in this book will contribute to a better knowledge in plant nutrition and will help deliver higher yields and better quality of agricultural production.

Michel Marchand
Senior Agronomist – Senior Technical Manager Fertilizers
Tessenderlo Kerley International, part of Tessenderlo Group

PREFACE

After 17 years with Tessenderlo Group promoting the agronomic benefits of SOP across the globe, Michel Marchand, our Senior Technical Manager SOP, is retiring.

Following many years of working in the sector, Michel has been the foundation of Tessenderlo Group's knowledge base for potash and SOP fertilization. Thanks to his extensive international experience in agricultural industries, Michel has been integral in terms of helping our team and customers build up a broad and comprehensive knowledge of agricultural science with specific expertise in fertilizers and especially plant nutrition. Nowadays, Michel is unquestionably one of the world's leading experts on potassium sulfate and he has expressed the wish that his legacy will be that of lasting knowledge and expertise within our group regarding SOP.

With this wish in mind, we are paying tribute to Michel's career by publishing this book that he has written. This book represents the culmination of more than 40 years of Michel working in agriculture.

We would like to thank Michel for his outstanding contribution to the agronomical development of Tessenderlo Kerley's products and customers over the years and we wish him all the best for his well-earned retirement.

Geert Gyselinck
BU Director
Tessenderlo Kerley International, part of Tessenderlo Group

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PART 1

BASICS OF PLANT NUTRITION

BASICS OF PLANT NUTRITION

Plants require nutrients for growth and for reproduction. Some elements are directly involved in the building of the plant while others are essential in plant metabolism. The organic elements are carbon (C), hydrogen (H) and oxygen (O). The mineral elements are divided into primary nutrients: nitrogen (N), phosphorus (P) and potassium (K); secondary nutrients: calcium (Ca), magnesium (Mg) and sulfur (S); and micronutrients: boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn).

Each nutrient is involved in essential functions:

- Carbon is the most important element in the plant, part of many molecules such as cellulose and starch. Carbon is fixed through photosynthesis from the carbon dioxide in the air. It forms the carbohydrates that store energy in the plant.
- Hydrogen is necessary for building sugars and building the plant. It is absorbed from air and liquid water.
- Oxygen is used for cellular respiration, which generates energy from the consumption of sugars made in photosynthesis, through ATP.
- Nitrogen is a component of all proteins, and as a part of DNA, it is essential for growth and reproduction.
- Phosphorus is important in plant bioenergetics. Part of ATP, phosphorus is needed for the conversion of light energy into chemical energy (ATP) during photosynthesis. It is also used to modify the activity of some enzymes by phosphorylation, and can affect cell signalling. This is why phosphorus is important for plant growth and flower formation.
- Potassium regulates water exchanges in the plant through the control of the opening and closing of the stomata. Potassium is also involved in translocation of mineral elements from the roots to the leaves and assimilates to fruits, tubers or any stocking organs.
- Calcium is a part of cell walls and cell membranes.
- Magnesium is a constituent of chlorophyll, a critical plant pigment involved in photosynthesis. It is important in the production of ATP through its role as an enzyme catalyst.
- Sulfur is an important component of amino acids and proteins.

- Micronutrients: Boron is necessary for cell division and synthesizing certain enzymes. Copper is important for photosynthesis. Iron is necessary for photosynthesis and is present as an enzyme cofactor in plants. Manganese is necessary for building the chloroplasts. Molybdenum is a cofactor to enzymes in building amino acids. Zinc is required in a large number of enzymes and plays an essential role in DNA transcription.

IMPORTANCE OF BALANCED FERTILIZATION

The discovery of the possibility to convert inert atmospheric nitrogen into ammonia in 1913, led to a considerable increase in nitrogen fertilizer production. The rapidly growing food demand, linked to an exploding global population, explains the development of nitrogen fertilizer consumption in agriculture. Apart from environmental issues, this massive use of nitrogen caused an imbalance with the other major and secondary elements, which did not follow the same rate of development.

The consequence is a change in the nutrient ratio, especially the N:K ratio. The N:K ratio of fertilizer use in developed countries decreased continuously from a fairly balanced ratio of 1:0.8 in the 60s and 70s to a current N:K ratio of 1:0.36 today. The N:K ratio for fertilizer use in developing countries has changed little and remains very wide at 1:0.23, ranging from 1:0.10 in the Middle East and North Africa, and 1:0.13 in South Asia to 1:0.22 in East Asia. An exception is South America with an N:K ratio of 1:0.96, because of the large area of soybean, which is very responsive to potash.

The very wide N:K ratio for fertilizer use for instance in Asia contrasts sharply with the N:K ratio in plants. Cereals take up N and K in almost equal amounts, root and tuber crops, leguminous crops and vegetables take up even more K than N. One consequence of the wide variation in the N:K ratio in fertilizer use is that the ratio of K input to K output has become highly unbalanced. The highly negative K balance indicates considerable mining of soil K reserves. In developed countries, there was up to the late 80s an increasing N balance, followed by a rather sharp decrease to currently around + 40 kg/ha N but the N balance is still positive.

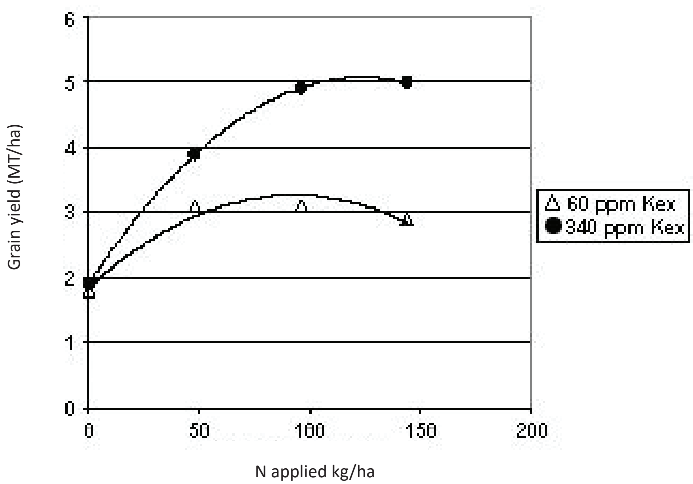
On the other hand, the K balance for Western Europe declined steadily from a rather comfortable surplus of almost 40 kg/ha K_2O to currently less than 10 kg/ha. Livestock farms still have a positive K balance due to the import of K in feed concentrates, whereas arable farms already have a negative K balance. The input/output balance of P is intermediate between that of N and K.

The consequence of the N:K imbalance can be summarized as followed:

- K is a highly versatile and mobile nutrient in plants.
- K is involved in all major physiological processes, from the assimilation and the transport of assimilate to its conversion into storage products such as sugar, starch, protein and oil/fats.
- K also plays a prominent role in the N metabolism.
- As a cation, K accompanies the nitrate anion as it is transported from the roots to the shoots where the nitrate is reduced to NH_3 to be incorporated into amino acids, the precursors of protein. K deficient plants have a repressed activity of the enzyme nitrate reductase.
- K accompanied by malate is then re-translocated from the shoots to the roots, where the K-malate is oxidized, yielding $KHCO_3$ which is exchanged for KNO_3, and the cycle continues.
- Plants inadequately supplied with K fail to transport nitrate efficiently into the shoots.
- This leads to nitrate reduction and accumulation of amino acids in the roots which signals, via a feedback effect, to the roots to shut down further nitrate uptake, despite the fact that nitrate might be present in the rooting zone (Marschner et al., 1996).
- Any surplus nitrate in the rooting zone of plants inadequately supplied with K is likely to be leached into the groundwater or lost to the atmosphere as NO_x gases.
- Accumulation of nitrate in K deficient plants leads to a reduced protein content.
- Furthermore, plants supplied with excessive N and/or inadequate K are more susceptible to pests and diseases and less resistant to soil-borne and climatic stress than plants with balanced nutrition, which also lowers the yield, and thus affects the fertilizer use efficiency.

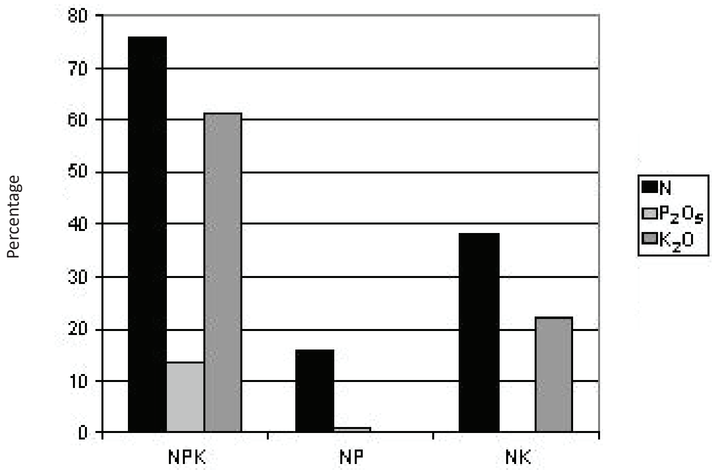
There are numerous results from field trials that demonstrate the beneficial effect of balanced fertilization on the efficiency of mineral fertilizers use as shown by the following examples.

- Effect of the K status of the soil on the efficiency of N fertilization: in a long-term field trial with spring barley, Johnston et al. (2001) demonstrated that the grain yield increased by more than 50 % with the same amount of N fertilizer only when the plants were grown on a soil well supplied with K (340 ppm Kex). The plants grown on the soil with inadequate exchangeable K (60 ppm Kex) were not able to accumulate enough K to meet the physiological demand of the plant. Similarly, barley cultivated on a soil poor in P (2 mg/kg Olsen-P) yielded only half of the crop, to that which was grown on a soil with 6 ppm P although receiving the same amount of N fertilizer.



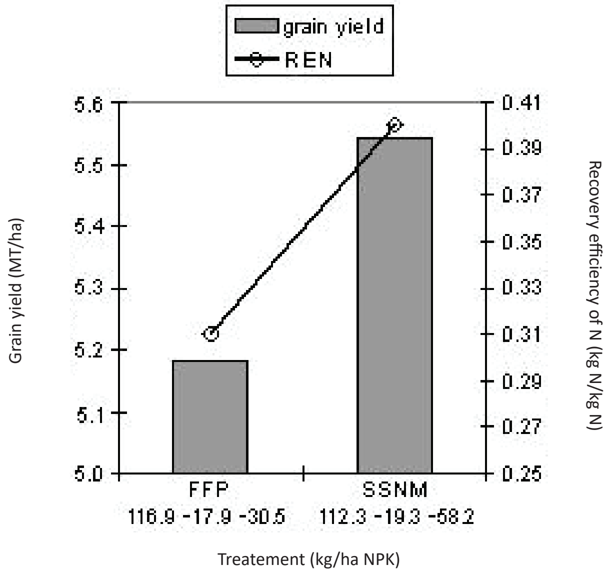
Effect of soil K status on the efficiency of N use by spring barley (Johnston et al., 2001)

- Nutrient recovery in maize on a degraded soil in SE Asia: Haerdter and Fairhurst (2003) showed that the recovery of N from fertilizers increased from 16 % with traditional NP fertilization to 76 % at balanced NPK supply. The better N recovery in the presence of adequate K (treatment NK) was due to the involvement of K in N metabolism. Also the recovery of P from fertilizers improved with balanced fertilization, namely from 1 % at NP to 13 % at NPK, and the recovery of K increased from 22 % at NK to 61 % at NPK fertilization. Addition of farm yard manure (FYM) had only a minor effect on the recovery of the nutrients.



Nutrient recovery in maize on a degraded soil in SE Asia (Haerdter & Fairhurst, 2003)

- Yield increase and better N fertilizer recovery in rice with balanced fertilization: in the multinational field trial program RTOP (Reaching Toward Optimal Productivity) for intensive rice systems organized by the International Rice Research Institute (IRRI), there are 179 farm sites in 7 countries. Rice grain yield was increased by 7 % by balanced fertilizer use although less N was applied. At the same time, the agronomic efficiency of N increased from 11.5 kg grain per kg N to 14.8 kg, and the recovery efficiency of rice from 31 % to 40 % (Dobermann et al., 2002).



Performance of site-specific nutrient management (SSNM) in comparison to farmers fertilizing practice (FFP) in irrigated rice in Asia (Dobermann et al., 2002)

To improve fertilizer use efficiency is essential and should be a common practice in farming. It not only helps to increase yield and income, it is also a major requirement to improve the image of farming. One of the quality criteria with which the consumer selects food at the market is whether the food is produced in environmentally acceptable ways. Another important aspect is that the agronomic and fertilizer community must be pro-ative in improving fertilizer use efficiency before harsh legislative measures are introduced, which can be to the detriment of the farmer's welfare as well as efficient food production.

All stakeholders should join efforts to search for better fertilizer use efficiency. There are many ways to achieve this goal: from better nutrient management, time-wise and quantity-wise, the balanced use of nutrients and the development and use of smart (or enhanced efficiency) fertilizers, which release the nutrients according to the demand of the plants.

POTASH FERTILIZATION

The roots of potash fertilization reach back to the beginning of the 19th century when Justus von Liebig discovered that plants need mineral elements such as nitrogen, phosphorus and potassium to build up biomass and that plant species require these nutrients in different proportions and quantities. He recognized that potassium is one of the essential nutrients for plants and is taken up in large quantities. Defined as the 'Law of the Minimum', the nutrient which is least available to the plant determines and limits its yield potential. One of the most limiting nutrients in crop production these days is potassium. The only available potassium source for agriculture previously was potash from industry and households giving this fertilizer its name.

But low availability restricted its use in agriculture forming one of the major constraints for crop production. The situation changed when the first potash deposits were discovered in Stassfurt providing new potassium sources for agriculture. Over the next four decades a rapid expansion of potash mining took place driven by a continuously rising demand from the agricultural sector.

Potash extraction from a mine

Potash mining was accompanied by extensive research, which was directly initiated in order to examine effects and crop response to potassium applications. Relatively early on the results revealed marked differences between potassium sources and their effects on crops.

In 1868, E. Heiden stated in his Manual of Fertilization: 'According to the present point of view the fertilizer salts containing potash in the sulfate form particularly merit the farmer's attention'.

The following decades have been characterized by intensive research on establishing proper potassium fertilization techniques and fundamental research on potassium functions in the soil and plants. Many private and governmental institutions such as the International Potash Institute and the Potassium and Phosphorus Institute were founded to carry out research and to facilitate the transition from research into practice through demonstration, education and agricultural promotion. Up until today the advantages and benefits of sulfate of potash on yield and quality, and its superiority in specific environmental and soil conditions, have been widely proven and demonstrated.

SULFATE OF POTASH - 100 YEARS OF EXPERIENCE

In sulfate of potash (SOP) the two essential nutrients potassium and sulfate form a 100 % nutrient carrier in a single fertilizer and represent the ideal combination for modern nutrient management systems.

Our knowledge relating to SOP has been generated over a period of more than one hundred years of fundamental research together with a series of national and international field experiments. Virtually free of chloride, all SOP based fertilizers form the optimal choice for agricultural and horticultural crops as both nutrients are water-soluble and meet the plant's requirements, with nutrients directly available and in the ideal form.

Its properties and beneficial effects in soil and plants make sulfate of potash the world's most important specialty potash fertilizer. The outstanding feature of SOP is the ideal combination of the two essential nutrients potassium and sulfur forming a highly concentrated fertilizer.

As both nutrients are soluble in water, SOP is considered as a quick acting fertilizer to prevent an undersupply of potassium and sulfur and to correct existing nutrient deficiencies in crops and imbalances in soils.

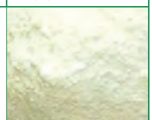
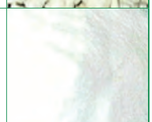
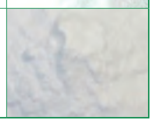
In the soil, sulfate of potash immediately dissociates into the cation K^+ and the anion SO_4^{2-} nutrient forms which are directly available to the plant.

Mannheim furnaces at Tessenderlo Kerley Ham plant

As no oxidation or reduction processes are involved to release these nutrients into the soil an application of SOP has no impact on soil pH. A light acidification is however observed around the roots.

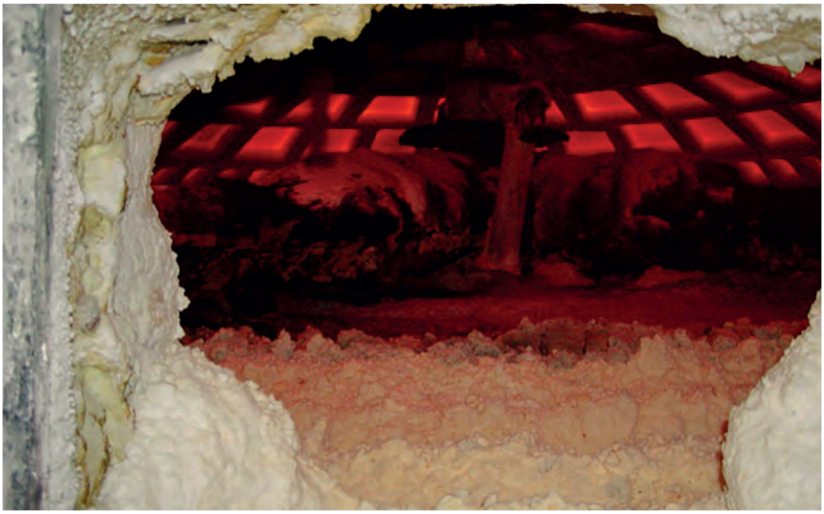
All grades and forms of SOP offered in the market have a minimal content of chloride which makes SOP the best source for chloride sensitive crops and intensive cropping systems. Grades of fine, standard or granulated SOP fertilizers are perfectly suited for mechanized spreading, bulk blending or straight application. Special grades of highly concentrated crystalline SOP for liquid formulations, foliar application and fertigation systems complete the product range offered worldwide.

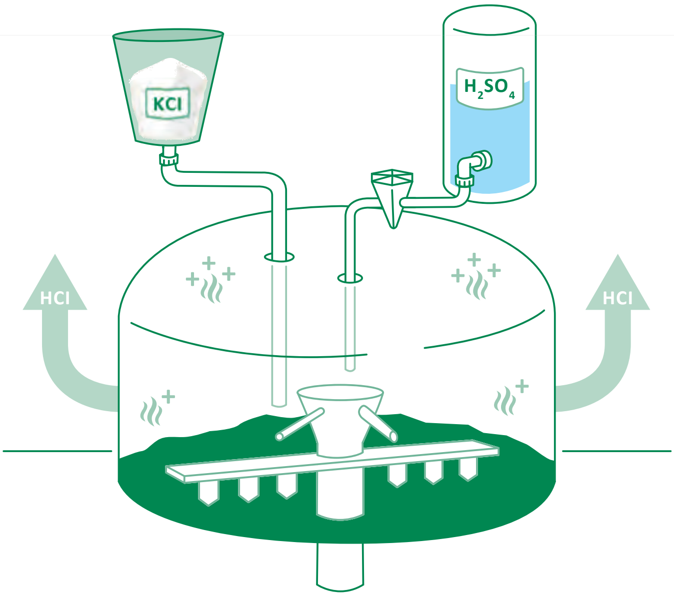
Tessenderlo Kerley's SOP production is based on the Manheim process, which is a chemical reaction between potassium chloride and sulfuric acid. This reaction takes place in a furnace at high temperature. Depending on the application method, the following speciality grades can be distinguished:

Name	K_2O	SO_4	Cl	Applications	Appearance
K50Potasse	50.4	52.6	2.1	For direct application or for use in the manufacture of compound fertilizers	
GranuPotasse	50.2	52.6	2.3	A dust-free granular form ideal for bulk blending or for direct application with an even distribution on the soil	
SoluPotasse	51.5	55.8	0.6	A fast dissolving highly soluble form for fertigation	
K-Leaf	52.0	55.8	0.2	A very fast dissolving, highly soluble form for foliar application	

The various different forms of SOP

Sulfate of potash from Tessenderlo Kerley is produced in Ham, Belgium. Potassium chloride reacts in the Mannheim furnace with pure sulfuric acid to yield potassium sulfate and hydrochloric acid. The reaction is endothermic and the temperature in the combustion chamber is brought to more than 800°C. Neutralization of the excess of acidity completes the reaction to produce standard and granular grades.





The Mannheim Furnace

The plant at Ham is part of the diversified chemical activities of Tessenderlo Group, which manufactures other products with the hydrochloric acid such as gelatine, ferric chloride for water treatment, calcium chloride, etc.

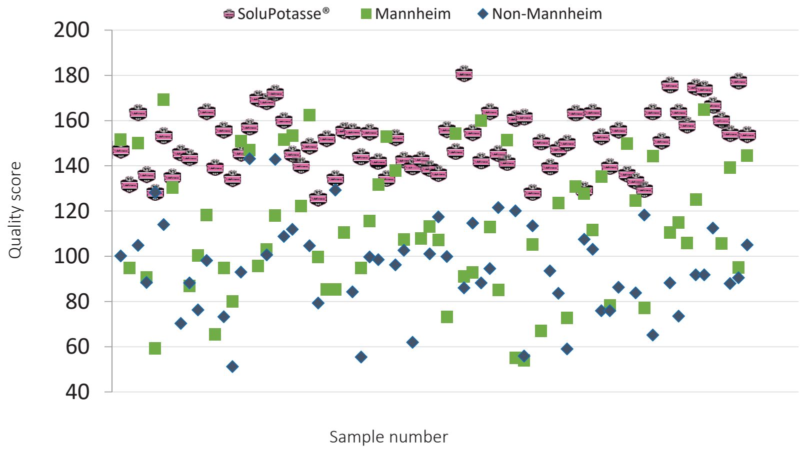
SOP production unit at Tessenderlo Kerley Ham, Belgium

THE TESSENDERLO KERLEY QUALITY

A leading producer of potassium sulfate, with one hundred years of experience, Tessenderlo Kerley uses the precise Mannheim process to deliver a full range of high grade SOP products to more than 100 countries worldwide. The production process at Ham is computer controlled and only the finest quality raw materials are used in the process. Sulfuric acid, which is one of the raw materials for our production, is even produced on site, ensuring a consistently high quality. The entire production and logistics at Ham are ISO certified and full environmental monitoring of production occurs on site, thus ensuring a safe and healthy environment both within and around the site.

Throughout the production process our in-house quality control lab monitors production continuously and checks batches prior to shipment based on several key criteria. For our best-in-class water soluble product, SoluPotasse®, besides chloride, potassium and moisture content, all parameters that may influence product solubility (insolubles, maximum solubility and speed of dissolution) are carefully measured. Consequently we can guarantee that our SoluPotasse is of a consistent top notch quality, as are all our other grades.

The control room for SOP production at Ham



Variation in quality of soluble SOP products found in the market

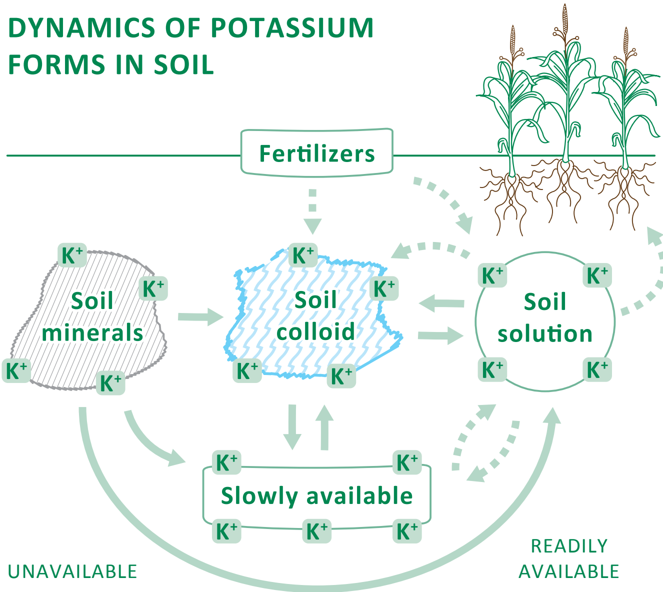
POTASSIUM IN SOIL

Potassium is present in relatively large quantities in soils, ranging between 0.5 and 2.5 %. However, in most cases only a small fraction of it is available to plants. Total K content is lower in coarse textured soils formed from sandstone or quartz minerals and higher in fine texture soils derived from parent material high in minerals containing K.

Potassium in the soil may be present in different chemical forms. As a soluble cation K^+, potassium is dissolved in the soil solution at concentrations that commonly range between 1 and 10 ppm. Under field conditions, soil solution K^+ varies considerably due to the effect of evaporation and precipitation. In normal soils, crop uptake of soil solution K^+ is affected by the presence of Ca^{2+} and Mg^{2+}.

K^+ in soil solution can be adsorbed by negatively charged clay and organic colloids that constitute the soil cation exchange capacity (CEC). Exchangeable K^+ and solution K^+ are in equilibrium and constitute the total plant available fraction of soil potassium. The kind and amount of other cations present, the concentration of anions and the properties of the soil cation exchange materials affect the distribution of K^+ between the soil CEC and the soil solution. In general, the greater the degree of Ca^{2+} saturation of the soil CEC, the greater is the adsorption of K^+ from the soil solution. The exchangeable K^+ role is to replenish soil solution K^+.

DYNAMICS OF POTASSIUM FORMS IN SOIL



The solution K^+ may be also be fixed by expandable clay minerals and rendered unavailable, at least during a growing season. However, K^+ fixed by expandable clays may become available over the years at a low rate of dissolution. The least available form of K is that contained in the mineral soil fraction. For all practical purposes soil minerals cannot supply potassium directly to growing crops.

The most commonly used laboratory test to estimate available soil K is to determine the K extracted from a soil sample by using a 1.0 M ammonium acetate solution at pH 7. Soil K values under 0.4 Cmol/kg (0.4 meq/100 g) are considered low and a response to fertilizer K is to be expected.

POTASSIUM AND PLANT PHYSIOLOGY

Potassium (K) is an essential element for all living organisms. In the plant tissue, the content of K is higher than that of other cations. A salient feature of K is the high rate at which it is taken up by the plant. Though it is not a constituent of organic compounds, it is universally present in the plant and very mobile.

On average, a plant is composed of 80 % water and 20 % dry matter. Dry matter is 30 % crude fibre, 12 % protein, 48 % nitrogen-free extracts, 4 % fat and 6 % ash of which 42 % is potassium.

Potassium is absorbed by roots and translocated inside the plant as the positive cation K^+. It is characterized by a high mobility at all levels inside the plant, in individual cells, tissues, and in long distance transport via the xylem and phloem, although no structural role of potassium has been found. This is in contrast to calcium and magnesium, which have important structural functions but only limited mobility in plants.

Control of plant water status is an important function of potassium. It promotes water absorption by the roots, keeps osmotic tension and turgor in cells and plant tissues and regulates the activity of stomata cells to prevent unnecessary water loss by transpiration.

Potassium has a role in photosynthesis and in the production and translocation of carbohydrate to areas of meristematic growth, fruit development and storage. The carbohydrate production and transport function are very important in vegetables and fruit production as it directly affects sugar and starch accumulation.

Early stages of potassium deficiency are only reflected in yield decreases. This stage of potassium deficiency is called “hidden hunger” as no specific symptoms appear in the plant. As the intensity of the deficiency increases, symptoms do appear, consisting of yellowing and eventual necrosis of the border in older leaves, beginning from the tip and progressing backward over the leaf. Because it is a mobile element, when potassium deficiency occurs, the element is transferred from old leaves to the young growing points. A slowdown of the growth rate is also observed at this level of potassium deficiency.

The main internal consequences of potassium deficiency are a general reduction of the strength of plant structures, loss of vigour, slow down of carbohydrate transport, and reduced resistance to low water availability as well as fungal diseases.

The physiological functions of potassium are of great practical significance in agriculture and horticulture:

- K makes plants more resistant to drought.
- K makes plants more resistant to frost.
- K makes plants more resistant to a number of diseases and pests.
- K is essential for the development of the root system.
- K increases the sugar content of crops such as fruits, carrots, onions, and sweet potatoes.
- K is most important for those crops where quality is of special concern (e.g. fruits, vegetables, ornamental plants).
- K increases the size of fruits.
- K improves the colour of fruits and flowers.
- K is essential for the efficient nitrogen fixation of the Rhizobium bacteria of leguminous crops (e.g. peas and beans).
- K improves the storage quality of fruits and vegetables.

SULFUR IN SOIL

Sulfur (S) content in soils is in the range of 0.02 - 0.2 %. The soil parent material is the first source of S, supplying metallic sulfides that are transformed to sulfate compounds in soils with no air restrictions. Plant and animal residues and soil organic matter are also important sources of soil S. An additional source of S is the SO_2 gas present in the atmosphere, produced by burning fossil fuels, wood or other organic fuels. Part of the atmospheric SO_2 is oxidized to the SO_4^{2-} or sulfate form and washed down to the soil by rainfall. The largest fraction of soil S is in organic compounds that are mineralized to SO_4^{2-}.

The SO_4^{2-} form is most abundant in well-drained soils, being the chemical form of S available to plants. The sulfide S^{2-} form predominates under anaerobic conditions. In waterlogged rice soils, SO_4^{2-} form is reduced into sulfide acid H_2S, which reacts with iron in the soil producing iron sulfide FeS that precipitates, preventing the H_2S toxicity to plants.

Inorganic S may be present in soils as SO_4^{2-} ions in the soil solution, as low solubility compounds of Fe and Al and as ions adsorbed to positively charged soil surfaces. Adsorption of negatively charged ions in soils depends on the type of soil, clay content, organic matter, pH and the presence of iron and aluminium hydroxides.

Organic S in soils may be present in the following forms:

- Free amino acids: small amounts of cysteine, cystine, methionine, cysteic acid and others.
- Organic sulfates: a high proportion as SO_4^{2-} linked to phenol radicals, choline, carbohydrates and lipids .
- Products derived from quinomas and amino acids containing S: a high proportion including part of the humus, all of them highly resistant to mineralization by microorganisms.

Sulfur mineralization is similar to that of nitrogen (N) as it depends on the carbon to sulfur ratio (C:S) in the substrate. Soil N mineralization takes place when the C:N ratio is 10-15:1.

When the C:S ratio is less than 200, mineralization of S from the organic matter takes place and the sulfate SO_4^{2-} ion is formed and accumulates in the soil whereas for C:S values of 400 or above all soil sulfate SO_4^{2-} is immobilized by the soil organic fraction. The level of SO_4^{2-} in the soil may be used to estimate S availability. A response to S fertilizers may be expected in soils with SO_4^{2-} levels below 10 ppm.

SULFUR AND PLANT PHYSIOLOGY

Sulfur in plants can be found in many organic compounds, being an important element because of its ability to form chemical bonds in complex organic molecules. It is a component in cystine, cysteine and methionine, the most important sulfur containing amino acids in plants that are building blocks of proteins. Because of its role in the development of proteins, sulfur is a complement to nitrogen in the protein forming function. Plant enzymes are another important group of organic compounds containing sulfur. The role of enzymes is to stimulate most internal reactions related to plant growth and development.

An important enzyme, Coenzyme A, is involved in the oxidation and synthesis of fatty acids, the synthesis of amino acids and the oxidation of intermediate compounds in the citric acid cycle.

Sulfur is a vital part of ferredoxins, iron-sulfur organic compounds occurring in the chloroplasts. Ferredoxins participate in the light reaction in photosynthesis by accepting electrons ejected from the chlorophyll. Ferredoxins also have a significant role in nitrite and sulfate reduction, the assimilation of nitrogen by root nodule bacteria, and free-living nitrogen fixing soil bacteria.

Sulfur also occurs as volatile organic compounds in plants and fruits in the mustard and onion families, being responsible for their characteristic taste and smell.

Deficiency of sulfur in plants impairs protein formation, slowing growth rate and yield formation. External symptoms of the early stages of sulfur deficiency consist of a pale yellow leaf colour progressing to the whole plant as the deficiency turns into more severe stages. Chlorosis and leaf death occurs in the most severe stages of sulfur deficiency.

MAIN SULFATE OF POTASH USES

CHLORIDE SENSITIVE CROPS

In contrast to potassium in the soil, chloride anions are not adsorbed on the soil sorption complex (clay minerals or organic matter). In soil, chloride is a very mobile ion and easily washed out downwards with the water stream under regular humid conditions. Therefore the Cl concentration in soils is usually low (up to < 35 ppm) but can accumulate to substantial levels in saline soils, irrigated areas or poorly drained soils (possibly more than 6000 ppm). In periods where evaporation exceeds rainfall/ irrigation, chloride can even be relocated from the subsoil to the surface through capillary rise and can accumulate in the root zone. Excessive levels of soil chloride particularly in the subsoil (main root zone) increase the osmotic potential in the soil solution and restrict the uptake of nutrients such as nitrate and sulfate through antagonistic effects.

Chloride in the soil solution is taken up by plants very rapidly and in considerable amounts and accumulated into the vegetative parts of plants where it exhibits a strong osmotic effect.

Chloride damage on citrus

This often leads to a reduced content of organic acids and an accumulation of low molecular compounds which is linked to a simultaneous reduction in the levels of desired storage assimilates such as starch, sugars or proteins. A typical phenomenon as a consequence of the strong osmotic effect exhibited by chloride in cells, is that the higher hydration of plant cells or water intake into the plant tissue makes it more susceptible to damage during transport, handling or packing.

Reduced storage and processing characteristics, particularly in root and tuber crops, are also frequently encountered problems in crops fertilized with chloride containing fertilizers. In severe cases chloride specific leaf injuries such as burning of leaf tips or margins, bronzing, premature yellowing and abscission may occur.

Chloride sensitivity of plants differs considerably among plant species and even different cultivars of the same species. Chlorophilic plant species, which require chloride for maintaining stomata activity, are include the Liliacea, Iridacea, Amarylladae and Palmae. Tolerant species which do not require but tolerate higher levels of chloride, primarily differ from sensitive species in their ability to:

- Restrict the chloride absorption.
- Restrict Cl-translocation from roots to shoots.
- Distribute chloride within shoots.

Unlike most agricultural crops, fruits, woody plant species and most vegetables are generally susceptible to Cl toxicity. The most detrimental effects of Cl result from its contribution to overall osmotic stress in plants caused by excessive salts in the root medium. Chloride sensitive crops accumulate excessive amounts of chloride, which are toxic to the plants. In general the natural Cl content of soils and the yearly addition of Cl through rainfall or irrigation more than fulfils the Cl requirement of crops. Additional Cl amounts through the application of Cl containing fertilizers are detrimental in particular to chloride sensitive crops or when a sufficient leaching of chlorides cannot be safeguarded. Potassium fertilization in vegetable and fruit production systems, therefore, is mainly based on sulfate of potash in order to avoid the adverse side effects caused by chloride containing fertilizers.

Highly sensitive		Moderately sensitive	
Mangoes	Apples	Grapes	Potatoes
Onions	Strawberries	Cucumber	Peanuts
Citrus	Citrus	Squash	Tomatoes

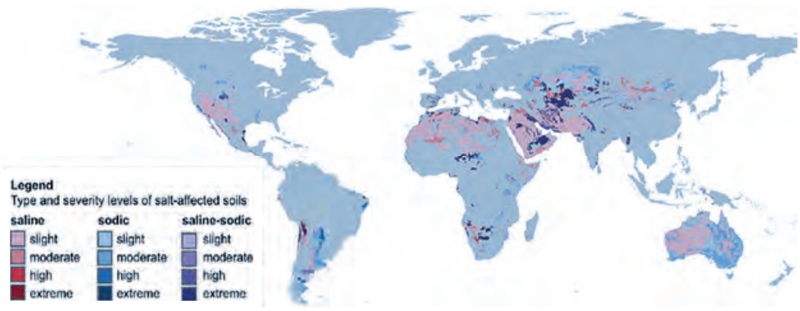
Chloride sensitive crops

SALT AFFECTED AREAS

In many regions of the world soil salinization is a serious threat to agriculture. A too high salt content, especially of sodium chloride (NaCl), in the soil solution hinders germination, vegetative growth, yield and quality of crops (Rhoades, 1990).
The salinity of soils comes from:

- Salts having been deposited in places that were under the sea in prehistoric times and which prevail in the soil or are present in the ground water.
- Natural salinization by weathering of rocks containing salts or erosion from geologic formations of marine origin and continuous deposition of wind-borne sea spray into the landscape.
- Anthropogenic salinization induced by improper land and irrigation management and inadequate fertilizer use.

Salt affected soils really constitute a global problem occurring everywhere irrespective of the climatic zone. Salt affected soils represent about 10 % of the total dry land.



Map of salt affected soils

Anthropogenic salinization is estimated at 76.6 Mio ha, and among these more than 45 Mio ha are under irrigation. Inadequate drainage or excessive evaporation from agricultural fields leads to an accumulation in the soil. Whenever the evapotranspiration exceeds the water input by rainfall and irrigation, the salts dissolved in the rain or in the irrigation water accumulate in the upper soil horizon.

Ascending soil water driven by capillary forces and evapotranspiration carry soluble salt into the rooting zone of the topsoil. Changes in the soil's chemical and physical properties, such as the formation of hard pans and a reduced infiltration, are typical problems of salt affected soils. Without sufficient drainage the salt concentrations can build up to toxic levels and can change fertile agricultural land into infertile and unproductive wasteland. It is being observed that the increasing use of saline water for irrigation purposes, due to lack of water fit for irrigation, leads to an accelerated salinization if an adequate leaching of salts by non-saline water in frequent intervals is not guaranteed.

Potato cropping in Jordan under saline conditions

Result after several years of fertilization with MOP

High salt concentrations in the soil solution affects plant growth mainly through

- Induced water stress by the high osmotic pressure of the soil.
- Plant physiological toxicity of the high concentration of anions and cations, mainly Na^+ and Cl^-.
- Ion imbalances and nutrient deficiencies of K, Ca and NO_3.

The accumulation of salts in the soil leads to an increase of the osmotic pressure and thus to a decreasing water potential and water availability to the plants.
Plants grown under such conditions suffer from directly induced water stress because high osmotic pressure binds the soil water and renders it less available to the plant roots. Plants react by osmotic adjustment (osmoregulation) to adapt to water stress. Plants absorb inorganic ions (Na^+, K^+, Cl^-, NO_3^-) from the soil solution and synthesize organic solutes, which accumulate in the cell vacuole and in the cell cytoplasm.

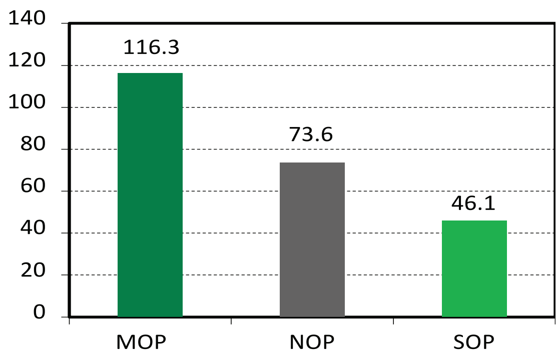
Toxicity often begins with an imbalance of ions in the plant tissue, mainly with a large excess of Na^+. To some degree the plant can cope with the excess Na^+ by excluding its uptake or secreting it into vacuoles. Because these regulatory processes require an additional amount of energy, plants grown on salt affected soils have higher respiration rates and deplete storage carbohydrates to a greater extent than plants grown under non-saline conditions. The lack of energy as a consequence of salinity may affect various energy requiring processes such as CO_2 assimilation, protein synthesis or the assimilation of inorganic N.
Excessive Na in the soil solution leads to a range of disorders caused either by competition between Na^+ or other cations such as K^+, Ca^{2+} and NO_3^- during uptake or physiological and metabolic malfunction as a result of high cytoplasmic Na^+:K^+ ratios.

By competing for uptake sites, Na interferes with the K supply of the shoots in many plant species. Already low concentrations of NaCl in the soil solution disturb the nutritional balance of plants, mainly through Na^+:K^+ competition during uptake and to a lesser extent by competition through Cl^-:NO_3^- interaction.

However, with increasing rates of K fertilizers the competitive effect of excessive Na can be suppressed and the K status of the plants improved by balancing the cation ratio and counteracting the sodium surplus.

Care should be taken in selecting the K source. Chloride containing fertilizers may exert a negative side effect on the cation balance in plant shoots. The preferred form of potash for conditions prone to salinity is SOP because it is virtually free of chloride and has a low salt index compared to other potassium sources such as MOP (muriate of potash) and NOP (nitrate of potash).

Owing to the fact that fertilizer applications always represent a specific input of salts to the soil, and that the impact on the germination rate and growth is specific to the type of fertilizer, Rader et al. (1943) introduced the concept of a salt index for fertilizers. The concept is based on the influence of fertilizers on the osmotic potential of the soil solution. As a reference material (salt index = 100) sodium nitrate was used.



Salt index of potash fertilizer (reference $NaNO_3$ = 100)

Sulfate of potash having the lowest salt index of 46 compared to potassium sources such as potassium chloride, potassium nitrate and sodium potassium nitrate, consequently has the least impact on soil salinity and represents the best potassium source for salt affected soils or at sites where salinity could be a risk through high fertilizer dressing or low water availability. Particularly where leaching is restricted or in production systems with high fertilizer applications and short production cycles with salt accumulation in the root zone, sulfate of potash is without doubt the best potassium source, due to its low salt index.

The successful management of salt affected agronomic systems is largely dependent on information about crop salt tolerance or the relative yield expected for a given root zone salinity. The sensitivity to salinity of a given species or cultivar may change during ontogeny. It may decrease or increase, depending on the plant species, cultivar or environmental factors. Sugar beet, for example, is highly tolerant during most of its life cycle but sensitive during germination.

Particularly for germination and early stages of growth, the seed and the seedling are very susceptible to even low salt concentrations in the soil. A low water uptake and imbalanced ion offer directly affects germination rate and vigour of the seedlings of many crops. Hence soil fertilizer applications based on sulfate of potash are required to guarantee a high germination rate and favourable growth.

Crops can be classified into sensitive, moderately sensitive, moderately tolerant and tolerant. The classification of the salt tolerance of a crop species is based on the EC of the soil saturation extract and the expected yield reduction related to a given EC value.

HIGH VALUE CROPS

Selected tropical fruits or vegetable crops are increasingly produced for overseas export markets fetching above average prices. To meet exactly the quality requirements of consumers, farmers and the processing industry, a top quality is necessary. Sulfate of potash improves yield as well as quality parameters such as sugar content, firmness, vitamins and storage quality.

INTENSIVE AGRICULTURE

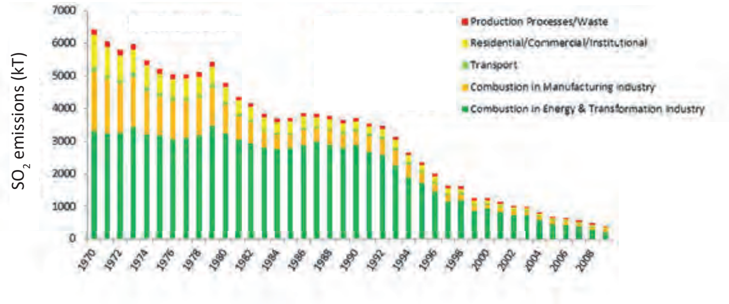
Increasing food demand and the high productivity per unit of land are the driving forces towards intensive cropping systems with sophisticated irrigation and fertilization practices. Often two or three cropping cycles per year are possible and yields per cropping season are considerably higher.
Therefore a balanced fertilization based on sulfate of potash is the optimal choice to sustain soil fertility. This guarantees the adequate nutrient supply with potassium and sulfur and avoids growth depressions caused by the accumulation of excessive chlorides.

HIGH SULFUR DEMAND

Though sulfur was always recognized as one of the six macronutrients, in the industrialized countries its implementation in regular fertilization practices has not been regarded as necessity before the 80’s when SO_2 emissions of industrial origin provided automatically sufficient sulfur for soils and cultivated crops. Hence sulfur balances in most cropping systems of industrial regions were generally positive in this period. Surveys carried out in Europe indicated an annual sulfur deposition of about 45 kg S/ha in the 70’s, well above the sulfur uptake of highly S-demanding crops such as oilseed rape.

However, since the beginning of the 80s, the implementation of the European environmental regulations resulted in a reduction of atmospheric SO_2 pollution by industry, households and traffic. Latest data show that annual sulfur deposition reached a level of about 10 kg S/ha, which is comparable to the quantity deposited at the end of the last century, just before the beginning of the industrial revolution in Europe. On the other hand, modernisation and rationalisation of agricultural production lead to concomitant change in the use of fertilizer sources towards highly concentrated “high analysis fertilizers”. The substitution of ammonium sulfate (24 % S) as the dominant nitrogen source by urea, and single super phosphate (12 % S) by triple super phosphate dramatically reduced the amount of sulfur applied through mineral fertilization during the same period.

Technical advancements in agriculture and the development of high yielding varieties resulted in a simultaneous rise in yields with a higher nutritional requirement and thus with a higher sulfur uptake of crops.



Decrease in UK atmospheric SO_2 emissions (NAEI)

Owing to both the effective measures in reducing air pollution in industrial countries and the generally low inherent sulfur deposition in most of the developing countries, an ever-increasing gap between sulfur supply and demand by cultivated plants is developing.

In the tropics sulfur deficient soils are widespread. Depending on soil type the low availability of plant available sulfate-S is often low due to:

- The low content of organic matter restricting the mineralization of organic bound sulfur.
- The strong anion adsorption capacity of clay minerals and the organic matter.
- High C:N ratios limiting the mineralization of organic matter through microbial activity.

Sulfur therefore has become a yield and quality limiting factor at many locations worldwide and will be one of the limiting plant nutrients in future.

PART 2

FRUITS AND NUTS

AVOCADO

MINERAL NUTRITION

The avocado is a tropical to subtropical tree with severe cold being the most limiting factor to its successful cultivation. It can be grown on a wide range of soil types, but requires good drainage, as it cannot tolerate flooding. A soil pH from 6 to 6.5 is preferable.

	N	P_2O_5	K_2O
Hass	3.60	0.55	6.10
Fuerte	1.30	0.39	2.35
Lula	2.80	0.80	5.46

Mineral requirements for different avocado cultivars (kg per ton of production)

In the past, the avocado was thought to need few mineral nutrients. Deficient trees may not show deficiency symptoms immediately, so mineral nutrition should be monitored through regular leaf and soil analysis.

POTASSIUM, THE KEY NUTRIENT

Potassium is an important factor for a high level of avocado production. Its role in sugar synthesis and translocation of assimilates is essential for the quality of the fruit. Potassium should be adjusted to an adequate level (150 - 200 ppm) in the soil before planting, while maintaining a balance with calcium and magnesium.

Ideally, potassium should represent between 0.7 and 2.4 % of leaf dry matter. In a potassium deficient tree, the leaves are small and narrow, and necrotic spots appear on the older leaves. A high level of potassium in the soil and leaves reduces the development of both vascular browning and pulpy spots in the fruit.

Potassium deficiency in avocado leaves

POTASSIUM SULFATE AND YIELD

The avocado tree does not tolerate high levels of chloride, either in the soil or irrigation water, with a toxicity threshold considered to be 0.25 % chloride in the leaf dry matter. Consequently, chloride-based fertilizers such as MOP (potassium chloride) should be avoided.

The main symptom of chloride toxicity is a light grey-brown scorch on the tips and edges of the older leaves, which spreads back along them in an irregular pattern.

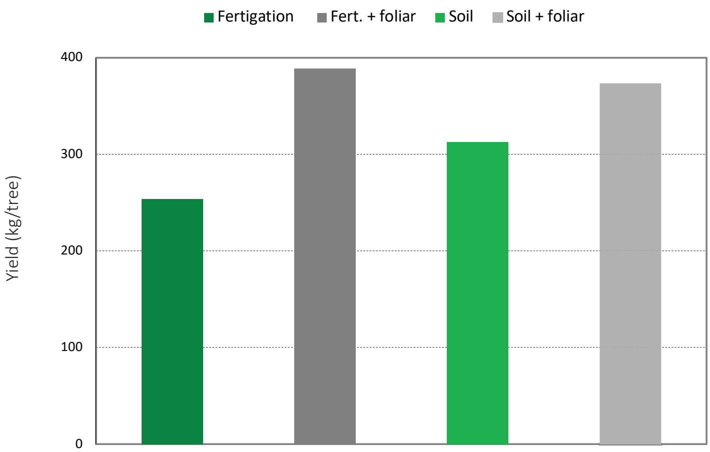
Below is an example of a fertilization program based on potassium sulfate (SOP), single super phosphate (SSP) and calcium nitrate (CaN). Calcium is an important element to increase the resistance of the roots to diseases and the storage life of the avocado fruit.

Canopy diameter (m)	CaN (g/tree)	SSP (g/tree)	SOP (g/tree)
2	50	200	50
4	175	300	200
6	350	400	400
8	650	600	750
10	1000	1000	900
12	1500	1200	1600

Example of a fertilization program for avocado

The experiment below compares different methods of applying 200 kg K_2O/ha to Hass avocados grown in the state of Michoacán in Mexico. These are fertigation with SoluPotasse, and soil application, with and without foliar sprays after flowering of K-Leaf®.

Results show the benefit of foliar application in enhancing root absorption and, consequently, on fruit production.



Cumulated 2004-2006 production according to application method (INIFAP, Mexico, 2006)

SULFUR IN AVOCADO PRODUCTION

Sulfur (S) is an important nutrient for plant growth, playing a key role in amino acid synthesis. However, sulfur deficiency is becoming increasingly frequent. The optimum range for the sulfur content in the avocado leaf dry matter is between 0.2 to 0.6 %. Potassium sulfate also contains 18 % S which covers the plant's sulfur requirements. In addition, sulfur is helpful in pest and disease control.

Sulfur deficiency on avocado leaf

Apart from major and secondary nutrients, the zinc status must also be checked in avocado orchards. In calcareous soils, iron deficiency can be observed frequently and hence should also be monitored.

BANANA

MINERAL NUTRITION

Banana is the main tropical fruit exported throughout the world, usually produced in large plantations. A balanced fertilization is a guarantee of a quality and marketable fruit production.

Banana prefers deep soils, a good drainage and a pH from 5.5 to 6.5, though it is cropped on a wide range of soils. A standard field production (50 to 60 MT/ha) requires 500-600 kg N/ha, 200 kg P_2O_5/ha and 1,300 - 1,500 kg K_2O/ha. Phosphorus is applied at planting and later broadcast in ratoon crops. Nitrogen and potassium are applied in split applications, along the cropping period. Fertigation is the best application method to match the demand of the plant.

POTASSIUM IN BANANA CROPPING

Banana has the highest potassium requirement amongst all crops.

Potassium deficiency on banana leaf

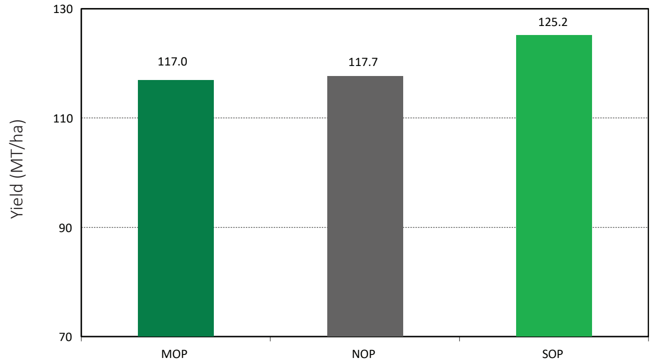
Potassium plays an essential role in high yields and fruit quality. It stimulates early shooting and significantly shortens the time required for fruit maturity. It improves bunch grade, and size of fingers.

The deficiency symptoms include orange yellow colour of old leaves, scorching along the margins, reduction in total leaf area, curving of midribs, etc. Choking of leaves delays flower initiation leading to reduction in yield and quality. Fruits are badly shaped, poorly filled and unsuitable for marketing.

POTASSIUM SULFATE FOR HIGH GRADE PRODUCTION

Banana is a chloride-sensitive crop. Chloride affects yield and fruit flavour. A high concentration of chloride disturbs water exchanges and reduces element uptakes from the soil. The risk is enhanced in case of saline irrigation water or poor drained soils.

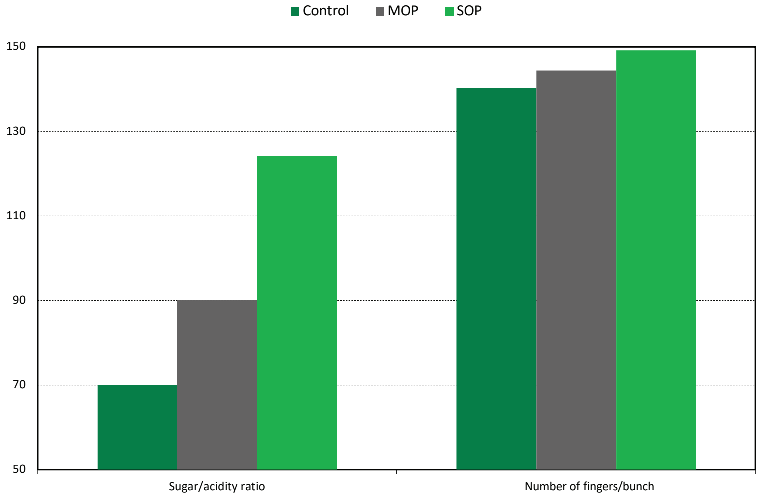
A number of experiments comparing potassium sulfate and potassium chloride treatments at the same dose of potassium illustrate the detrimental effect of chloride. A 10 to 20 % increase in total production is frequently observed with SOP over MOP treatment. NOP favours vegetative growth and reduces fruit production. Finally, SOP is the best choice as presented below in this example from India. SOP also allows an earlier maturity and better flavour thanks to higher sugar content.



Effect of potash sources on banana production
(Banana Research Station, Jalgaon, India, 2017)

POTASSIUM SULFATE FOR QUALITY

Potassium sulfate also has a positive effect on quality parameters. An illustration is given below from an experiment in India comparing SOP and MOP application at 330 g per tree, on total soluble sugar and on the sugar/acidity ratio as well as on production parameters.



MOP and SOP effect on quality (Ebert, India, 2004)

SOLUPOTASSE USE IN BANANA PRODUCTION

As for many plants with fast growth, banana crops benefit from fertigation. SoluPotasse, Tessenderlo Kerley's soluble grade of potassium sulfate, contributes to high quality production and a better water and fertilizer use efficiency with an NPK ratio adapted to each stage of the banana's growth.

Treatment	Yield parameter			
	Yield (MT/ha)	kg/bunch	Hands/bunch	Fruit/hand
N1PK1	33.75	11.3	10.0	16.0
N1PK2	36.25	12.5	10.0	16.0
N1PK3	40.00	17.9	11.0	17.0
N1PK4	42.50	18.2	12.0	20.0
N2PK1	50.50	20.5	11.0	18.0
N2PK2	66.50	24.1	11.0	20.0
N2PK3	75.25	27.3	12.0	25.0
N2PK4	84.75	30.0	13.0	25.0

Effect of nitrogen and potassium fertilization on banana production
(N: 250 or 500 kg/ha; K_2O: 250, 500, 750 or 1000 kg/ha) (DRC, Egypt, 2007)

SoluPotasse can be used in fertigation, allowing growers to apply separately nitrogen and potassium. Below is an example of a fertigation program for a standard banana production.

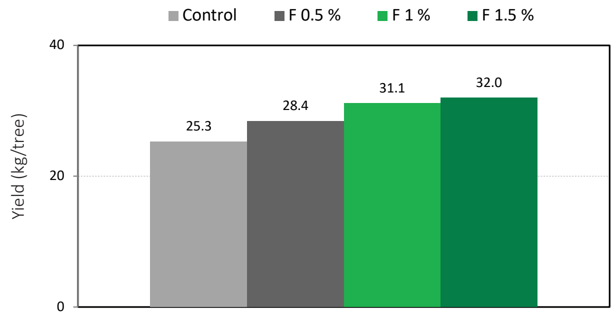
Week after planting	N	P_2O_5	SoluPotasse
0 to 6	10 kg/ha/week	200 kg/ha	35 kg/ha/week
6 to 12	15 kg/ha/week	-	50 kg/ha/week
12 to 18	20 kg/ha/week	-	50 kg/ha/week
18 to 24	15 kg/ha/week	-	85 kg/ha/week
24 to 30	15 kg/ha/week	-	65 kg/ha/week
30 to 36	15 kg/ha/week	-	50 kg/ha/week
36 to 42	15 kg/ha/week	-	85 kg/ha/week
Total	630 kg/ha	200 kg/ha	2520 kg/ha*

* 1260 kg K_2O

Example fertigation program for standard banana production

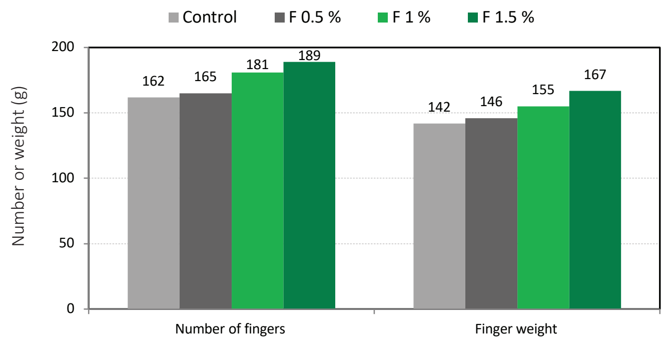
BENEFITS OF FOLIAR POTASH APPLICATION WITH K-LEAF

As many plants with fast growth, bananas benefit from foliar applications. K-Leaf contributes to high quality production and a better efficiency of basal dressing. Foliar applications of K-Leaf improve yield, sugar content and the shelf life of fruits which show an earlier maturity. In the experiment below, 2 foliar sprays at 0.5, 1 and 1.5 % concentration were applied at the opening of last hand and 30 days later.



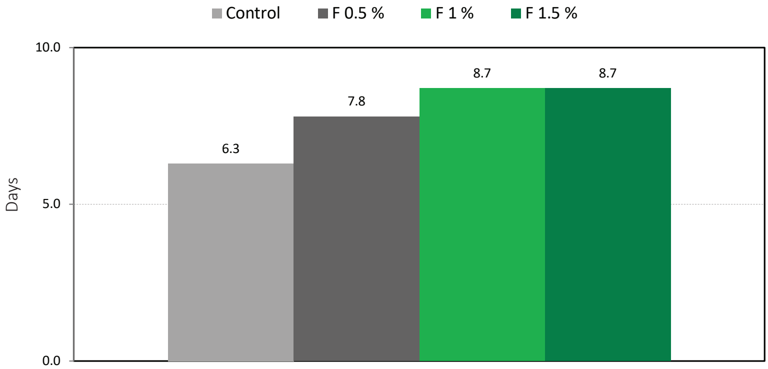
Effect of K-Leaf on banana production (TNAU, India, 2008)

The 1.5 % treatment shows a yield increase by 25 %, mainly due to more fingers and higher finger weight, as shown below.



K-Leaf effect on yield components on banana production (TNAU, India, 2008)

Foliar applications of K-Leaf also induce early maturity and improve shelf life.



Effect of K-Leaf on banana shelf life (TNAU, India, 2008)

THE IMPORTANCE OF SULFUR

Sulfur is the main component of amino acids and vegetal proteins. It performs the role of enzymatic activator and participates in chlorophyll synthesis. 0.23 % of S in banana leaf is considered as the critical concentration. Deficiency symptoms include a generalized yellowing of the foliage, and new leaves show light colours. This is consistent with the fact that S in not a mobile element within the plant. Deficiency symptoms should be most apparent on the youngest foliage. Plants severely deficient in sulfur will develop necrotic leaf margins along with a slight thickening of the veins.

Some micronutrients such as zinc and boron can also be frequently deficient.

CITRUS

LOOKING FOR BALANCED NUTRITION

Fertilization prior to planting is aimed at promoting good rooting and rapid development, whereas the annual fertilization program should target a balanced nutrition in order to optimize yield and quality. Choices will be largely guided by soil analysis, subsequently complemented by foliar diagnosis.

Citrus cropping requires an NPK balance of 1-0.3-1.2. In a fertile soil, the fertilization recommended for a target yield of 60 MT of fresh fruits and for balancing the removal of mineral nutrients is: 180 kg/ha of N, 55 kg/ha of P_2O_5, 220 kg/ha of K_2O.

Potassium deficiency in citrus leaves

Potash fertilization will be fully efficient only if other limiting factors have been addressed beforehand and should take in account the nature of the irrigation system. The efficiency of fertilizers is sharply reduced when the plant canopy lacks space and sun. If branches are too close, a program of pruning must first be implemented.

WHAT FORM OF POTASSIUM?

Citrus crops are very sensitive to chloride. The maximum permissible level of chloride anions in soil water without leaf injury is 20 mol/m^3 (i.e. an EC of 2 mmhos/cm).

Therefore, the use of fertilizers with a high chloride content such as potassium chloride (MOP) must be avoided. Amongst all potash fertilizers, sulfate of potash (SOP) has the lowest salt index that is the reason why it is recommended in citrus cropping. Sulfur is also an important nutrient for plants and plays a key role in protein synthesis: the normal sulfur content in citrus leaves is 0.20 to 0.40 % of dry matter. 70 % of S-protein is contained in the chloroplasts (photosynthesis). Potassium sulfate also contains 18 % S which largely covers the sulfur requirements of the plant.

FERTILIZER EFFICIENCY AND APPLICATION

The efficiency of fertilizers, as well as irrigation and ploughing, depends upon root location. The roots of citrus crops are in general shallow and located just below the canopy.

Fertilizer efficiency is drastically reduced when trees have diseases such as Phytophtora. Fertilizers have various effects on diseases: potassium generally contributes to the reduction of fungal damage, while nitrogen increases the tree's sensitivity to diseases.

The method of application plays a key role in fertilizer efficiency, especially for potassium, which is not mobile, except in sandy soils. Since the uptake of mineral nutrients occurs at the root level, fertilizers must be applied close to the roots, either on the soil surface, or "side dressed" along the lines of trees (if possible in clay soils, at 15/20 cm depth), or at about 50 cm from the trunk through fertigation drippers.

	N	P_2O_5	K_2O
1st year	40 to 60	12 to 18	25 to 30
2nd year	70 to 80	20 to 25	40 to 70
3rd year	90 to 100	25 to 35	70 to 80
4th year	110 to 120	35 to 45	80 to 100
> 5 years	120 to 140	45	120 to 140

NPK requirements in young trees (kg/ha)

With traditional irrigation, split applications, especially for P and K, are not really necessary for tree growth and fruit production in deep loamy-clay soils. Budding, growth of young branches, flowering, leaf formation, and fruit setting mainly depend upon mineral reserves gathered in the tree (trunk, branches, roots and old leaves).

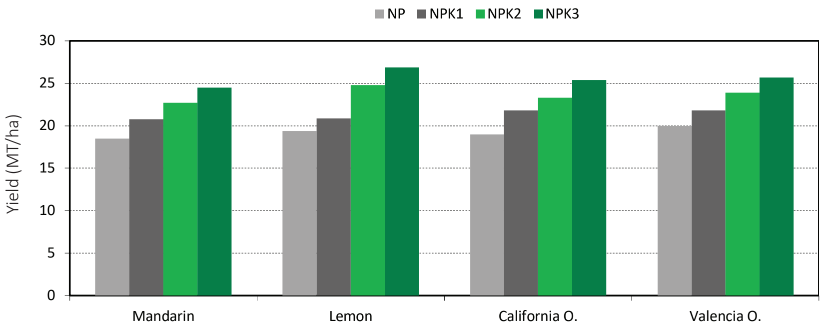
These reserves have to be replenished regularly. Breakdown of fertilizer applications should be based on the type of production as shown in the table below.

	Winter	Spring	Summer
N (early orange)	40 %	40 %	20 %
N (late orange)	25 %	25 %	50 %
P_2O_5	50 %	50 %	0 %
K_2O	40 %	40 %	20 %

Proportion of total amount applied in each period

SULFATE OF POTASH FOR IMPROVED QUALITY

The benefits of sulfate of potash are not only limited to an improvement in yield. It also has a positive effect on the size of the fruits, sugar content, juice production, fruit colour and on the quality of the edible part of the fruit. The following graph shows the benefit of SOP on citrus, and the response to potassium doses: K1 is 50 kg K_2O/ha, K2 is 100 kg K_2O/ha and K3 is 150 kg K_2O/ha, when nitrogen is 100 kg N/ha and phosphorus is 35 kg P_2O_5/ha.



Effect of SOP on the yield of 4 citrus varieties (DRC, Egypt, 2008)

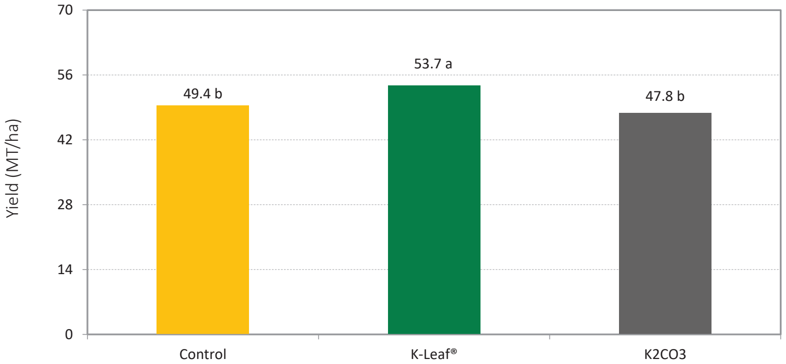
USES OF SOLUBLE SOP

SoluPotasse is the soluble grade of potassium sulfate specially prepared for fertigation and K-Leaf for foliar applications. Fertilizer applications via irrigation water have to be made according to the age of the trees, their actual production, and according to the requirements corresponding to each vegetative stage.

The efficiency of foliar sprays with primary nutrients is multiple. They can be used either as a complementary application to complete nutrition, or to correct cases of severe deficiency, where they will simultaneously improve the soil nutrient content.

Sulfur deficiency in citrus leaves

Foliar applications of potassium sulfate have a positive effect on production and quality. In the following experiment, two sprays of K-Leaf at 21 kg K_2O/ha (beginning of fruit growth and mid-growth) significantly improved yield by 9 %, whereas potassium carbonate does not show any benefit.



Effect of K-Leaf on clementine yield (IAV Hassan II, Morocco, 2017)

Other possible deficiencies including iron, manganese and zinc must also be monitored.

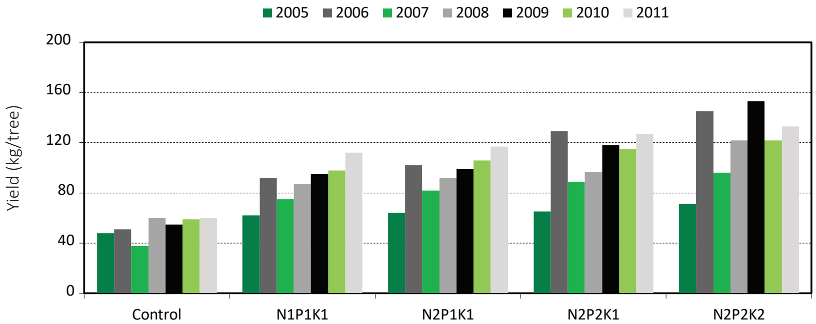
DATE

MINERAL NUTRITION

In many countries, date palm is not fertilized; however, mineral nutrition can improve production and quality. Date is also known as being resistant to saline conditions, and potassium chloride appears to be the most common source of potassium used. In some highly saline conditions as is often the case in North Africa and the Middle East, it is advisable to use potassium sulfate.

BENEFIT OF SOP

An experiment carried out during three years in Siwa, located in the western part of Egypt, shows the effect of balanced fertilization with potassium sulfate on date yield. EC of the soil solution varied from 6 to 12 dS/m.

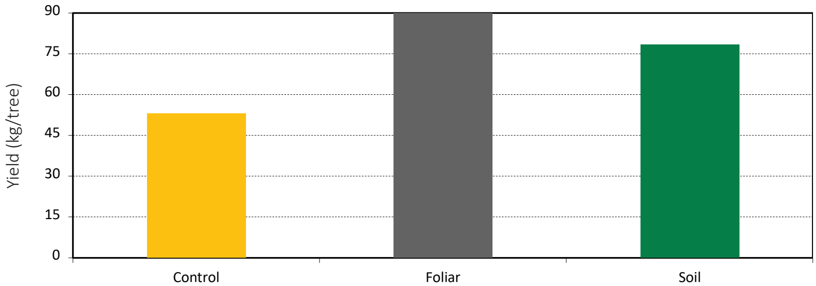


Effect of fertilization on date production (DRC, Egypt, 2011)

Harvest is significantly increased with fertilization, and applying higher doses of nitrogen (from 1.2 to 1.6 kg per tree, N1 and N2 respectively) requires the application of more potassium sulfate (from 0.5 to 1 kg per tree, K1 and K2 respectively) to maintain the correct N:K balance.

THE USE OF FOLIAR SOP

K-Leaf can be used for foliar applications on date as demonstrated in an experiment from Tunisia, where 2 sprays at 1.5 kg per tree were compared to a control and 2 soil applications of 1.5 kg per tree.



Effect of K-Leaf on date production (INAT, Tunisia, 2017)

K-Leaf increases fruit weight and cluster weight and consequently increases yield.

FIG

MINERAL NUTRITION

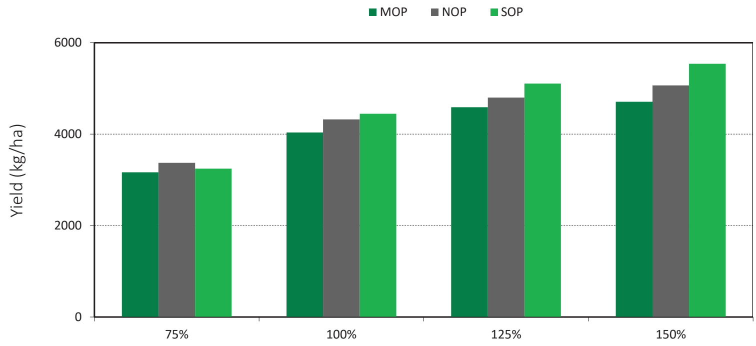
Fig trees are usually grown in warm and dry climates. Mineral fertilization is only used in modern cropping systems and must be well controlled, particularly nitrogen. An excess of nitrogen can limit fruit production. Split applications from late winter to the end of spring are recommended. Fertilizers must be spread under the canopy, away from the trunk. A typical recommended dose is 200 g N per tree, 60 g P_2O_5 per tree and 225 g K_2O per tree to ensure sufficient mineral content in the plant as described below.

Plant analysis data – Macronutrients					
Plant part	% of dry matter				
	N	P	K	Mg	Ca
Leaves	2.0 - 2.5	0.1 - 0.3	1.0 - 1.6	0.8	3.0 - 3.6
Fruit	0.47	0.057 - 0.070	0.57 - 0.68	0.06	0.13 - 0.17

Standard element content in fig

BENEFITS OF SOP

In the following experiment from India, 100 % corresponds to the standard fertilization, supplying 162 kg N, 20 kg P_2O_5 and 343 kg K_2O per hectare. The first treatment is 75 % of this dose and the second is the full dose, when the third treatment is 125 % and the fourth treatment is 150 %.



Effect of Potassium form on fig production (SSAC, India, 2007)

Three forms of potash fertilizers were compared, potassium chloride, potassium nitrate and potassium sulfate. As shown in the graph, potassium sulfate gives the highest yield. It can also be concluded that the recommended dose is too low according to the local potential of production. Concerning quality parameters, potassium sulfate improves flavour and fruit size.

KIWI

MINERAL NUTRITION

Kiwifruit vines grow best on deep, alluvial soils. Kiwifruit vines prefer loamy and silt-loamy soils rather than loamy sands. Kiwifruit vines also prefer low-salt water as do many other fruit crops. Safe levels for irrigation water are: chloride less than 70 ppm, bicarbonate less than 200 ppm, sodium less than 50 ppm. pH should not exceed 7.3.
Nitrogen (N) and potassium (K) are the most important elements required by kiwifruit in relatively large quantities in intensive orchards. Nitrogen participates in vine and leaf development favouring photosynthesis. In a season, the nitrogen required by the vine is estimated around 125 kg/ha. To limit leaching of nitrogen, it must be applied close to bud break.

Potassium is essential for rapid canopy development from bud break to fruit set. It is needed for transport functions and to control water exchanges. Low potassium levels result in poor fruit growth, and older leaves fall later in the season. As an average, 220 kg K_2O/ha are usually required in modern cropping systems. The sulfate form, which is less sensitive to leaching, is preferable.

Nutrient uptake (estimated) - Macronutrients								
Vine age (years)	Fruit yield (MT/ha) fresh	N	P_2O_5	K_2O	MgO	CaO	S	Cl
3	10	74	23	116	22	97	13	29
4	20	126	37	193	35	162	21	48
> 5	20	94	27	160	23	129	15	43
> 5	30	129	39	219	35	176	22	59
> 5	40	165	50	278	45	225	28	75

Nutrient requirements for kiwifruit

Leaf analysis is recommended to monitor mineral nutrition. Calcium and magnesium are also important nutrients, but a large part is recycled in pruning. Sulfur is a major element often provided by fertilizers in sulfate form. Concerning trace elements, kiwifruit mainly needs iron, zinc, manganese and boron.

POTASSIUM, THE KEY NUTRIENT

The first sign of a potassium deficiency is a poor growth at bud break. On severely affected vines, the leaves are small and pale yellow-green with a slight marginal chlorosis on the older leaves.

As the deficiency becomes more pronounced, there is an upward curling of the margins of the older leaves particularly during warmer period. This symptom can be easily confused with a lack of water. Later the margin of the affected leaves remain permanently curled and the tissue between the minor veins is often ridged upwards. The light green chlorosis, which developed initially at the leaf margin, spreads between the veins towards the midrib leaving a zone of green tissue close to the major veins and at the base of the leaf.

Chloride damage on kiwi leaf

POTASSIUM SULFATE FOR QUALITY

Kiwifruit is not particularly a chloride-sensitive crop, but chloride can affect the leaves in commercial orchards. Nevertheless, in many cropping conditions, potassium sulfate improves quality of fruits. In the following example, from an experiment carried out in Te Puke, New Zealand, the main production area in the world, two potassium forms (SOP and MOP) and two doses (150 and 350 kg K_2O/ha) as well as a mixture 1:1 of SOP and MOP at the higher dose, were compared.

	SOP1	SOP2	MOP1	MOP2	SOP/ MOP2
Fruit weight (g)	112.5	115	111.9	112	111.8
Dry matter (%)	17.7	18	17.95	17	17.6
Soluble sugar (%)	13	14.2	14	11.8	12.9

Quality of kiwi fruit according to potassium sources (Hortresearch, New Zealand, 2007)

MANGO

MINERAL NUTRITION MANAGEMENT

Prior to planting, mango fertilization focuses on phosphorus in order to promote good rooting and rapid plant development, whereas an annual fertilization program should aim at a balanced nutrition, in order to optimise yield and quality. Choices will be largely guided by soil analysis, subsequently complemented by foliar diagnosis.

The mango tree can be cropped in a wide variety of soil types, however well-drained deep sandy-clay soils (> 2 m), rich in organic matter are recommended. A pH from 6 to 6.5 is preferable.

The table below shows the mineral requirements of the crop according to tree age:

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Age of tree	N	P_2O_5	K_2O
1	0.1	0.1	0.1
2	0.15	0.15	0.15
3 - 5	0.24	0.12	0.44
6 - 8	0.36	0.18	0.66
> 8	0.48	0.24	0.88

Standard mineral fertilization in kg/tree for field production

POTASSIUM, THE KEY NUTRIENT

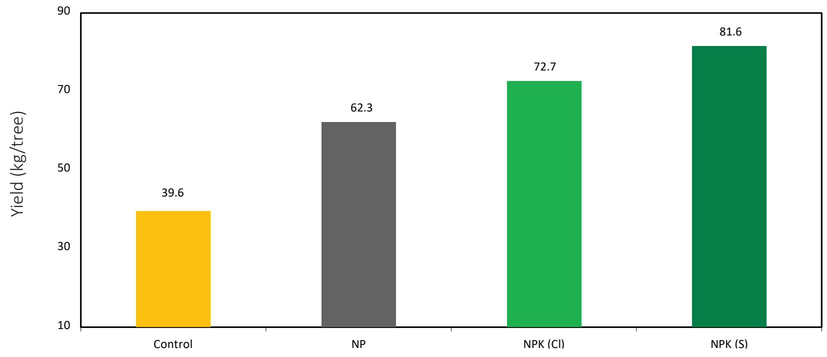
Potassium deficiency symptoms are seen in the trees' oldest leaves as small red, irregularly distributed spots. The leaves are smaller and thinner than normal and, at a later stage, necrosis appears along the leaf edges. Leaf fall occurs when the leaves are completely dead.

Potassium deficiency on the leaf

Potassium improves mango fruit quality: especially skin colour, aroma, size, and shelf life. In addition, it improves the ability of the plant to withstand stress conditions, such as drought, cold, salinity and disease.

POTASSIUM SULFATE TO CONTROL SALINITY

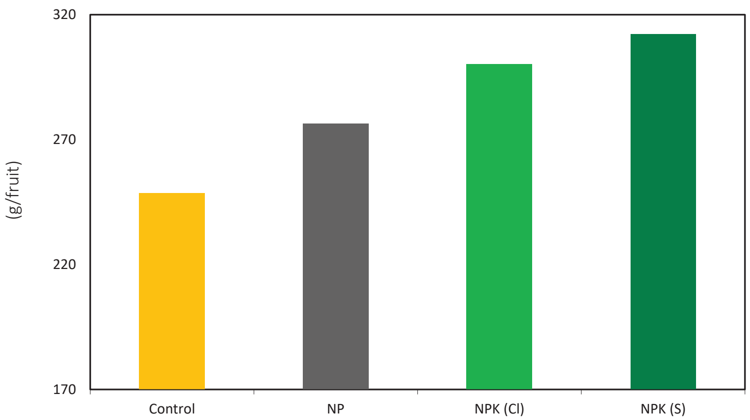
Mango is a chloride-sensitive crop, particularly during the two first years. Later on, production can also be affected by the use of chloride-based fertilizers. An experiment comparing treatment with potassium sulfate (SOP) and potassium chloride (MOP) shows the detrimental effect of chloride on production.



MOP and SOP effect on production (India, 2004)

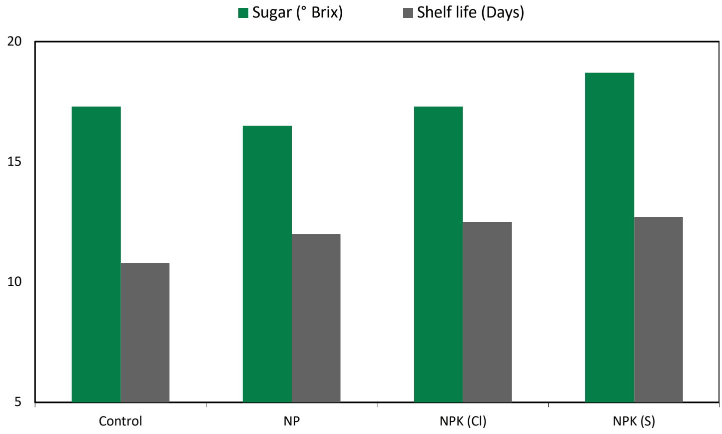
POTASSIUM SULFATE FOR BETTER QUALITY

From the same experiment, the results regarding quality parameters are clearly in favour of potassium sulfate. The graph below shows an increase in fruit size when applying SOP compared to MOP application.



MOP and SOP effect on fruit size (India, 2004)

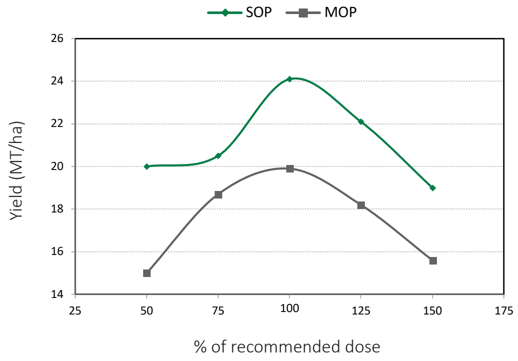
The following graph shows the impact on sugar content and shelf life.



MOP and SOP effect on quality (India, 2004)

SOLUBLE SOP USE IN MANGO PRODUCTION

When used in fertigation, SoluPotasse allows growers to apply nitrogen and potassium separately and so to adapt the fertilization to the plant's requirements at different stages. In the following experiment carried out in Brazil in 2014 and 2015 comparing MOP and SOP at different doses using fertigation, SOP improves yield by 21 % over MOP at the recommended dose (180 g per tree). Fertigation is split as follows: 45 % before induction, 20 % during flowering, 20 % after fruit setting and 15 % fifty days after fruit setting.

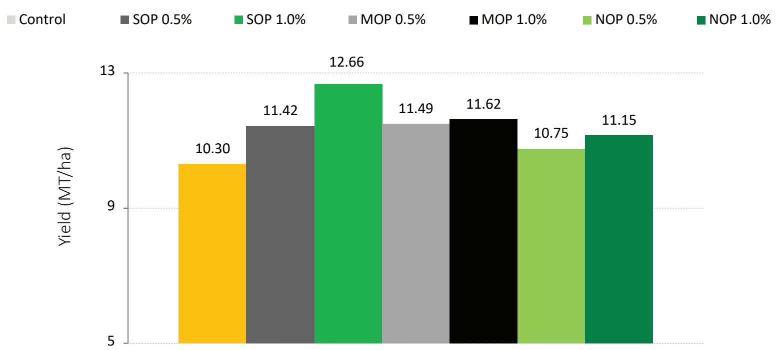


Response curve of SOP vs MOP on mango
(Universidad Federal do Vale do São Francisco, Brazil, 2017)

FOLIAR APPLICATIONS OF K-LEAF

Foliar application of K-Leaf can also contribute to high quality production and enhance the efficiency of soil application. A complementary foliar application of SOP in soluble form has been shown to have a significant effect on mango yield and fruit quality.

An experiment carried out in India, comparing 4 foliar applications of SOP, MOP and NOP at 0.5 and 1 % shows the advantage of the sulfate form on yield and sugar content in fruits.



Effect of foliar applications of different K sources on mango production
(Mohanpur University, India, 2011)

DO NOT NEGLECT SULFUR

Sulfur is the main component of amino acids and vegetal proteins, performing the role of an enzymatic activator and participating in chlorophyll synthesis.

In the case of a deficiency, plant growth is slowed, necrotic spots appear on young leaves and ultimately leaf loss can be observed. Potassium sulfate contains 18 % S which largely covers the sulfur requirements of mango production.

MELON

MINERAL NUTRITION OF MELON

1:0.7:2 is usually considered as the best ratio for a balanced fertilization. The mineral nutrition as well as water management should be carried out in accordance with the cropping system, soil analysis and the production target. Melon prefers deep, light and well-drained soils. Outdoor crops require per hectare 80 - 120 kg N, 60 - 80 kg P_2O_5, and 150 - 200 kg K_2O, whereas higher production in greenhouses requires up to 400 kg N, 200 kg P_2O_5, and 700 kg K_2O. Melon is particularly sensitive to micronutrient deficiencies, especially molybdenum.

Stage	Days	N	P_2O_5	K_2O	CaO	MgO
Planting to first flowering	17	7	6	8	7	8
Flowering	28	35	31	42	33	48
End of flowering to end of fruit development	11	25	28	31	26	30
End of fruit development to harvest	14	33	35	19	34	14
Total (%)		**100**	**100**	**100**	**100**	**100**

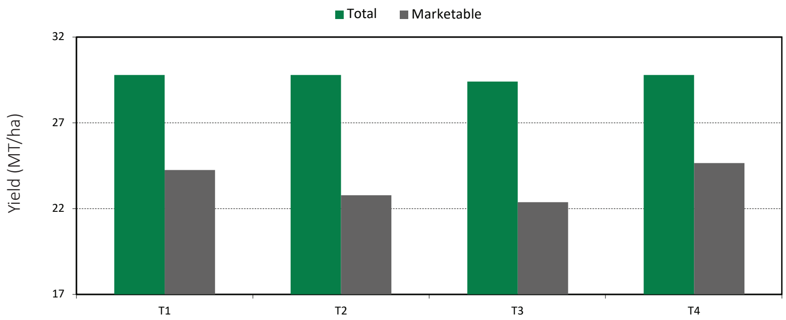
Percentage of the total nutrient uptakes according to the growing stage (CTIFL, France)

Traditional field cropping is the most important method of cultivation, and nowadays water management through drip irrigation is widespread. Fertilization takes advantage of this particular cropping technique using soluble fertilizers and the technique of fertigation to adapt application timing to instant requirements of the plant.

IMPORTANCE OF POTASSIUM

Potassium is particularly important at the flowering and fruit development stage, as shown in the previous table.

Application timing is of a great importance to marketable production. This is illustrated in an experiment comparing potassium applied throughout growth through fertigation (T1), soil application at planting (T2), the farmer practice (T3) and a combination of soil application and fertigation (T4), for the same amount of fertilizer. Fertigation is the best way, even when it is only use to deliver a part of the fertilizer, particularly when it comes to the marketable part of the production.

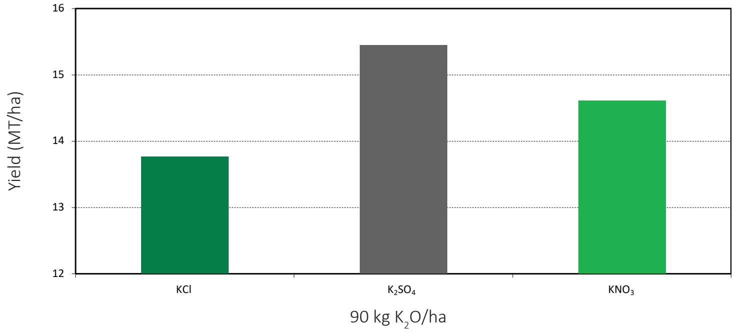


Production according to application program 250 kg K_2O/ha (CEHM, France, 2006)

Among the major elements, potassium plays a key role in sugar synthesis and translocation, and reduces the risk of bursting. Potassium deficiency is characterized by brown necrosis on leaf edges. Fruits are gritty and bitter.

WHAT SOURCE OF POTASSIUM?

The cropping system and climatic conditions are the main criteria for the choice between the different forms of potash. Under semi-arid conditions or with drip irrigation, sulfate of potash (SOP) is the preferable form. Its impact on fruit size results in a higher marketable production.



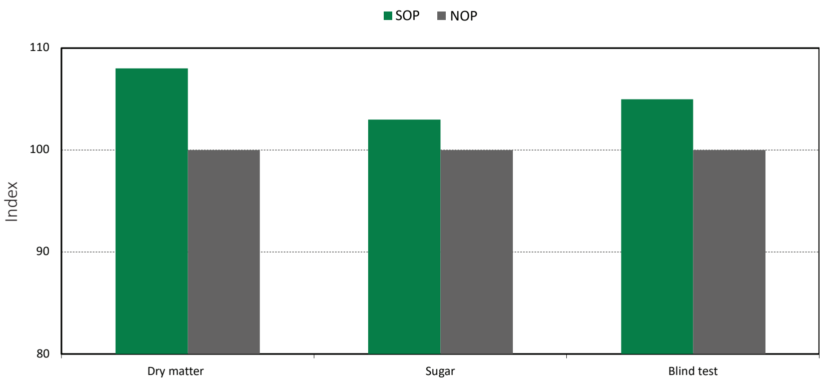
Marketable production of melon according to main potash fertilizers (EMBRAPA, Brazil)

Regarding quality parameters, SOP increases hardness and sugar content. As a consequence, melons produced with SOP are sweeter. An investigation on consumers' preferences have shown that taste is the main criteria for the choice of melon, in a much more important way that for any other fruit or vegetable.

Sulfate of potash also contains 18 % S which is the main component of amino acids and vegetal proteins. It performs the role of enzymatic activator and participates in chlorophyll synthesis.

SOLUPOTASSE USE IN MELON PRODUCTION

An experiment carried out under drip irrigation shows the benefit of SoluPotasse, soluble SOP, compared to NOP. Melons fertigated with SoluPotasse have a higher percentage of dry matter, a better firmness, more sugar and a more uniform production period.



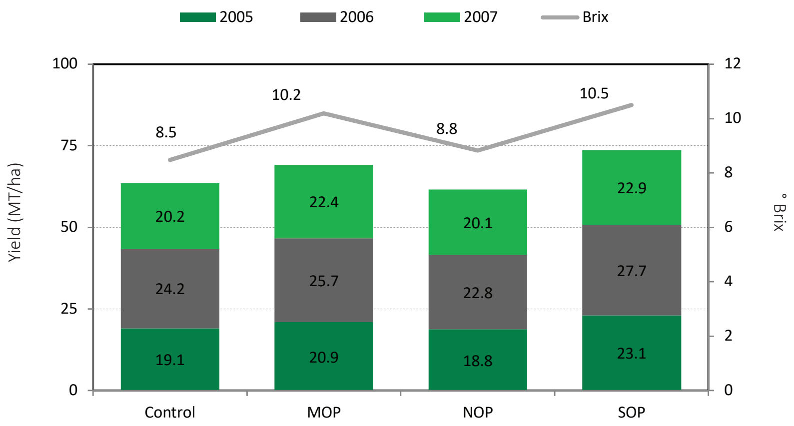
Impact of potassium source on quality parameters (Aspach Research Center, France, 1998)

A blind tasting test involving 140 persons confirms chemical analysis, showing the advantage of SOP on quality parameters and, as a consequence, on taste.

K-LEAF USE IN MELON PRODUCTION

During fruit growth, the melon's demand for potassium is high and may not be fully supplied only by roots. Foliar applications of K-Leaf can help, as shown in an experiment carried out at Texas University during 3 growing seasons.

NPK soil fertilization was 100, 20 and 0 kg/ha N, P, K respectively (soil rich in K). Foliar sprays of potassium were made weekly from fruit set to maturation at 4.5 kg K_2O/ha for each application.



Foliar spray effect on cumulated production of muskmelon (Texas Univ., USA, 2007)

Soluble SOP treatment improves yield by 16 % over control, 7 % over MOP, and 19 % over NOP. Sugar content remains the highest of all treatments.

NUTS

MINERAL NUTRITION

Nut is a general term for the dry seed or fruit of some plants. Nuts are an important source of nutrition, containing mineral elements and vitamins. While a wide variety of dried seeds and fruits are called nuts, only a certain number of them are considered by biologists to be true nuts. In the following, we are considering the most common nuts, which include almond, cashew, chestnut, hazelnut, pecan, pistachio, walnut, etc. For each species, a large variation in yield can be observed, due to cropping practices and particularly to fertilization. As a general fact, nut trees can be cropped in any soil types except on saline soils, where particularly almond is sensitive.

A BALANCED FERTILIZATION: THE COMMON DENOMINATOR

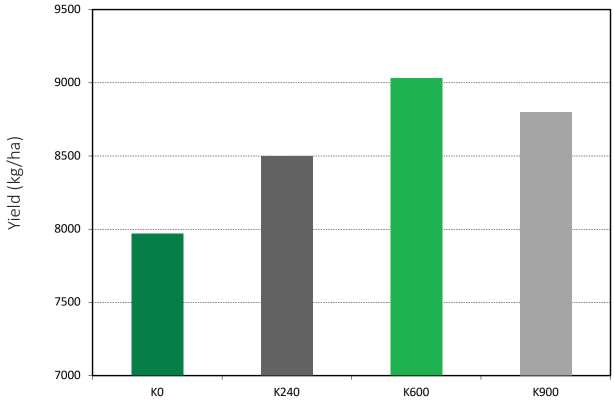
Little research has been done on nut crops. Because of their economic importance, data is available mainly on pistachio and almond.

	N	P_2O_5	K_2O
	kg/ha for mature trees		
Almond	150	50	250
Cashew	300	100	250
Chestnut	80	20	100
Hazelnut	200	100	150
Macadamia	120	80	200
Pecan	200	80	200
Pistachio	100	70	150
Walnut	170	50	250

NPK standard fertilization of nut trees

Though these crops can be very different, their common characteristic is a relatively high requirement in potash compared to nitrogen and phosphorus, as presented in the table above.

A balanced fertilization is a prerequisite to ensure root growth and a full development of the plant. Potassium is the most important element to produce marketable nuts. All nuts are rich in potassium, phosphorus and magnesium. They are also a valuable sources of vitamins.

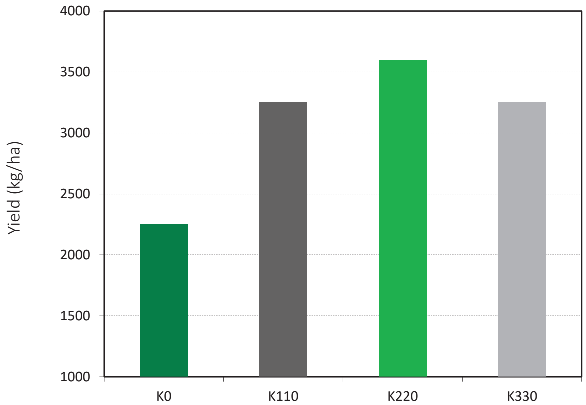


Cumulated production 1998-2000 in almond (USA, 2006)

The above graph is the response curve to potassium doses during three seasons. Production is improved up to a dose of 600 kg K_2O/ha, which is higher than common practice as described in the table above. It is worth noting that almond yields in California are higher than the world average.

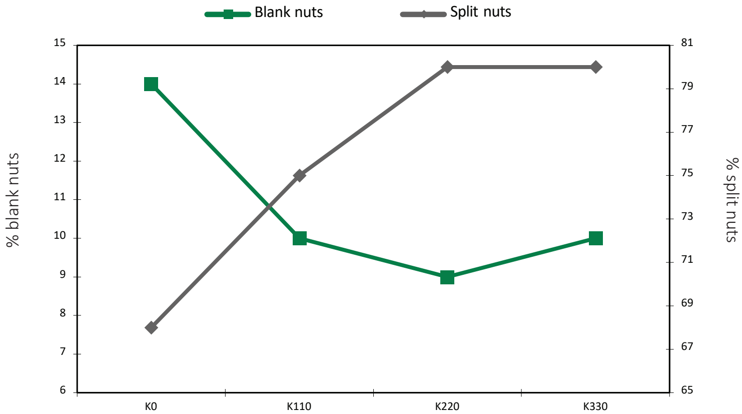
Potassium deficiency on almond leaf

Many nuts are still cropped under traditional practice, although, some recent research demonstrates the benefits of potash fertilization in modern nut production. Using sulfate of potash in nut fertilization is the guarantee to produce more and better nuts as demonstrated in a trial carried out in California.



Response of pistachio to potassium sulfate (USA, 2006)

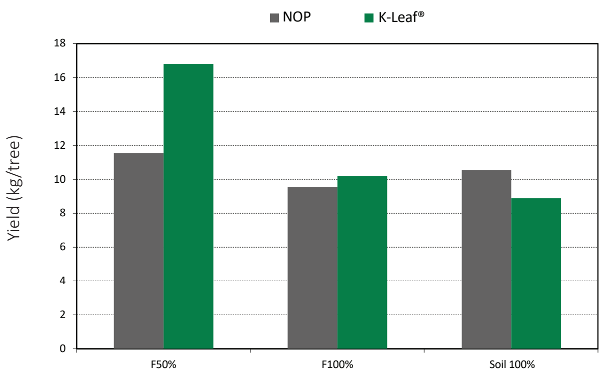
As an example of the effect of potassium sulfate on quality, the percentage of split pistachio increases with SOP doses and the percentage of blank pistachio are decreased. This is illustrated in the following graph.



Effect of potassium sulfate on the % of blank pistachio and % of split pistachio (USA, 2006)

SOLUBLE SOP FOR FERTIGATION AND FOLIAR SPRAY

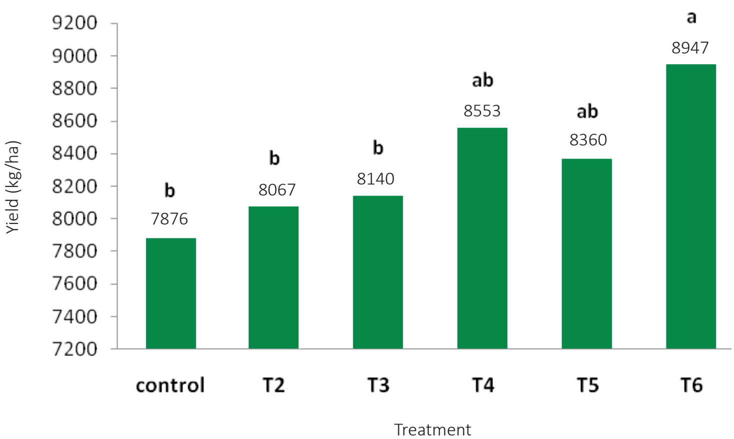
More and more, nuts are produced under drip irrigation and fertigation. SoluPotasse is the best source of potassium to be used in fertigation and K-Leaf for foliar application. An example is given below on the use of K-Leaf as a foliar spray, compared to potassium nitrate, as well as both forms as soil application. Application was based on export quantities of potassium (0.7 kg K_2O/per tree). Treatments were soil application at full dose for SOP and NOP, alongside full dose and half dose applied as foliar sprays for both K-Leaf (SOP) and NOP. The half dose of SOP in the form of K-Leaf applied as foliar sprays improves production of pistachio in this experiment carried out in Tunisia, as well as quality of the production.



Effect of K-Leaf vs NOP on pistachio production (INAT, Tunisia, 2004)

Another experiment was carried out in Iran, one of the most important pistachio producers in the world, in order to compare dose and application timing of K-Leaf in foliar spray. Treatments are the following:

T1 is the control (N,P,K in basal fertilization according to local recommendations)
T2 is control + 1 foliar application of 8 kg K-Leaf, at fruit formation stage
T3 is control + 1 foliar application of 16 kg K-Leaf, at fruit formation stage
T4 is control + 1 foliar application of 8 kg K-Leaf, at nut filling stage
T5 is control + 1 foliar application of 16 kg K-Leaf, at nut filling stage
T6 is control + 2 foliar applications of 8 kg K-Leaf each, at fruit formation and nut filling stages



Effect of different treatments on pistachio yield (SWRI, Iran, 2017)

This experiment is a good illustration of the benefit of K-Leaf on pistachio production as well as the importance of application timing when it comes to foliar applications.

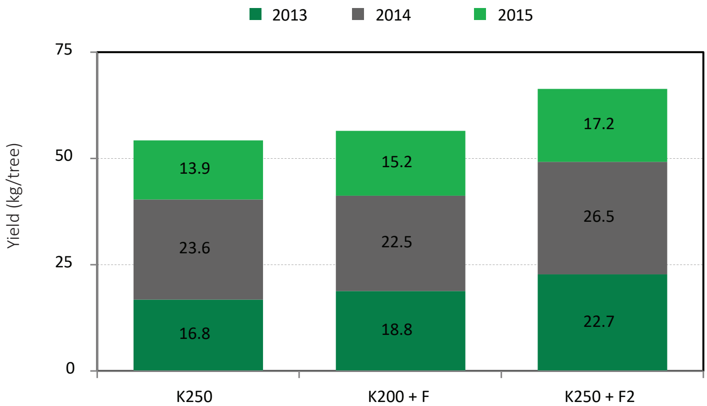
Potassium deficiency on cashew leaf

As a general fact, potassium sulfate encourages better fruit wood development and flowering and contributes to the overall health of the tree. It helps trees grow consistent bud sets and crops and increases the size and quality of nuts.

SOP improves water use through regulation of photosynthesis and transpiration. Low chloride content minimizes potential chloride damage and subsequent yield reductions.

Another example on walnut illustrates the benefit of foliar applications of K-Leaf. In this experiment, the first treatment was the standard treatment calculated according to expected production: 125 kg K_2O/ha applied to the soil. The second treatment was 100 kg K_2O/ha applied to the soil and 5 foliar applications of 5 kg K_2O/ha and the last treatment was the combination of 125 kg K_2O/ha applied to the soil and 5 foliar applications of 5 kg K_2O/ha.

The following graph illustrates the cumulative production from 2013 to 2015.



Effect of K-Leaf on walnut production over 3 years (France, 2013)

The advantage of foliar sprays of K-Leaf is clear at the same total dose of potassium as well as a complement of the standard fertilization. Walnut quality is also improved: less waste, more extra quality and a better kernel/shell ratio leading to a 20 % increase in the grower's income.

OLIVE

MINERAL NUTRITION

Olive trees are typical of the Mediterranean area, but are also cropped in California, Latin America and Australia. Mineral nutrition is the main factor affecting yield in cropping the olive tree, together with water management and planting density. Although cropping conditions vary from one place to another, nutrient uptake averages 300 g N, 75 g P_2O_5 and 500 g K_2O per tree, per year.

Foliar diagnosis is an excellent method for monitoring fertilization, especially when fertigation is being used. Foliar analysis needs to be carried out annually on leaf samples collected during the winter months.

Normal ranges under Mediterranean conditions are shown in the following table.

	N	P	K	Mg	Ca	S
Minimum	1	0.05	0.22	0.08	0.56	0.02
Mean	1.77	0.12	0.80	0.16	1.43	0.15
Maximum	2.55	0.34	1.65	0.69	3.15	0.28

Foliar analysis data (% of dry matter)

The general recommendation for standard production is to apply 500-1000 g N, 300-500 g P_2O_5 and 600-1200 g K_2O per tree, in order to cover the instantaneous requirement and plant growth.

The method of application plays a key role in fertilizer efficiency, especially for potassium, which is not mobile except in sandy soils. Since the uptake of mineral nutrients occurs at the root level, fertilizers must be applied close to the roots, either on the soil surface, or “side dressed” along the lines of trees (if possible at 15/20 cm depth in clay soils), or at about 50 cm from the trunk when fertigation drippers are used.

Production level	N	P_2O_5	K_2O
< 15 kg/tree	400	200	500
15 - 30 kg/tree	500	300	600
30 - 50 kg/tree	700	400	800
> 50 kg/tree	1000	500	1200

Fertilizer recommendation (g/tree/year)

POTASSIUM FOR PRODUCTIVITY

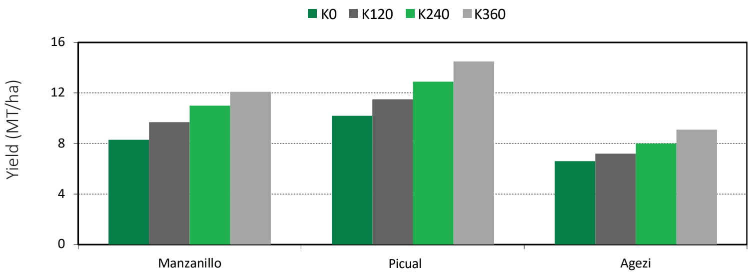
Potassium is essential in olive production: it is an activator of the main biological reactions and it plays a key role in transport of elements within the plant. As the controller of water exchange, potassium is vital in a Mediterranean climate.

Potassium deficiency in olive tree leaves

Potassium deficient leaves are light green and, in the case of a severe deficiency, show tip burn as well as dead branches in the tree.

BETTER RESULTS WITH POTASSIUM SULFATE

Potassium sulfate (SOP) is strongly recommended for use on chloride sensitive crops, such as olive trees grown under semi-arid conditions. Furthermore, compared to other potash fertilizers, it enhances micronutrient uptake: experiments have demonstrated that SOP contributes to the reduction of iron deficiency in orchards growing on calcareous soils, thanks to the acidification effect of SOP in the rhizosphere.

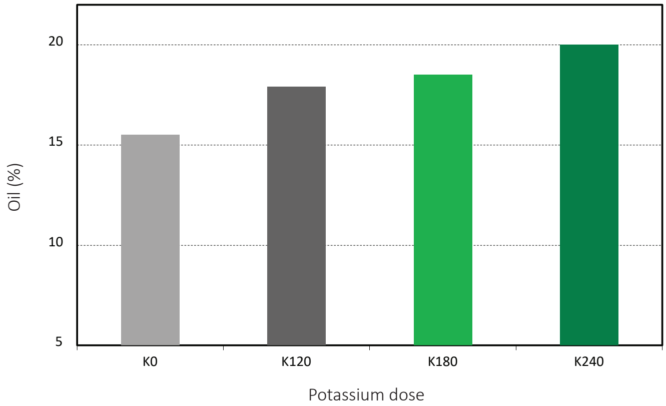


Olive cultivar response to potassium sulfate (doses in K_2O) (Egypt, 2006)

Sulfur is also an important nutrient for olives. It plays a key role in protein and oil synthesis: the normal leaf content for olive trees is 0.10 to 0.25 % of the dry matter. 70 % of S-protein is contained in the chloroplasts for photosynthesis. SOP, which contains 18 % S, easily covers the sulfur requirements for olive trees, improving oil content as well as total yield.

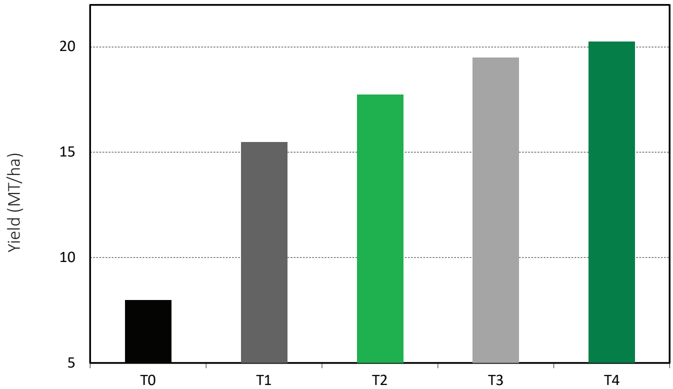
SOLUBLE SOP FOR FERTIGATION AND FOLIAR SPRAY

Whichever method of irrigation is selected, it is always advisable to improve soil fertility before planting. With traditional irrigation, split applications, especially for P and K, are not really necessary in deep loamy-clay soils for tree growth and fruit production. In contrast, split application is very efficient with fertigation. When SoluPotasse is used in fertigation, its acid reaction helps to prevent the clogging of drippers. Based on a crop density of 200 trees/ha, SoluPotasse should be applied over 10 weeks between May and July (Northern Hemisphere), on the basis of 40 kg SoluPotasse per week, per ha. The graph below illustrates the effect of the dose of potassium sulfate on the production of olive oil.



Oil content according to SOP application (doses in K_2O) (Egypt, 2001)

In this second experiment, we compared two doses and two application methods: soil and foliar. At the same level of potassium, foliar application provides higher yield. Soil application in fruit trees usually shows a slower response whereas foliar sprays provide an immediate availability of nutrients to the plant.



Olive response to application method
kg/ha K_2O: T0= 0, T1= 50 (soil), T2= 100 (soil), T3= 50 (foliar), T4= 100 (foliar)
(Egypt, 2003)

Foliar spraying of K-Leaf has also been proven to complement soil application and is particularly effective in correcting severe deficiency. After a soil application of granular SOP in late winter at a rate of 1 kg per tree, K-Leaf should be applied as foliar spray 2-5 times from spring until mid-summer. Concentrations of the solution should be between 2 and 4 % when the application volume is 10 l/tree.

Whatever the type of application, ground fertigation or foliar spray, olive production and quality will benefit from the applications of SOP.

PINEAPPLE

MINERAL NUTRITION MANAGEMENT

Pineapples are usually produced in an intensive cropping system and balanced mineral nutrition is the basis for high quality production and marketable fruits. Phosphorus must be applied at planting or during the first months of cropping, whereas it is preferable to split application of nitrogen and potassium throughout the cropping period. It is advisable to base fertilizer dosage on soil analysis and foliar diagnosis.

Pineapples prefer light soils, with good drainage and a pH from 4.5 to 6.5. For standard field production, fertilization is in the range of 500-650 kg/ha for nitrogen, 50-180 kg/ha for phosphorus and 300-600 kg/ha for potassium. The table below presents a fertilization program according to pineapple growth.

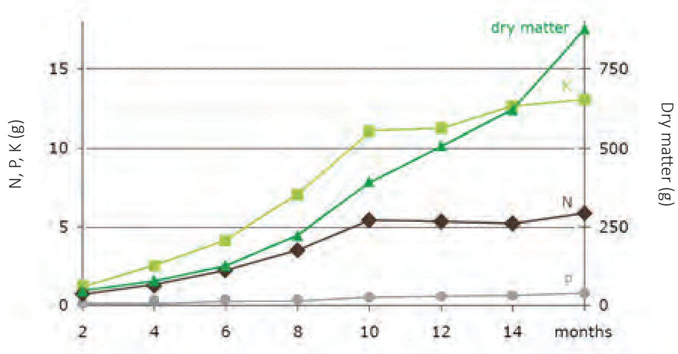
	N	P_2O_5	K_2O
Plant crop			
Within 1 month of planting	15 %	33 %	20 %
Early spring (at 6 months)	20 %	33 %	20 %
Early summer (at 9 months)	20 %	33 %	30 %
Early autumn (at 12 months)	15 %		10 %
Late autumn (at 14 months)	10 %		
Early spring (at 18 months)	20 %		20 %
Ratoon crop			
Late summer (after harvest of plant crop)	40 %		60 %
Mid-autumn	20 %		
Early spring	40 %		40 %

% of N, P_2O_5 and K_2O according to growth

CHAPTER 2

POTASSIUM, THE KEY NUTRIENT

Potassium has an essential role in high yields and fruit quality. It stimulates plant growth and fruit size, and enhances fruit aroma and fruit flesh coloration.

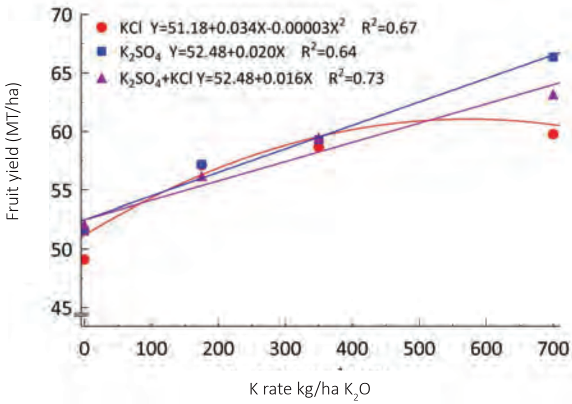


Element uptakes (left scale) and dry matter growth (right scale)

Shortened leaves with pale colour characterize potassium deficiency. Older leaves turn yellow-brown and the fruits are smaller with a pale colour and a shorter shelf life. The form of potassium influences plant growth and quality of the fruit, particularly in intensive production where high doses of potassium are applied.

POTASSIUM SULFATE FOR HIGHER YIELD

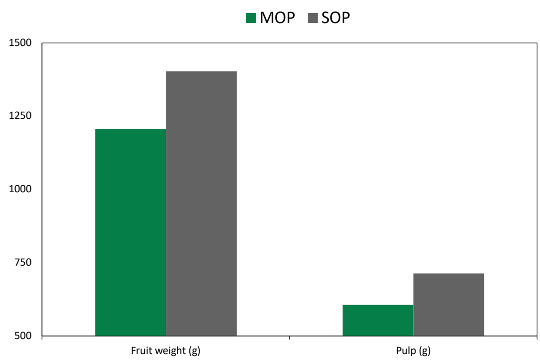
The pineapple crop has a medium sensitivity to chloride. An excess of chloride affects fruit yield, colour and taste, by decreasing the sugar/acidity ratio, and high concentrations reduce water and mineral uptakes from the soil. A number of experiments comparing treatment with SOP and MOP treatments show the detrimental effect of chloride.



MOP and SOP effect on production (Brazil, 2010)

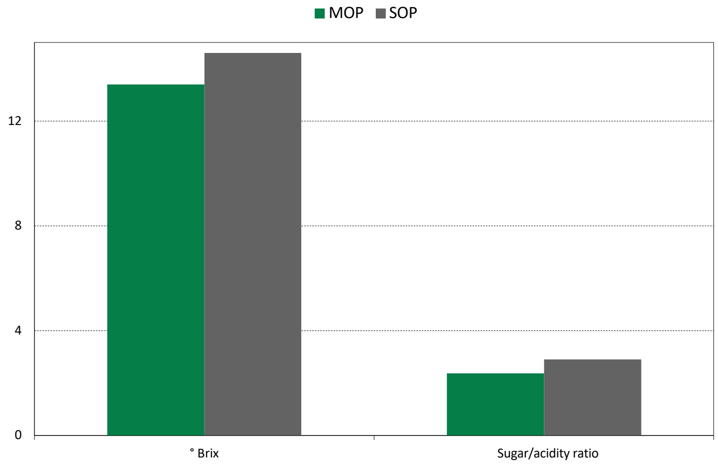
POTASSIUM SULFATE FOR QUALITY

Experimental results for quality parameters also favour potassium sulfate.



MOP and SOP effect on fruit size (Brazil, 1984)

The following graphs show an increase of the fruit size when SOP is applied compared to MOP, as well as the effect on the taste through a higher sugar/acidity ratio.



MOP and SOP effect on fruit taste (Brazil, 1984)

K-LEAF AND SOLUPOTASSE USE IN PINEAPPLE PRODUCTION

As with many plants from the Bromeliaceae family, the pineapple has aerial roots on its stem that can absorb mineral fertilizers. Therefore, foliar application of K-Leaf contributes to higher quality production and a better efficiency of the basal dressing. Applied directly at the base of leaves, it is easily absorbed.

SoluPotasse can be used in fertigation, allowing growers to apply nitrogen and potassium separately.

POME FRUITS

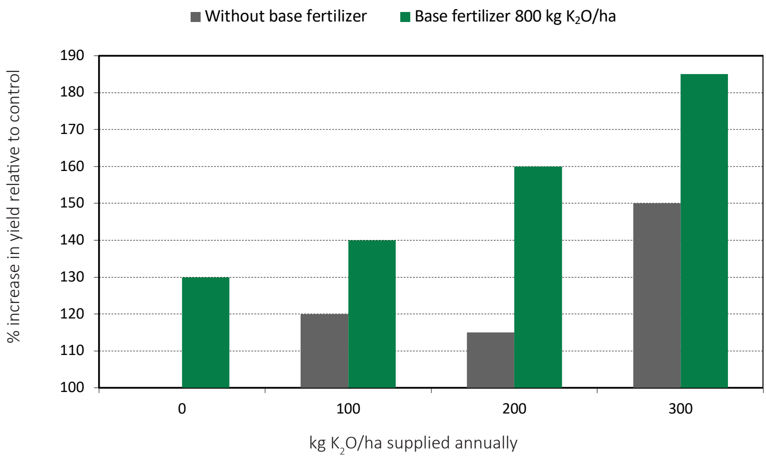
LOOKING FOR BALANCED NUTRITION

The best-known example of a pome fruit is the apple. Other plants that produce fruit classified as a pome are loquat, nashi, pear and quince. Fertilization prior to planting is aimed at promoting good rooting and rapid development, whereas the annual fertilization program should target a balanced nutrition in order to optimise yield and quality. Choices will be largely guided by soil analysis, complemented by foliar diagnosis.

Potassium deficiency in apple tree

For an orchard in production, nitrogen fertilizer should be supplied at the end of winter or beginning of spring. Phosphorus, which has limited mobility, should be applied close to the roots.

When it comes to potassium fertilization, the key to success is the combination of the base fertilizer and the annual supply of potassium. A ten year study on apples, carried out at the Pôle d'Aspach research centre in France, demonstrates the benefits of the two sources of potassium (cumulative results of 10 years of trials).



Effect of potassium application on apple yield
(Pôle d'Aspach Research Station, France, 10 years study)

The two supplies are necessary even after ten years: the annual supply will not compensate for the absence of a base fertilizer and vice versa.

Potassium deficiency in pear tree

WHAT FORM OF POTASSIUM?

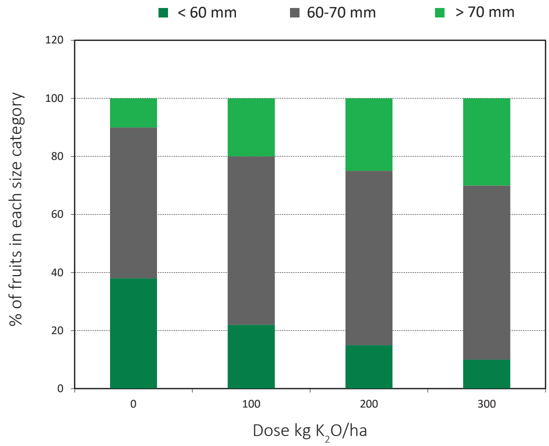
A supply in the sulfate of potash form is always preferable, notably for its beneficial role in the formation of sugars and organoleptic components. Sulfate of potash is ideal for fruit tree cultivation in cases where there is sensitivity to chloride or excess salinity.

In soils that have high chloride levels, the active calcium tends to block the uptake of available iron, leading to ferric chlorosis. The sulfate anion has an acidifying effect on the soil, helping to free the iron. In fact in any situation, sulfate of potassium helps to ensure an adequate uptake of iron.

In addition, sulfate of potash improves resistance to frost and enhances the production of dry matter: this gives firmer fruits that are consequently easier to transport and have a greater resistance to storage.

SULFATE OF POTASH FOR IMPROVED QUALITY

As a result of its action on the transport of sugars from the leaves to the storage organs, sulfate of potash has a direct influence on the calibre of fruits. The result of the following experiment clearly demonstrates the positive effect of potassium sulfate on the calibre of apples. Equally noteworthy is its influence on sugar levels and the balance between sugar and acidity, which have a key influence on the taste of the fruits.



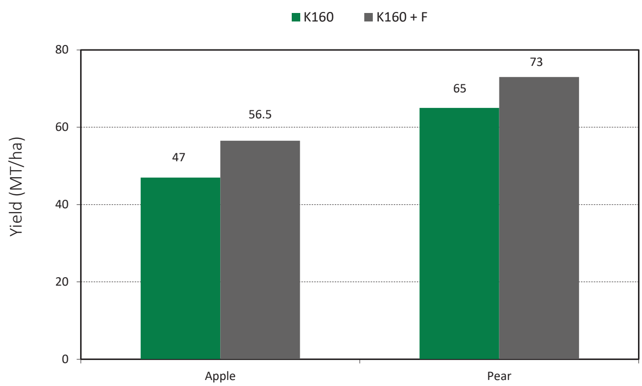
Distribution of apple calibre relative to dose of potassium sulfate.

Sulfate of potash also increases the levels of pigments in fruits, giving them an improved appearance with more vivid colouration.

BENEFIT OF SOLUBLE SOP

SoluPotasse, the soluble grade of SOP produced by Tessenderlo Kerley, is specially designed for fertigation and K-Leaf for foliar sprays.

Foliar applications of K-Leaf allow the correction of potassium deficiency more quickly than soil applications. It can help to feed the plant when instant requirement in potassium is high. In the example below three sprays of K-Leaf at 3 kg/ha in 1000 litres of water was applied.



Effect of foliar spray of K-Leaf (IAV, Morocco, 2008)

Amongst the other benefits of sulfate of potash is the supply of sulfur in a form that is readily taken up by the tree.

Finally, the sulfate form does not contain any chloride, which can perturb plant transpiration and growth. The supply of water is also better regulated, reducing the impact of dry periods.

On the left an apple from an orchard treated with SOP, compared to the control on the right.

POMEGRANATE

BASE OF MINERAL NUTRITION

Pomegranate are grown in sub-tropical climates, preferably with cool winters and hot and dry summers An example of fertilization from California is presented in the table below.

Age (year)	N	P_2O_5	K_2O
1 - 2	150 - 225	150 - 225	150 - 225
3	225 - 340	225	225 - 340
4	340 - 450	225	340 - 450
5 +	450	225	450

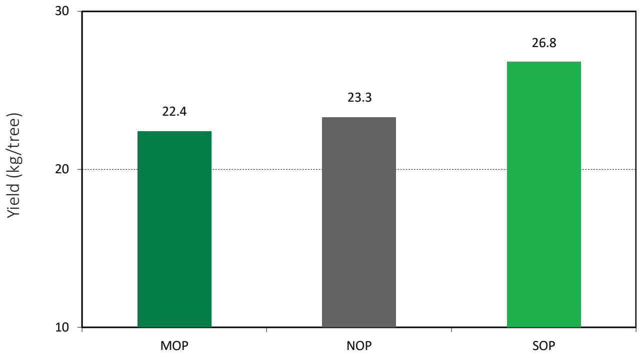
Pomegranate fertilization (g/tree)

Excess of nitrogen can limit fruit production. Split applications from late winter to late spring are recommended.

Plant analysis data – Macronutrients					
	% of dry matter				
	N	P	K	Mg	Ca
Leaves	1.5 - 2.0	0.1 - 0.2	0.6 - 0.8	0.3	0.7 - 1.5

Standard element content in pomegranate

The following experiment was carried out in India, supplying 625 g N, 250 g P_2O_5 and 250 g K_2O per tree, which are the common recommendations in this country. Potassium was supplied in three different forms: chloride (MOP), nitrate (NOP) and sulfate (SOP).



Effect of potassium form on pomegranate production (CAPM, India, 2007)

As shown in the graph, potassium sulfate gives the highest yield. Potassium sulfate also improves quality parameters, such as fruit size and earlier maturation.

FOLIAR APPLICATION OF K-LEAF

An interesting experiment was carried out in the Ismailia region of Egypt with the National Research Centre in 2011 and 2012. Basal dressing was as follows: 37 m^3 per ha of farmyard manure during December/January. NPK rates were 200 Kg N/ha as ammonium nitrate (33.5 % N) and calcium nitrate (15.5 % N), 75 kg P_2O_5/ha, as phosphoric acid (60 % P_2O_5) and 175 kg K_2O/ha as potassium sulfate (50 % K_2O) using fertigation with a drip irrigation system (application divided throughout the growing season). The different treatments studied were foliar applications of K (60 g K_2O/tree), Mg (24 g MgO/tree) and Mn (9.5 g Mn/tree) and their combinations.

Treatment	Yield (kg/tree)	Juice volume per fruit (ml)	Fresh weight (g per fruit)	K (%) in grains
Control	7.62	64.81	190.46	1.03
K	12.98	116.44	324.42	1.58
Mg	12.84	109.30	321.23	1.20
Mn	11.53	98.08	288.10	1.30
K + Mn	16.01	136.22	400.34	1.38
Mg + Mn	13.24	112.65	331.07	1.10

Effect of foliar applications on pomegranate yield and quality (NRC, Egypt, 2012)

This trial is an excellent example of the limitations of good NPK fertilization in the presence of a micro-nutrient deficiency, in this case manganese. The use of potassium improves yield by 70 % and manganese by 50 %, but the use of both nutrients improves yield by 110 %. In addition, quality parameters are also improved.

STONE FRUITS

THE BASE OF BALANCED NUTRITION

Stone fruit is the general term used for some fruit of the Prunus species. The most popular stone fruits are plum, cherry, peach, nectarine and apricot. The good rooting and rapid development of an orchard depend on a comprehensive knowledge of fertilization techniques and products. The annual fertilization program should target a balanced nutrition in order to optimise yield and quality. Choices will be largely guided by soil analysis and complemented by foliar diagnosis.

As a general rule, for orchard in production, nitrogen fertilizer should be supplied at the end of winter or beginning of spring. Phosphorus, which has limited mobility, should be applied close to the roots.

Potassium deficiency in plum leaf

When it comes to potash fertilization, the combination of a good fertilization at planting and the annual potassium supply is the right strategy. Potassium uptake reaches its maximum at the end of spring and early summer, during fruit growth. Potassium deficiency is sometimes found in peaches, plums, and nectarines, but it is more frequently observed in plums.

Symptoms first develop in early summer on mid-shoot leaves, which show a pale colour similar to nitrogen deficiency. Leaves show a characteristic curling or rolling, especially in peaches. Leaf margins become chlorotic and then necrotic, leading to a marginal scorch that is particularly evident in plums. This necrosis extends, leading to cracks and necrotic spots. Both shoot growth and leaf size are reduced. Fewer flower buds are produced and the resulting fruit are smaller. Fruit colour in peaches is poor.

Potassium deficiency in peach leaf

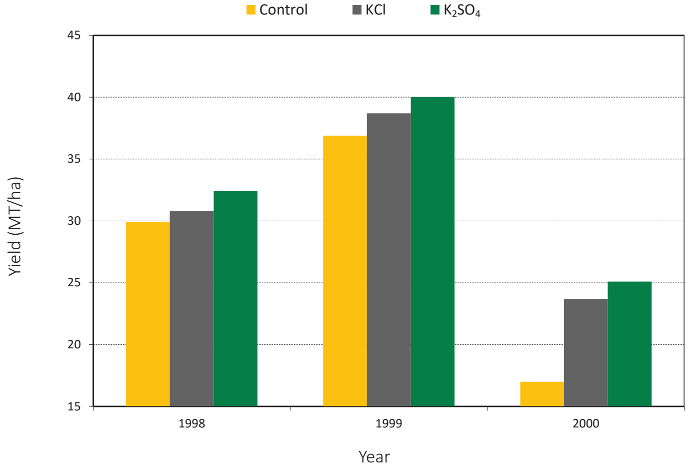
WHAT FORM OF POTASSIUM?

Potassium chloride is not recommended because of chloride's detrimental effects. The nitrogen component must be accounted for when applying potassium nitrate. Heavy applications may supply more nitrogen than is desirable for good fruit quality.

	Requirement (K_2O/ha)	Optimum K level in leaf (% of dry matter)
Apricot	100 - 200	2.70
Cherry	80 - 100	1.80
Peach/Nectarine	100 - 200	2.10
Plum	60 - 100	2.25

Potassium and stone fruit standard production

A supply in the sulfate of potash form is always preferable, notably for its beneficial role in the formation of sugars and organoleptic components. It is ideal for stone fruits that are particularly sensitive to chloride and excess of salinity. In an experiment from Chile, the benefit of potassium sulfate is obvious.

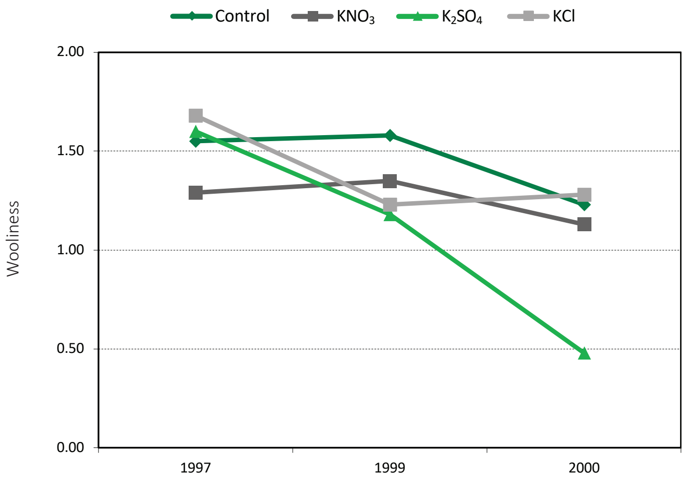


Effect of the form of potassium on nectarine (Chile, 2004)

In addition, sulfate of potash improves resistance to frost and enhances the production of dry matter: this gives firmer fruits that are consequently easier to transport and have a greater resistance to storage.

SULFATE OF POTASH FOR IMPROVED QUALITY

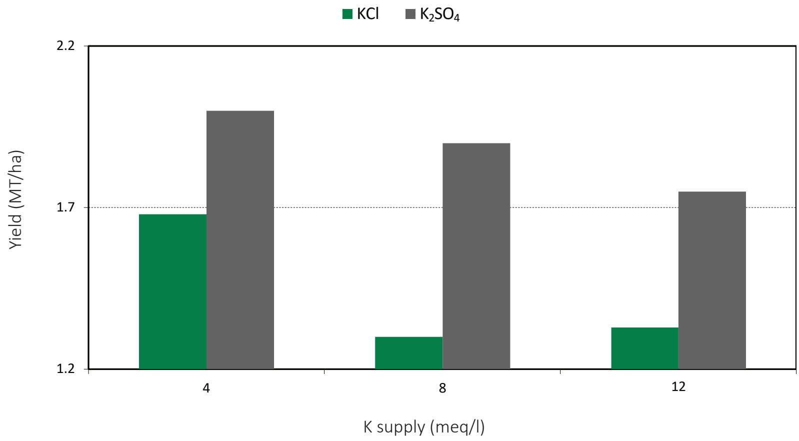
In peach and nectarine production, woolliness is a serious problem that appears after cold storage. K treatments reduced wooliness, with potassium sulfate being the most effective as shown in the following experiment, carried out in Chile.



Effect of potassium sources on woolliness in nectarine production (Chile, 2006)

Three fertilizer sources were compared: potassium nitrate (KNO_3), potassium sulfate (K_2SO_4) and potassium chlorine (KCl), at an annual dose of 300 kg K_2O/ha. After three years, only potassium sulfate showed a positive effect, decreasing the percentage of wooliness in fruits. Measurements are made after 30 days at 0°C followed by 3 days at 20°C. Scale is 0 = without wooliness, 1 = moderate and 2 = severe.

Another example of the effect of potassium source on yield is given in an experiment on sour cherry.



Effect of the form of potassium on sour cherry (Germany, 1990)

Sulfate of potash also increases the levels of pigments in fruits, giving them an improved appearance with more vivid colouration. As a result of its action on the transport of sugars from the leaves to the storage organs, sulfate of potash has a direct influence on the size and taste of fruits.

FOLIAR APPLICATION OF K-LEAF

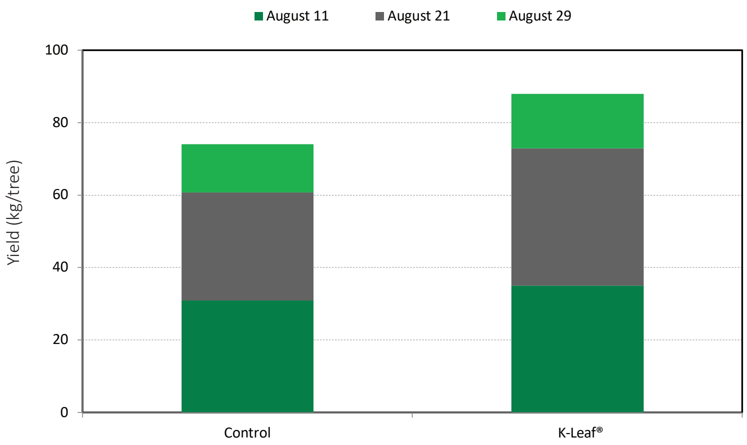
Stone fruits benefit from foliar applications of K-Leaf, the soluble grade of potassium sulfate from Tessenderlo Kerley. In an experiment on plum from Tunisia, comparing the control, a half dose (120 g K_2O/tree) and the full dose required (240 g K_2O/tree), applied as spray, a better yield was observed due to fruit weight improvement and better quality parameters as shown below.

Treatment	Control	F 50 %	F 100 %
Weight (g)	66.5	74.2	79.2
Diameter (cm)	4.9	5.0	5.4
Firmness (kg/cm²)	2.2	2.9	3.7
Brix (°)	12.8	12.9	13.1
Acidity	4.0	4.6	5.2

Foliar applications of K-Leaf on plum (INAT, Tunisia, 2010)

Amongst the other benefits of sulfate of potash is the supply of sulfur in a form that is readily taken up by the tree. Finally, the sulfate form does not contain any chloride, which can perturb plant transpiration and growth. The supply of water is also better regulated, reducing the impact of dry periods.

Another trial on prune (plum for dry fruit production) confirms the benefit of K-Leaf on yield and quality. 3 sprays of 8 kg per ha each improve yield by 18 % as well as sugar content.



Effect of K-Leaf on prune production (3 harvest times) (BIP, France, 2017)

STRAWBERRY AND SMALL FRUITS

MINERAL NUTRITION

The mineral nutrition of strawberry is well documented, but less information is available concerning other small fruits. As a general rule, small fruits prefer acid soils. The table below shows mineral requirements for the main species.

	N	P_2O_5	K_2O
Blueberry	85 - 110	50 - 65	50 - 95
Cranberry	30 - 80	30 - 70	70 - 120
Redcurrant	85 - 120	30 - 70	100 - 150
Gooseberry	100 - 150	30 - 75	100 - 200
Raspberry	55 - 70	60 - 100	60 - 110
Strawberry	70 - 150	30 - 80	100 - 200

Small fruits mineral requirements in kg/ha for standard field production

POTASSIUM, THE KEY NUTRIENT

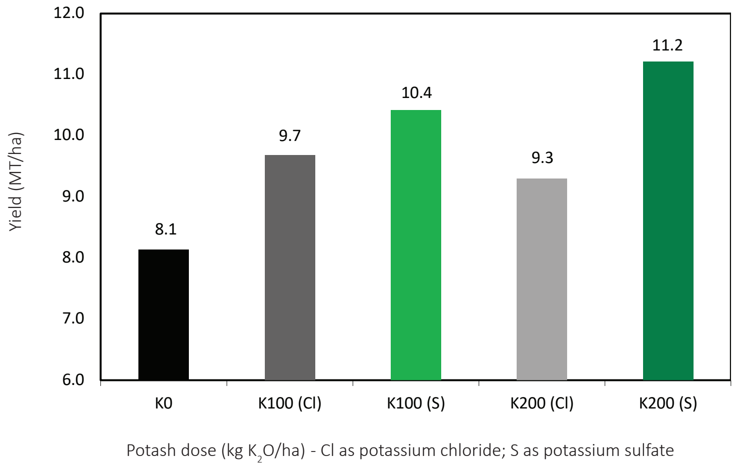
Small fruits prefer loamy-sandy soils to sandy-clayey ones. Potash is an important factor for a high productivity. The role of potassium in sugar synthesis and assimilates translocation is essential for quality.

Potassium deficiency on blueberry leaf

Mineral nutrition can vary widely according to the cropping system and to the yield expectation. For strawberry, a 30 tons/ha production of the Gariguette cultivar requires 180 kg N, 110 kg P_2O_5, and 270 kg K_2O per hectare. A higher level of greenhouse production requires up to 400 kg N, 200 kg P_2O_5, and 700 kg K_2O. Potassium is particularly important at the flowering and fruit development stages. Split applications of potassium are usually recommended for strawberry and cranberry.

POTASSIUM SULFATE FOR HIGHER YIELD

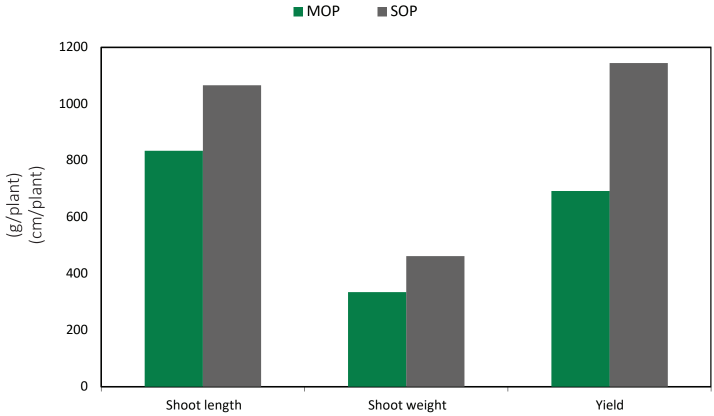
Small fruits are chloride-sensitive crops, particularly gooseberries, redcurrants and strawberries. This is clearly demonstrated by the results from an experiment comparing SOP and MOP treatments on strawberries.



Effect of MOP and SOP on strawberry production (CAAS, China, 2000)

The experiment shows that 200 kg K_2O best meets the requirements of the crop, but that chloride has a detrimental effect. The higher rate of potassium chloride gives a worse result, confirming that potassium sulfate is the more suitable form of potash.

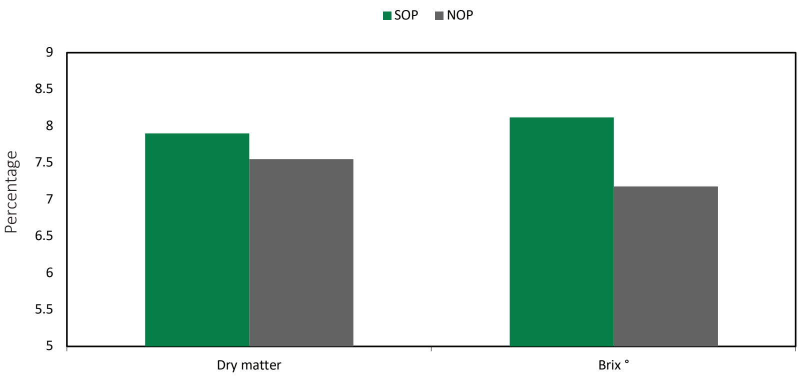
This is also demonstrated by an experiment on raspberries, in which sulfate of potash has a better effect on growth and yield.



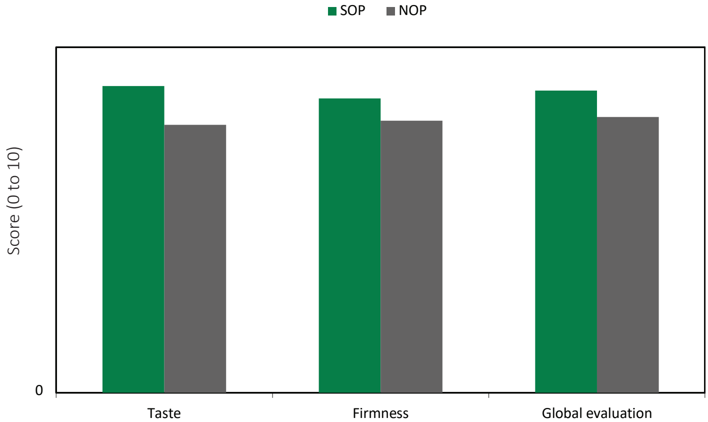
Effect of MOP and SOP on raspberry production (Papp, 1975)

POTASSIUM SULFATE FOR QUALITY

An experiment carried out under drip irrigation in France shows the benefit of SoluPotasse, the soluble grade of SOP, compared to potassium nitrate (NOP).



Effect of SOP and NOP on strawberry quality (Aspach Research Center, 2000)



SOP and NOP treated strawberries in blind tasting (Aspach Research Center, 2000)

Strawberries fertigated on the basis of 360 kg K_2O, split into 13 applications, have a higher percentage of dry matter, better firmness, more sugar and greater production consistency. In short, SoluPotasse helps to produce fruit that better meets market requirements. In order to complete the experiment, a blind tasting test involving 70 people was organized. Evaluations were made on a scale from 0 to 10 (10 being the best), and tests were undertaken for each harvest. The results were statistically significant and in line with chemical analysis. They show the clear advantages of SOP on quality parameters.

Foliar application of K-Leaf can also contribute to high quality production and a better efficiency of standard fertilization for small fruit.

Potassium deficiency on strawberry leaf

SULFUR IN SMALL FRUIT PRODUCTION

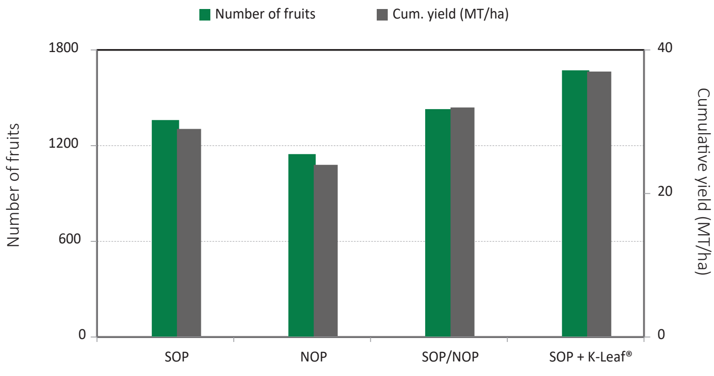
Sulfur is an important nutrient for plant growth, which plays a key role in amino acid synthesis. It should be not neglected, as S deficiencies are more and more frequent. Potassium sulfate contains 18 % S, enough to cover the sulfur requirements of small fruit.

Sulfur deficiency on strawberry leaf

Thanks to the combined effects of potassium and sulfur, sulfate of potash is highly recommended for high quality small fruit production.

K-LEAF IN SMALL FRUIT PRODUCTION

Foliar applications of K-Leaf, combined with fertigation with SoluPotasse improve blackberry production as shown in the graph below. 2 sprays of 25 kg/ha were applied at flowering and 15 days later.



Blackberry production (INIFAP, Mexico, 2016)

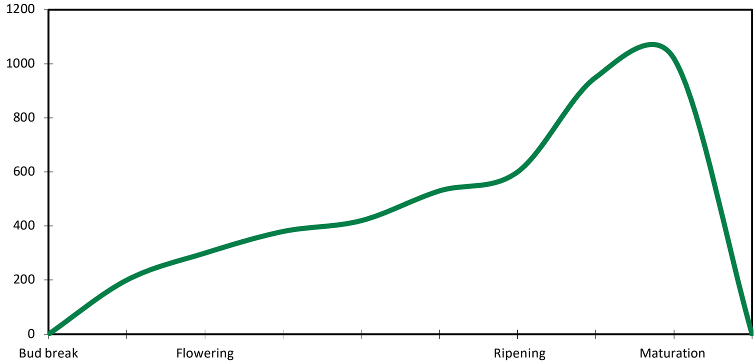
The benefit of K-Leaf on small fruits is confirmed in other experiments on strawberry.

TABLE GRAPE

MANAGING FERTILIZATION

The fertilization strategy for vines for table grapes is different to that for wine grapes. For table grapes, yield, taste and appearance are the main production objectives and managing the equilibrium of the mineral elements in the soil is the main task.

The supply of nitrogen needs to be limited to that removed from the soil, typically 70-80 units (kg) per year in the case of a production of 20 - 25 t/year. Vines do not have a high demand for phosphorus and should only require around 30 units (kg) per year. Magnesium should be monitored on a case-by-case basis. Calcium export can reach 120 units (kg).



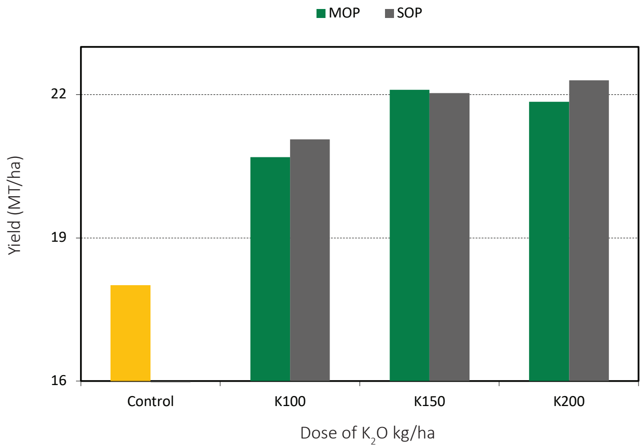
Absorption of potassium by vines (grams of potassium/ha/day)

Uptake of potassium in table grape production represents 100 to 130 kg K_2O/ha. A potassium deficiency (corresponding to less than 0.5 % potassium in the leaf dry matter) will lead to a reduction in the sugar content and will also weaken the plant. Availability is most important from flowering to the maturation stage.

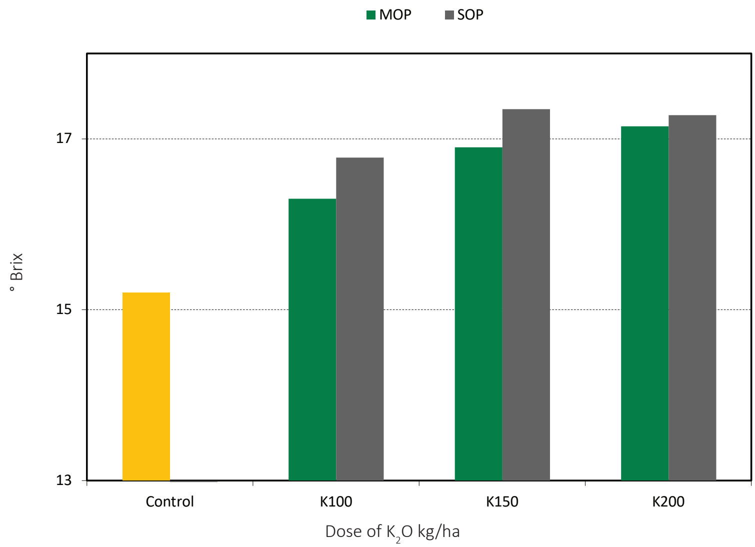
Potassium deficiency in grape

THE CHOICE OF POTASSIUM FORM

Potassium, delivered in the form of sulfate of potash (SOP) is always the preferable choice, notably because of its beneficial role in the formation of sugars. This is illustrated by the experiment below.



Effect of MOP vs. SOP on Red Globe production (CAAS, China, 2005)



Effect of MOP vs. SOP on sugar content in Red Globe (CAAS, China, 2005)

Sulfate of potash is also preferable in regions where there is a risk of salinity, such as the Mediterranean, where vines are widespread. Of all the potassium fertilizers, sulfate of potash is the form that has the lowest salinity index.

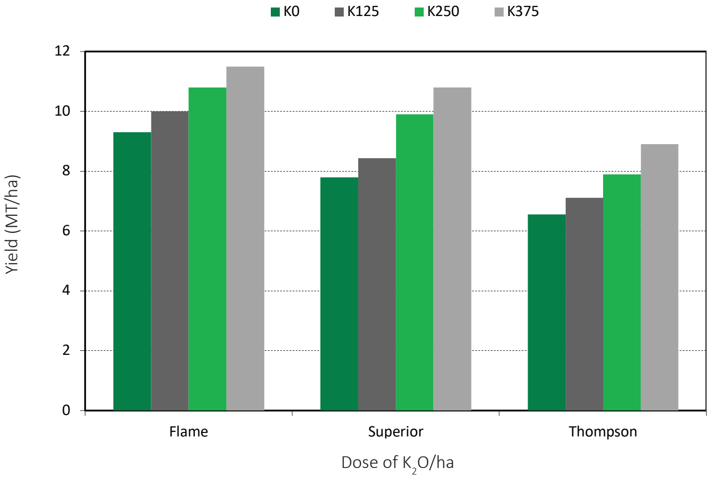
In highly calcareous soils, the calcium has a tendency to block the availability of iron to the vine. The sulfate anion helps acidify the soil, liberating both iron and also phosphorus, which would otherwise be rendered insoluble by the excess calcium. This helps improve the supply of iron and phosphorus to the plant.

Excess of chloride in grape

In addition sulfate of potash increases the vine's resistance to frost and encourages growth of fruit-bearing branches. The fruits are firmer and less sensitive to parasites.

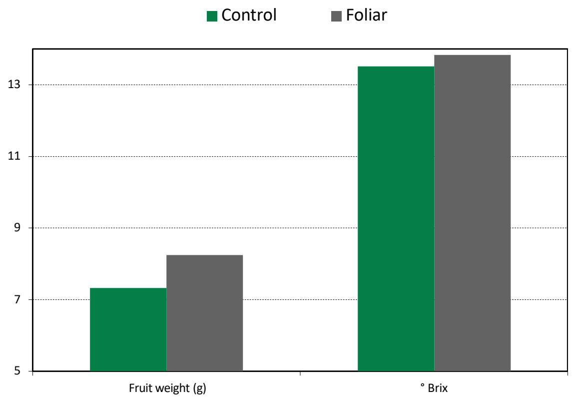
POTASSIUM SULFATE FOR HIGH PRODUCTION

Among the many benefits of sulfate of potash, is the supply of sulfur in a form that is readily available to the vine.



Effect of SOP on production of different varieties (Egypt, 2007)

SoluPotasse, the soluble grade of SOP from Tessenderlo Kerley, can be also used for grapes grown under drip irrigation. Its main advantage is to allow potassium application when required but when nitrogen would be detrimental to high quality production.



Effect of SOP on production of different varieties (Brazil, 1998)

K-Leaf is specially designed for foliar spraying, to avoid mineral deficiency or an imbalance between potassium, magnesium and calcium. Three to five applications at 5 kg-10 kg/ha help the required level of potassium in the leaves to be reached.

Finally potassium delivered in the sulfate form does not add chloride, which can perturb the transpiration of the plants, affecting their growth. With potassium sulfate, the supply of water is better regulated, minimising the effects of dry periods.

TROPICAL FRUITS

THE SEARCH FOR RAPIDLY AVAILABLE NUTRIENTS

Most tropical species are characterized by fast growth, involving short periods of high nutritional requirements. In addition, tropical fruit is frequently grown in poor soil conditions. Fertilization programs should, therefore, take into account these two constraints. Fertilization prior to planting should ensure good rooting and rapid development, whereas annual programs should aim at a balanced nutrition to optimise fruit yield and quality. Choices will be largely guided by soil analysis, subsequently complemented by foliar diagnosis.

Dragon fruit, durian, guava, jackfruit, longan, mangosteen, passion fruit, papaya, rambutan, sapodilla, and star fruit are the most important fruit species after bananas, mango and pineapple.

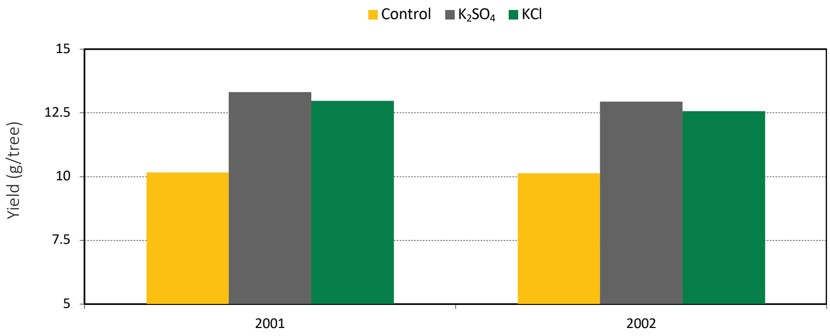
Although the crops can be very different, their common characteristic is a high requirement for potash in order to produce marketable fruits. The K/N ratio is generally greater than one, as shown in the table below.

	N	P_2O_5	K_2O
	g per tree and per year		
Ber (Indian jujube)	80	30	120
Dragon fruit	540	420	500
Durian	800	400	600
Guava	600	600	850
Longan	400	180	400
Mangosteen	1200	600	1200
Papaya	245	145	260
Passion fruit	135	30	150
Rambutan	420	420	600
Sapodilla	420	420	600
Star fruit	600	600	850

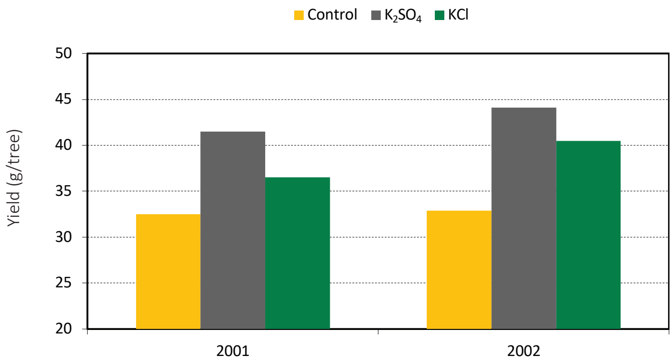
Mineral requirements

WHAT FORM OF POTASSIUM?

Sulfate of potash is ideal for tropical fruit, which are sensitive to chloride or excess salinity. Its effect on fruit yield is now well documented as shown in the two graphs below.



Effect of potash form on dragon fruit production (SOFRI, Vietnam, 2003)



Effect of potash form on longan production (SOFRI, Vietnam, 2003)

SULFATE OF POTASH FOR IMPROVED QUALITY

New research into potash fertilization shows the key role potassium sulfate plays in producing sweet, tasty fruits with good keeping quality. This is due to its beneficial action in the formation of sugars and organoleptic components.

K_2O g per tree and per year	K fertilizer	Yield kg/tree	Fruit flesh ratio	Taste
200	KCl	237.23	19.05	+
750	K_2SO_4	288.24	19.79	++
1050	K_2SO_4	343.16	22.50	+++
1350	K_2SO_4	308.19	22.72	++++
1050	KCl	283.37	21.97	+

Effect of potash form on durian production and quality

As a result of its action on the transport of sugars from the leaves to the storage organs, sulfate of potash has a direct influence on the calibre of fruits.

SULFUR, AN IMPORTANT SECONDARY ELEMENT

Tropical cropping conditions mean low organic matter and the risk of leaching. These two factors often lead to sulfur deficiency. Among the other benefits provided by sulfate of potash is the supply of sulfur in a form that is readily taken up by the plant.

SOLUPOTASSE USE IN TROPICAL FRUIT PRODUCTION

SoluPotasse is widely used in modern papaya production. A standard fertigation program using SoluPotasse is presented below.

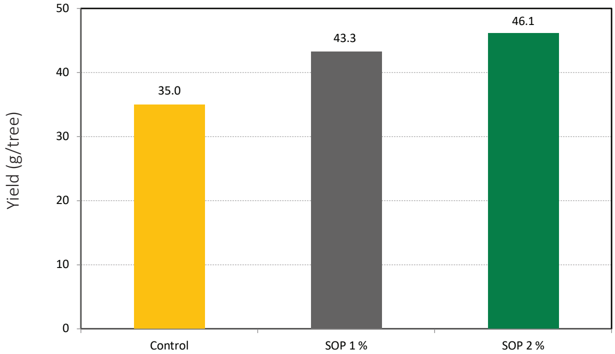
	Planting density from 2000 to 2500 plants/ha			
	Urea	MAP	SoluPotasse	Split in
Planting		10 kg		
1st month	55 kg	20 kg	40 kg	2 - 3 appl.
2nd month	85 kg	40 kg	80 kg	3 - 4 appl.
3rd month	140 kg	80 kg	120 kg	4 - 5 appl.
4th month		100 kg	200 kg	5 - 6 appl.
	From flower initiation to fruit setting			
Every month	75 kg	65 kg	135 kg	5 - 6 appl./ month

The example also shows that SoluPotasse allows potassium to be applied alone, at times when less nitrogen is needed for high quality production.

There is a great potential for the growth of tropical fruit on the world market. Using sulfate of potash for tropical fruit production guarantees a greater volume of fruit with a quality ideally adapted for export markets.

K-LEAF USE ON TROPICAL FRUITS

Foliar applications of K-Leaf can be of interest in fruit production. On guava, fruit production has been increased by 30 % when applying a 2 % solution of soluble SOP (equivalent to 10 kg per ha), as well as the sugar content of the fruits.



Effect of foliar application of soluble SOP on guava yield (Varanasi University, India, 2012)

Another example is coming from India on ber (also called Indian jujube), in the following experiment comparing different form of potash fertilizers sprayed on ber trees during the 2012/2013 season.

Treatment	Fruit length (mm)	Fruit thickness (mm)	Fruit weight (g)	Pulp/stone ratio	TSS° Brix	Acidity as anhydrous citric acid (%)	Ascorbic acid (mg/100 g of pulp)	Fruit yield (kg/tree)
K_2SO_4 1.0 %	41.25	29.82	20.19	16.68	15.2	0.20	106.89	117.94
K_2SO_4 2.0 %	42.05	30.45	20.66	17.62	16.5	0.18	127.48	121.34
KNO_3 1.0 %	40.60	28.21	17.70	14.55	15.5	0.20	80.16	109.64
KNO_3 2.0 %	40.88	28.43	18.80	15.01	15.9	0. 19	93.52	111.40
KCl 1.0 %	39.20	26.76	15.40	15.43	14.3	0.23	80.16	91.50

Treatment	Fruit length (mm)	Fruit thickness (mm)	Fruit weight (g)	Pulp/stone ratio	TSS° Brix	Acidity as anhydrous citric acid (%)	Ascorbic acid (mg/100 g of pulp)	Fruit yield (kg/tree)
KCl 2.0 %	39.45	27.06	15.70	18.06	14.9	0.21	100.20	99.20
KH_2PO_4 1.0 %	40.31	27.70	17.09	15.64	13.6	0.23	86.84	100.96
KH_2PO_4 2.0 %	40.38	28.41	17.70	16.78	14.5	0.21	113.59	104.30
Control (water)	38.12	25.77	14.00	13.56	12.9	0.25	73.48	85.70
CD at 5 %	1.825	0.841	0.577	1.154	0.033	0.024	1.154	8.05

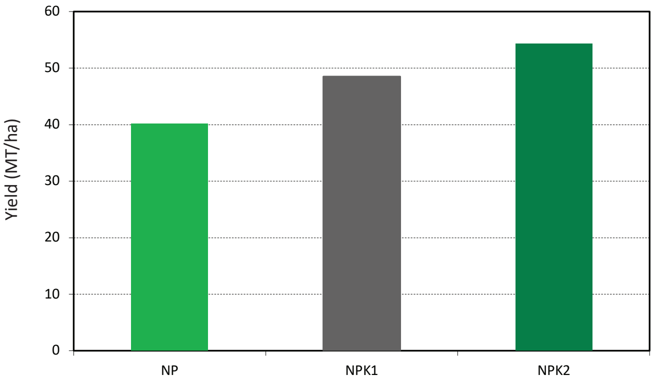
Effect of foliar application of potassium compounds on yield and physico-chemical composition of Ber cv. Banarasi Karaka fruit

The advantage of SOP at 1 or 2 % over NOP, MOP and MKP is clear on yield and numerous quality parameters.

WATERMELON

MINERAL NUTRITION

A production from 25 to 30 MT/ha of watermelon requires the application of 50 - 100 kg N, 100 - 150 kg P_2O_5, 140 - 200 kg K_2O/ha, usually applied along the rows. N is preferably applied in split dressings, at planting, at branching, just before flowering and after first fruit setting. Potassium is important for sugar content in the fruit and to prevent fruit cracking. Watermelon is sensitive to Mg, B, Fe and Zn deficiencies.

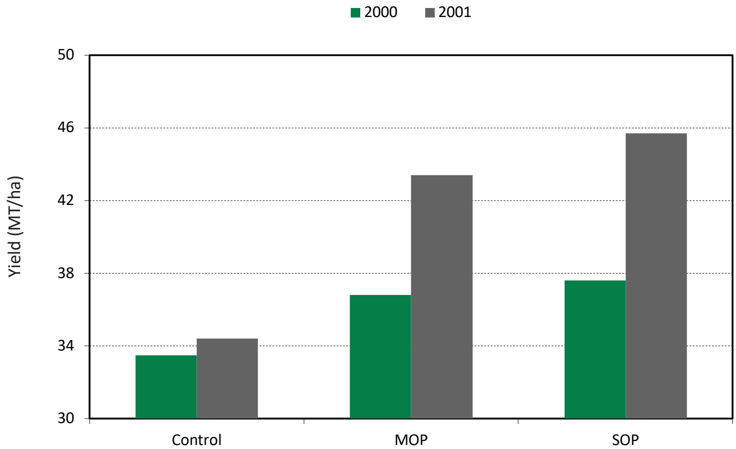


Effect of potassium doses on watermelon production (FAB, Turkey, 2003)

In the experiment above, NP fertilization (120 kg N and 80 kg P_2O_5/ha) was compared to NPK fertilization supplying 120 (K1) or 240 (K2) K_2O/ha. K1 improves by 20 % and K2 by 35 % the production.

SULFATE OF POTASH FOR BETTER YIELD

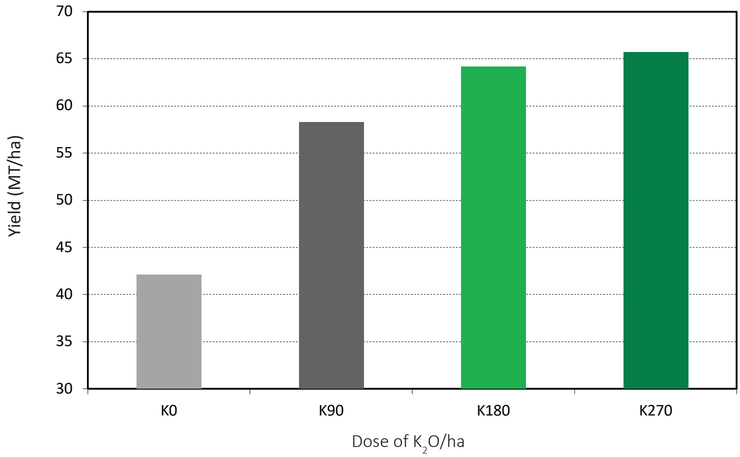
In another experiment carried out in Vietnam, basal dressing without potassium as a control was compared to application of 120 kg K_2O/ha as potassium chloride (MOP) and potassium sulfate (SOP). SOP treatment shows an advantage not only on yield, but also on quality parameters such as fruit weight and sugar content.



Effect of potassium forms on watermelon production (ISA, Vietnam, 2000 & 2001)

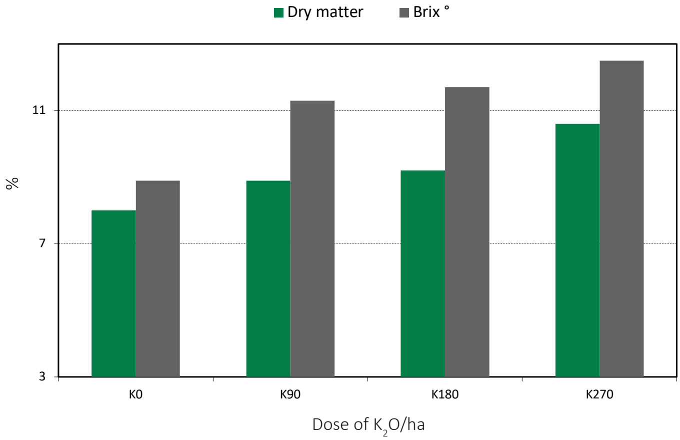
SULFATE OF POTASH FOR QUALITY

An experiment from Hungary confirms the effect on yield and quality.



Effect of potassium sulfate on watermelon production (Corvinius Univ., Hungary, 2011)

The graph above illustrates the role of potassium sulfate on fruit production. The response of watermelon to SOP doses is well demonstrated from 90 to 270 kg K_2O/ha. In addition, potassium sulfate improves dry matter and sugar content as shown in the graph below.



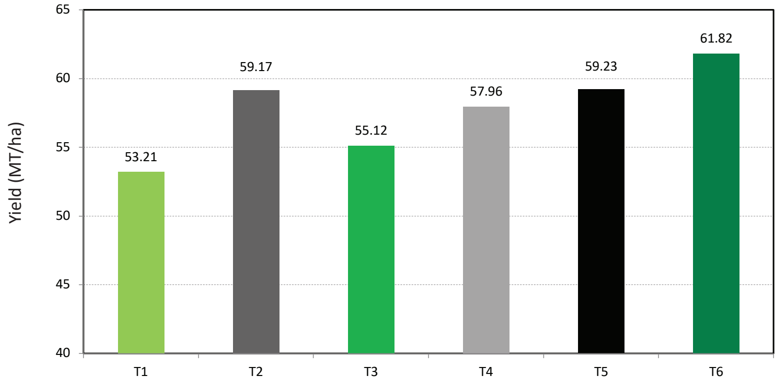
Effect of potassium sulfate on watermelon quality (Corvinius Univ., Hungary, 2011)

Finally, the combination of potassium and sulfur secures production and quality, and improves watermelon resistance.

K-LEAF USE IN WATERMELON PRODUCTION

The demand for potassium is particularly high during fruit growth. Foliar applications of K-Leaf have a double action in potassium nutrition by supplying potassium and stimulating root absorption. In an experiment carried out in Iran, in addition to NPK soil fertilization, the following treatments were applied:

T1. control (N, P, K in basal fertilization according to local recommendations)
T2. control + 1 foliar application of 8 kg K-Leaf, at pre-blooming stage
T3. control + 1 foliar application of 8 kg K-Leaf, at fruit formation stage
T4. control + 1 foliar application of 8 kg K-Leaf, at fruit colouring stage
T5. control + 1 foliar application of 16 kg K-Leaf, at fruit formation stage
T6. control + 2 foliar applications of 8 kg K-Leaf each, at pre-blooming and fruit colouring stages



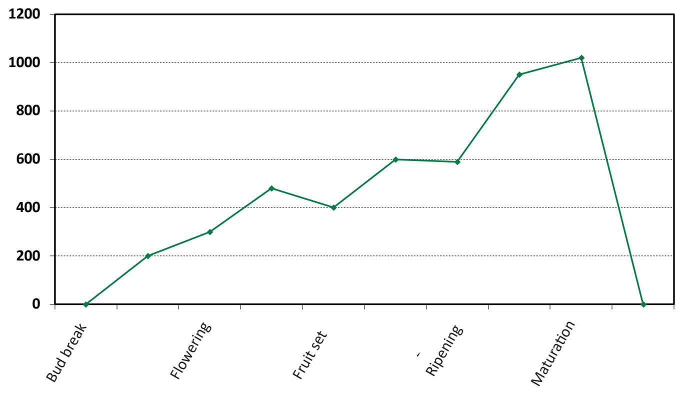
Foliar spray effect on watermelon production (SWRI, Iran, 2017)

Although there is no statistically significant difference, K-Leaf in T6 improves yield by 16 % over control. As a general comment, there is a clear trend in favour of pre-blooming stage (T2 and T6), with a dose effect in the case of T6.

WINE GRAPE

MANAGING THE EQUILIBRIUM

The fertilization of vines is a delicate agronomic operation that has a decisive effect on the quality of the grapes and the resulting wine. The fertilization program must successfully complement the supply of plant nutrients available in the soil in order to allow the vines to express the land's full potential. The fertilization of perennial plants, such as vines, consists primarily of managing the equilibrium of the mineral elements present in the soil. Excess will increase plant vigour to the detriment of grape quality, whereas a deficiency will compromise production as well as the long term quality of the vine. The supply of nitrogen should therefore be limited to the replacement of that removed, typically 30-50 units (kg) per year in the case of vines that are not very sturdy Demand for phosphorus is low and should only requires around 30 units (kg) per year. Magnesium should be monitored on a case-by-case basis.



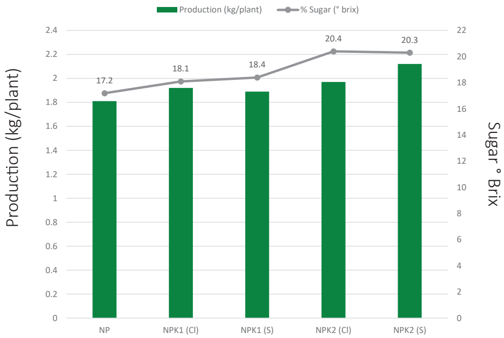
Absorption of potassium by vines (g K_2O/ha/day)

In winemaking, the element potassium is essential for obtaining a good quality must. A potassium deficiency (corresponding to less than 0.5 % potassium in the leaf dry matter) will lead to a reduction in the alcoholic level of the wine and will also weaken the plant. A production of 60 hl/ha requires from 50 to 80 kg K_2O/ha. Availability is most important from mid-June to the end of August (northern hemisphere).

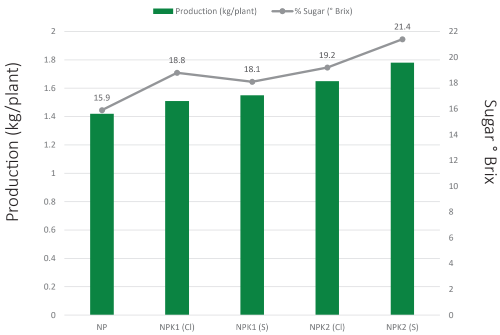
Potassium deficiency in vines

THE FORM OF POTASSIUM

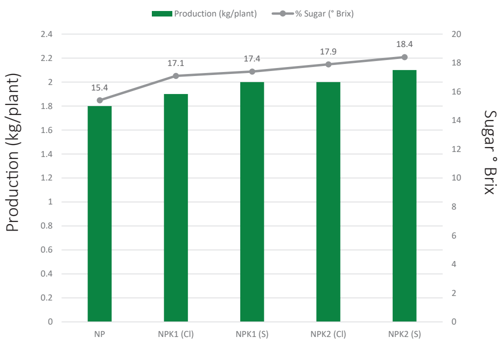
Potassium, delivered in the form of sulfate of potash (SOP) is always preferable, notably because of its beneficial role in the formation of sugars and organoleptic constituents, the contents of which will determine the quality of the wine. In highly calcareous soils, the calcium has a tendency to block the availability of iron to the vine. The sulfate anion helps acidify the soil, liberating both iron and also phosphorus, which would otherwise be rendered insoluble by the excess calcium. This helps improve the supply of iron and phosphorus to the plant. In addition sulfate of potash increases frost resistance and encourages growth of fruit-bearing branches. The grapes are firmer and less sensitive to parasites. Hereafter are some examples of the effect of form (MOP or SOP) and doses (100 or 150 g/plant) of potassium from an experiment carried out in 2004/2005 by the Shandong University in China.



Effect on Italian riesling (Shandong University, China, 2004 & 2005)



Effect on chardonnay (Shandong University, China, 2004 & 2005)



Effect on cabernet (Shandong University, China, 2004 & 2005)

Sulfate of potash is also preferable in regions where there is a risk of salinity, such as the Mediterranean, where vines are widespread. Of all the potassium fertilizers, sulfate of potash is the form that has the lowest salinity index.

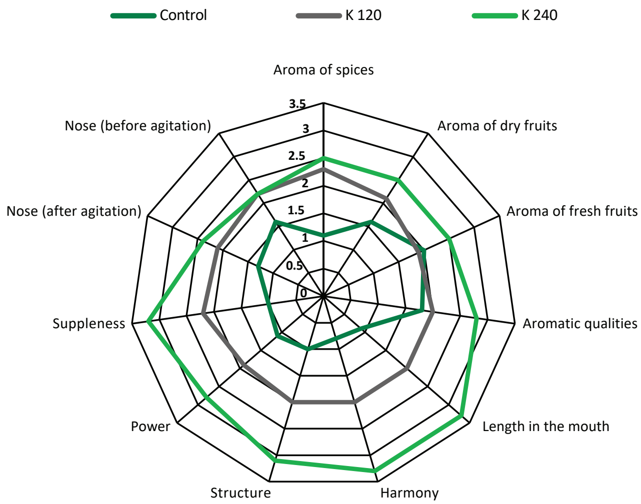
Excess chloride in vines

POTASSIUM SULFATE AND THE QUALITY OF WINE

In wine production, there are three important components at the beginning of fermentation: sugar, malic acid and tartaric acid. Potassium is essential for the biosynthesis and transport of sugars from the leaves to the grapes. It also reacts with the various acids, influencing the pH of the must.

A long term experiment conducted in the Bordeaux region of France has demonstrated that a well-balanced fertilization program, based around potassium sulfate, improves production by maintaining the pH of the must between 3.2 et 4, permitting good transformation of the acids during fermentation.

Notations made by wine experts concerning the aroma and other taste characteristics show the positive effect of potassium in sulfate form over control. The dose of potassium is also important, particularly on power, structure and harmony of wine.



Results of tasting wines from plots receiving 0, 120 or 240 kg K_2O/ha in the form of SOP

This study also demonstrated the positive effect of potassium sulfate on the sugar levels in the fruit and consequently the level of alcohol in the wine, as well as its quality. Sulfate of potash reduces the formation of tartaric acid and the subsequent formation of sediments. The colour of the wine is improved and blind tasting tests confirm the improvement in the taste and character of the wine.

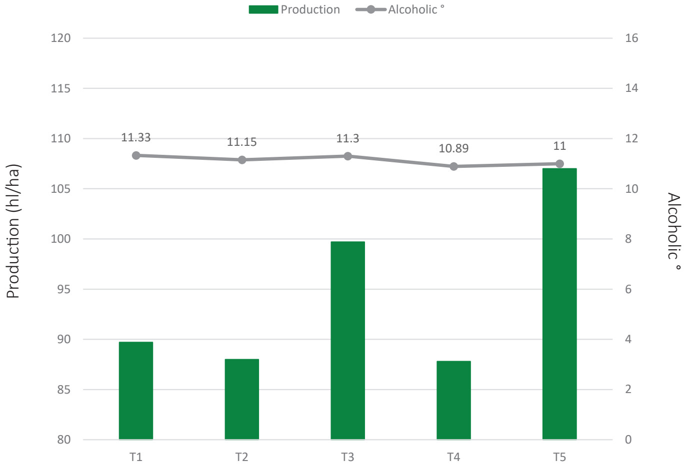
WINE BENEFITS FROM ALL GRADES OF POTASSIUM SULFATE

The soluble grade of SOP, SoluPotasse, can be also used on grapes grown under drip irrigation. In many parts of the world such as South Africa, India, Australia, Latin America, it is the ideal fertilizer for late season application when potassium is required and nitrogen would be detrimental for quality production. K-Leaf is used as a foliar spray, to supplement soil application. Three to five applications at 5-10 kg/ha per application help to reach the required level of potassium in the leaves.

In a recent experiment carried out in the southeast of France, we found that the combination of soil and foliar application is the best answer in order to control a strong potassium deficiency.

View of the control (T1)

The different treatments were control (T1), soil application of MOP (T2) and SOP (T3), foliar application (T4) and soil and foliar application (T5). Doses were 200 kg K_2O/ha for soil application and four sprays at 2 % concentration for foliar application in 300 l/ha of water. Foliar application alone leads to a better aspect of the plant, while soil and foliar application allows a better recovery and consequently a better production and better quality.



Effect of forms and application methods of potash on grape (SADEF, France, average 2006 - 2008)

View of the plot with soil and foliar application (T5)

In addition, among the many benefits of sulfate of potash, is the supply of sulfur in a form that is readily available to the vine. Finally potassium delivered as the sulfate does not add chloride, which can perturb the transpiration of the plants, affecting their growth. With potassium sulfate, the supply of water is better regulated, minimising the effects of dry periods.

PART 3

VEGETABLES

BEAN & FABACEAE

NUTRITIONAL REQUIREMENTS

The Fabaceae or legume family covers a large range of plants, including many vegetables such as bean, pea, lentil and lupine. The root nodules, a symbiotic relationship between legumes and bacteria, enable them to fix nitrogen from the air. Leguminous crops generally require only small quantities of nitrogen at the early stage. The main fertilization is based on phosphorous and potassium. Recommended application rates greatly vary, depending on crop rotation, target yield and soil fertility. It is strongly recommended to use soil analysis in the fertilization decision process. General recommendations concerning phosphorus and potassium are given in the table below.

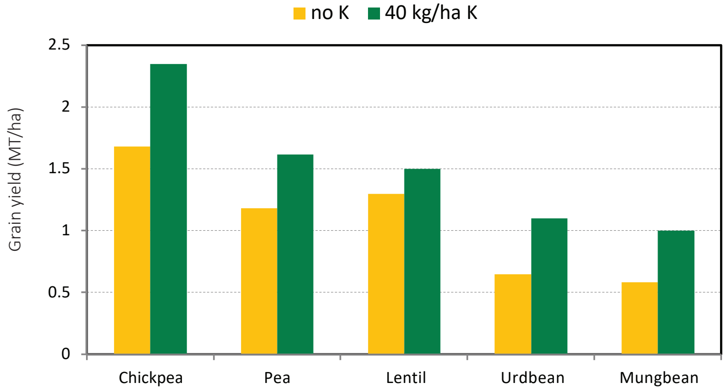
	P_2O_5	K_2O
Broad beans, faba beans	125 - 150	100 - 200
Dwarf beans, green beans, French beans	30 - 150	80 - 200
Lima bean	20 - 120	50 - 180
Peas and lentils	40 - 125	30 - 150
Alfalfa	30 - 230	25 - 300

P_2O_5 and K_2O requirements (kg/ha)

When sulfur content in soil is below 20 ppm, application of 10 - 20 kg/ha S is recommended. Soil pH should ideally be between 6 and 7.

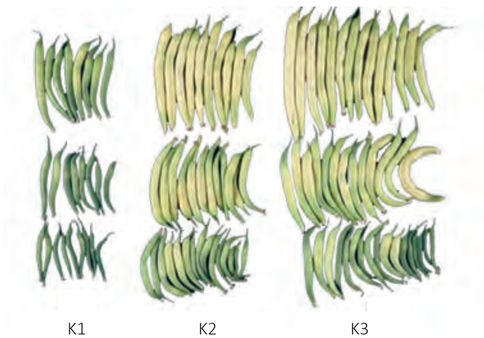
POTASSIUM, AN IMPORTANT ELEMENT

Potassium can be considered as the most important macronutrient for legumes, thanks to its role in enhancing nitrogen fixation and protein content of grains. A good supply of potassium K improves Grain yield, as shown in the graph below.



Impact of potassium on Grain yield (India, 1999)

Serious K deficiency causes yellowing or scorching of leaf margins, forward curled leaves and, in beans, shortening of internodes. Because of its involvement in nitrogen fixation, K deficiency may also appear as an apparent nitrogen shortage, with stunted plants.

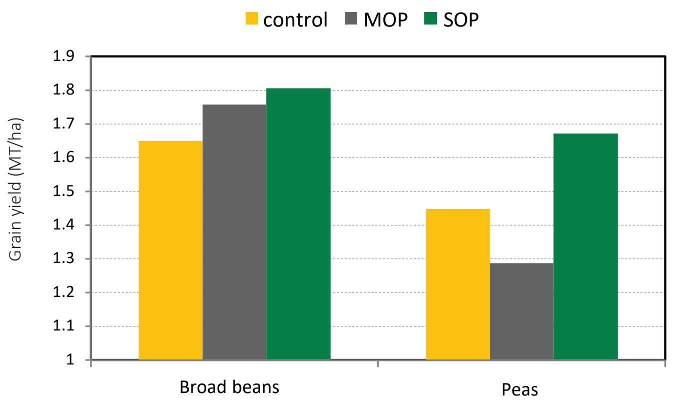


Potassium deficit beans (left) vs. well-nurtured beans (right)

WHAT FORM OF POTASSIUM?

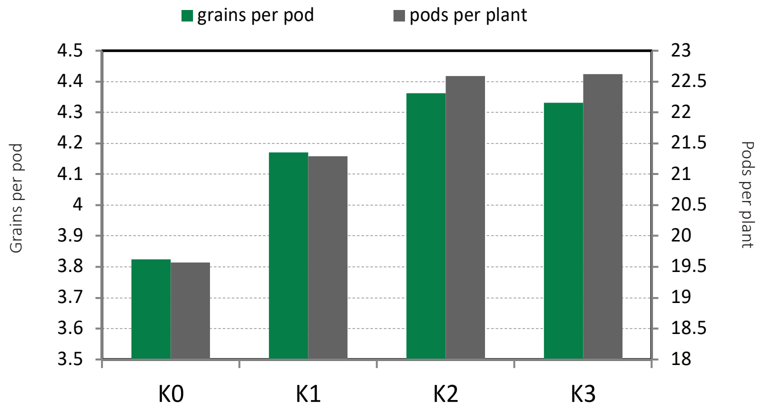
Most common legumes are rather sensitive to salt. The use of potassium chloride (MOP) must be avoided, particularly in saline conditions and semi-arid conditions. Sulfur is an essential secondary nutrient for leguminous crops, as sulfur participates in the nitrogen fixation process. Sulfur deficient legumes are characterized by a pale green to yellow discoloration of younger leaves and veins. Plants lacking sulfur will remain small and slender.

Trials from Egypt confirm the benefits of sulfate of potash (SOP) compared to MOP at 140 kg K_2O/ha for a high yield. The graph below illustrates the benefit of SOP for broad beans and peas.



Effect of potassium source on crop yield (Egypt, broad beans 1998 and peas 2010)

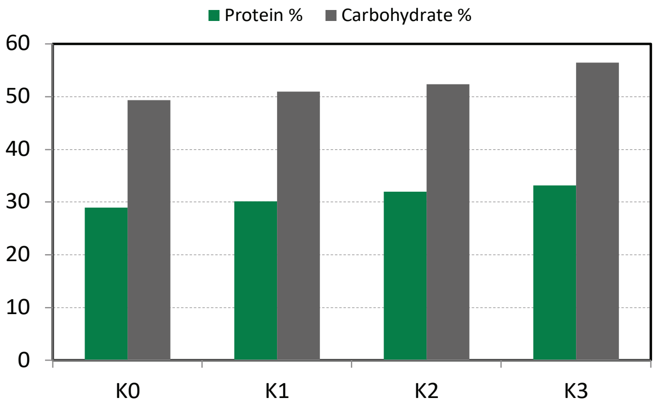
Experiments in Pakistan on pea show that the yield increase is not only due to a higher number of pods per plant, but the number of grains per pod also increases. Potassium sulfate doses are 0 (K1), 50 (K1), 100 (K2) or 150 kg K_2O/ha (K3).



Effect of SOP on pea pod yield and pea Grain yield (Pakistan, 2003)

Furthermore, research in Germany (1997) demonstrated that an adequate supply of SOP increases germination rate of green beans to 98% compared to 89% with MOP application.

Another important quality characteristic of legumes is the nutritional value of the grains. A trial conducted in Egypt illustrates the effect of SOP on the nutritional value of broad beans. The trial shows that SOP contributes to an increased protein and carbohydrate content in the grain. Potassium sulfate doses are 0 (K1), 60 (K1), 120 (K2) or 180 kg K_2O/ha (K3).

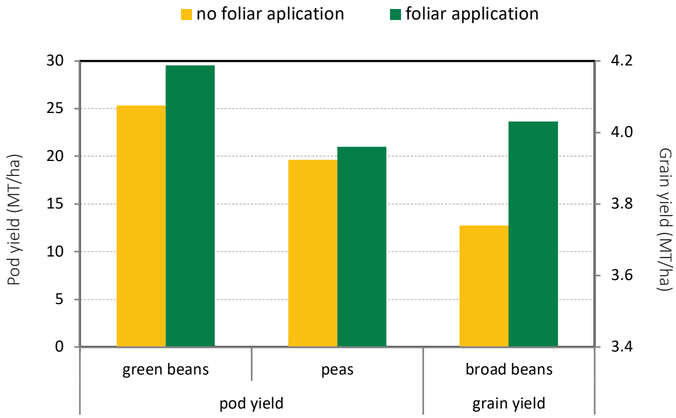


Effect of SOP on broad bean nutritional value (Egypt, 1998)

K-LEAF FOLIAR APPLICATIONS

Potassium uptake requirements during growth can be difficult to maintain. Foliar application of potassium allows correction of deficiency more quickly and efficiently than soil application. Thus, foliar application prevents yield loss. Moreover, a foliar application of K-Leaf improves K uptake by the plant when plant potassium demand is very high or when potassium uptake by the roots is limited.

Trials in China (2 applications on pea at 8 kg K_2O/ha), France (3 applications on green bean at 6 kg K_2O/ha) and Egypt (2 applications on broad bean at 6 kg K_2O/ha) illustrate the benefits of a foliar application of SOP for various legumes.



Effect of foliar applications of SOP on legumes (France, 2000; China, 1998; Egypt, 2008)

BULB CROPS

NUTRIENT REQUIREMENTS

The most popular bulb crops, onion, shallot, garlic and leek belong to the Alliaceae family. All plants are characterised by a shallow root system that explains why fertilizers should be banded 8-10 cm below the seed row. General requirements are relatively high in potassium and sulfur.

Crop	Yield	N	P_2O_5	K_2O	SO_3	MgO
	MT/ha	kg/ha				
Garlic	35	120	50	160	50	15
Onion	40	160	75	195	62	20
Leek	60	200	70	320	100	15
Shallot	25	100	75	180	45	15

Recommendations for a balanced fertilization

Due to the shallow root system, it is preferable to split fertilizer application (before sowing or planting, at the fully expanded leaf stage, and just before bulb formation). High nutrient availability is important during bulb formation; in this phase a high K:N ratio is required.

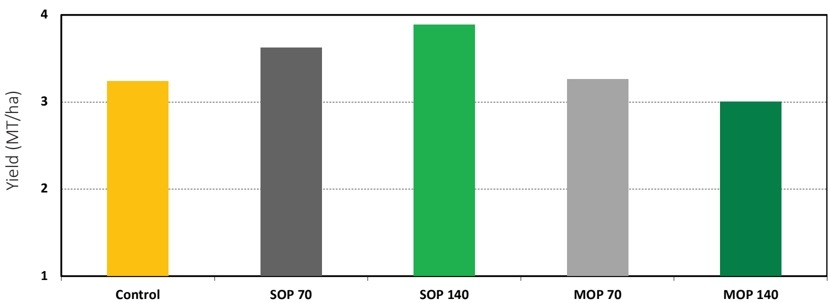
THE IMPORTANCE OF POTASSIUM

In general, the potassium requirement of vegetable crops is very important. A deficiency in potassium will lead to a reduced growth rate, inefficient uptake and transformation of nitrogen, resulting in low yields and inferior quality. In bulb crops, potassium deficiency leads to light green plants with brown plant tips and poor bulb development.

Potassium deficiency in onions

ALLIACEAE ARE SENSITIVE TO CHLORIDE

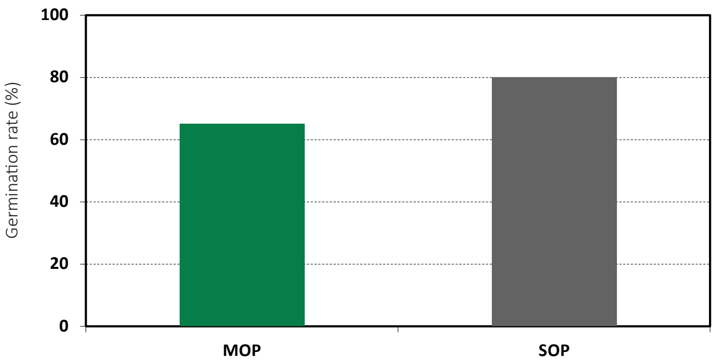
In general, vegetables do not tolerate chloride and onions and garlic are highly sensitive to it. It is important, therefore, to select fertilizers without chloride so as to avoid the detrimental effects shown in the experiment below, in which SOP and MOP were compared at two doses 70 and 140 K_2O/ha.



Effect of SOP vs MOP on onion (ARC, 1996)

Chloride toxicity is demonstrated by scorch on the edges of the leaves, which eventually fall off. The presence of chloride also leads to a perturbation of plant transpiration and nutritional disorders resulting from the chloride's competition with other elements. As a result, both yield and quality are directly affected. In fact, when it comes to choosing fertilizers, avoiding the risk of chloride toxicity is just as important as selecting the right combination of nutrients.

Chloride also affects germination as illustrated in the experiment on onion presented below.

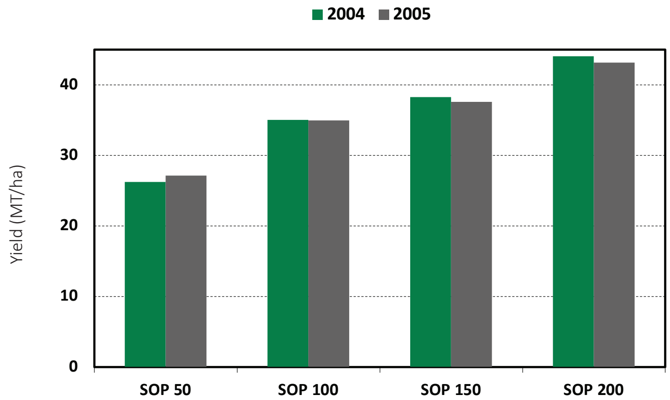


Effect of potash form on onion germination (Germany, 1997)

ALLIACEAE NEED SULFUR

The sulfur requirements of vegetables are higher than those of the other crops, particularly the requirement of Alliaceae. Sulfur is a component of cysteine and cystine, which are present in a higher concentration in Alliaceae plants and give their particular flavour.

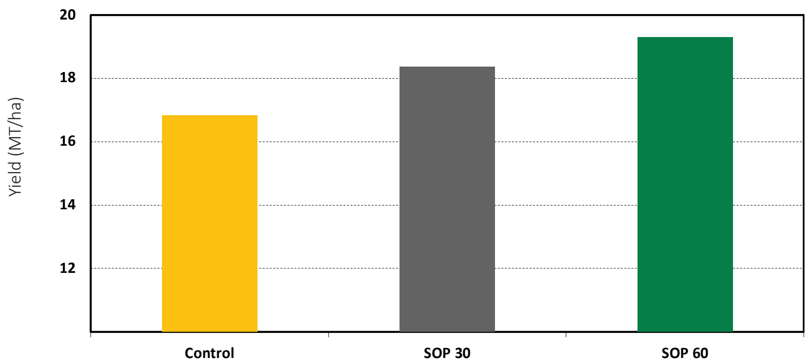
Plants take up sulfur in the sulfate form. Sulfur deficiency is demonstrated by a generalised chlorosis, with initial yellowing appearing on the young leaves. The graph below shows the response of onion to increasing doses of SOP (from 50 to 200 kg K_2O/ha).



Onion's response to SOP (Egypt, 2006)

SULFATE OF POTASH BRINGS BOTH SECURITY AND QUALITY

SOP produces larger bulbs and more dry matter. The bulbs are firmer and consequently, they are more resistant to storage and transport. An experiment in China shows the improvement of garlic yield when using SOP at 30 or 60 kg K_2O/ha, compared to the control (NP fertilization only).

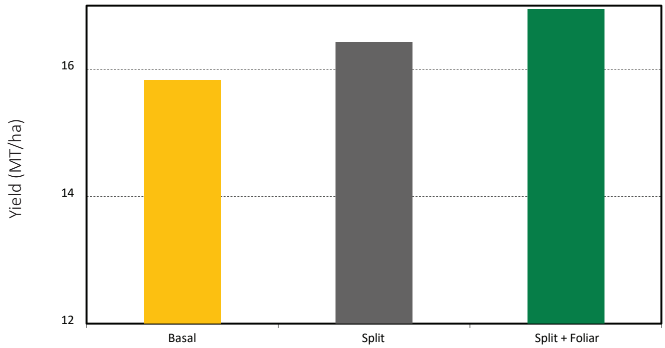


Garlic's response to SOP (CAAS, China, 1997)

SOP increases the assimilation of nitrogen, hence nitrate levels are therefore lower, giving a healthier product, which stores better. The choice of SOP as a potassium source is therefore preferable, notably for the beneficial role it plays in the formation of sugars and organoleptic components.

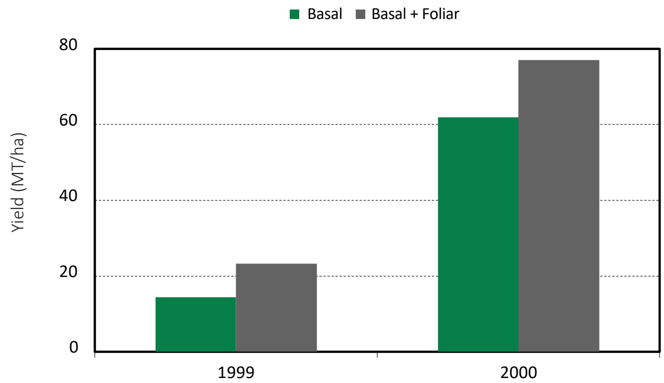
FOLIAR APPLICATION BENEFITS

Bulb crops respond particularly well to foliar application of K-Leaf, foliar grade of potassium sulfate from Tessenderlo Kerley. Two applications with 2 - 3 % of K-Leaf at the bulb formation stage increase shallot yield and quality.



Response of shallot to application methods (IVEGRI, 2004)

Another example is given below from a two-year experiment in France. It shows the benefit of 3 foliar applications on onion yield whatever the cropping conditions: 1999 spring was cold and rainy whereas 2000 spring was perfect regarding cropping conditions.



Response of onion to foliar applications (Pôle d'Aspach, France, 2000)

SOP delivers both potassium and sulfur in a concentrated form and offers the crop the additional security of a chloride-free fertilizer. A good illustration of the benefit of the combination of soil and foliar application is given in the following experiment carried out in India.

	Treatment	Yield (MT/ha)	
		Fresh bulb	Dry matter
T1	Control (only N and P_2O_5, no K_2O)	67.23	2.92
T2	50 kg K_2O/ha (MOP applied through soil and fertigation)	72.14	3.26
T3	100 kg K_2O/ha (MOP applied through soil and fertigation)	77.71	3.94
T4	150 kg K_2O/ha (MOP applied through soil and fertigation)	75.40	4.38
T5	50 kg K_2O/ha (SOP applied through soil and fertigation)	72.21	3.32
T6	100 kg K_2O/ha (SOP applied through soil and fertigation)	77.67	4.34
T7	150 kg K_2O/ha (SOP applied through soil and fertigation)	77.97	4.72
T8	100 kg K_2O/ha (MOP applied as basal through soil plus 2 sprays of SOP applied through foliar sprays at 2.5 kg K_2O/ha)	78.34	4.89

From this experiment, it can be concluded that SOP is more succesful than MOP and the higher dose of MOP (150 kg K_2O/ha) leads to a lower yield than 100 kg K_2O/ha, due to negative effect of chloride. In contrast, increasing SOP dose leads to an improvement in onion production. Finally, the combinaison of a medium potassium soil dose complemented with foliar application of soluble SOP gives the best results in terms of productivity and quality.

CABBAGE & BRASSICACEAE

BRASSICA NUTRITION

The brassica family is more commonly known as the crucifer or cole family. Mustard, swede, kale, cauliflower, broccoli, Brussels sprouts, turnip and cabbages belong to this family. Most of these crops prefer a cooler environment, especially broccoli, whose heads quickly bolt into flowers when the temperature rises.

Brassica generally require quite a high amount of primary nutrients. Average NPK recommendations for various brassica crops are listed in table 1.

	N	P_2O_5	K_2O
Broccoli	140 - 300	60 - 140	75 - 240
Brussels sprouts	160 - 250	60 - 140	125 - 370
Cabbage	120 - 350	50 - 140	60 - 300
Cauliflower	140 - 300	50 - 140	110 - 300
Chinese cabbage	110 - 250	60 - 115	120 - 230
Kohlrabi	120 - 200	60 - 80	180 - 210
Radish	25 - 100	20 - 60	80 - 180
Swede	50 - 140	50 - 105	150 - 180
Turnip	50 - 110	50 - 60	150

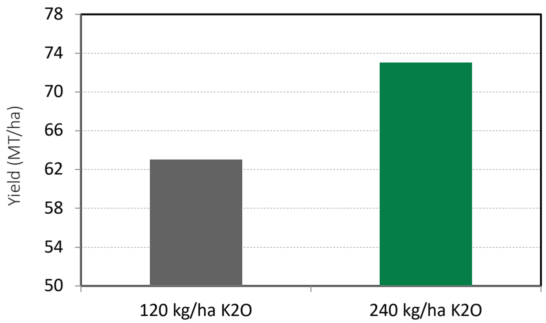
NPK requirements (kg/ha)

To avoid damage to the root systems, it is advisable to apply split applications. Also, it is recommended to thoroughly incorporate the fertilizers into the soil before drilling or transplanting to prevent damage to the seedling and decreased germination. Crucifers also require certain trace elements in moderate to high amounts. Their sensitivity to boron, manganese, molybdenum and iron deficiencies is significant. These types of crops are most productive when grown on soil with an approximately neutral pH.

IMPORTANCE OF POTASSIUM

Potassium plays an essential role in transport systems within the plant. This means that potassium is crucial for the development of proteins, enzymes and vitamins as well as plant photosynthesis. For brassica in particular, this element helps to prevent soft rot disease and makes the plant less prone to frost damage. Potassium deficiency manifests as interveinal chlorosis near the leaf margins and curling of these margins. In cauliflower the leaves turn bluish-green.

A trial conducted at Ege University in Bornova, Turkey in 1998 clearly demonstrates the importance of potassium for cabbage. By doubling the dose of potassium (from 120 kg K_2O/ha to 240 kg K_2O/ha), yield increased by 10 MT/ha.



Effect of K application on yield of cabbage (Ege University, Turkey, 1998)

IMPORTANCE OF SULFUR

Crucifers have high sulfur requirements. Sulfur is a component of some amino-acids and is essential for the formation of chlorophyll. It also assists in oxidation-reduction processes. For these reasons sulfur is not only important for yield, but it also contributes to the flavour of these crops.

A fertigation trial on Chinese cabbage, carried out at the Zheijang Agricultural University in China (1997), comparing Muriate of Potash (MOP) to Sulfate of Potash (SOP) showed improved fresh weight, dry matter content and plant photosynthesis with SOP.

	No K	MOP (6 mmol/L)	SOP (6 mmol/L)
Total fresh weight (g)	1.306	2.723	3.853
Total dry weight (g)	95.9	209.6	290.4
Rate of net photosynthesis (CO_2 µmol/m²s)	6.09	11.32	12.11

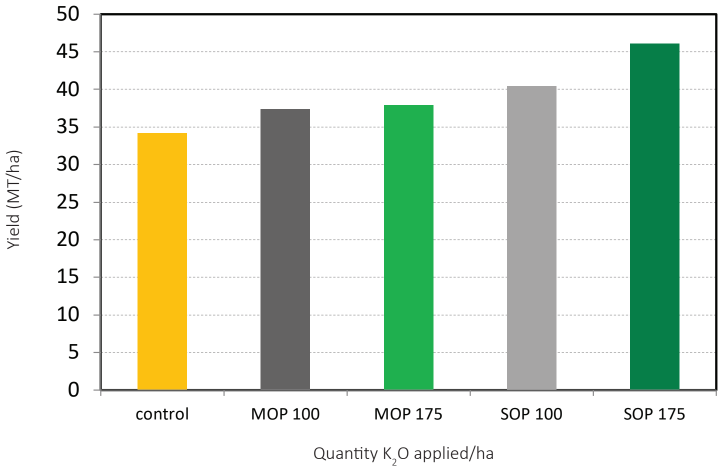
Effect of SOP vs. MOP on quality of Chinese cabbage
(Zhejiang Agricultural University, China, 1997)

Symptoms of sulfur deficiency are most commonly seen at the bud and flowering growth stages because of the crop's high need for sulfur during this period. Deficiency symptoms first occur on new leaves. A deficiency of sulfur will cause a general yellowing of younger leaves.

SOP FOR HIGHER YIELD AND IMPROVED QUALITY

Brassica are medium sensitive to chloride. Excessive chloride may damage the plant and ultimately reduce yield. Thus, use of MOP as a source of potassium is best avoided.

Additionally, SOP provides the plant with sulfur , thereby improving both yield and quality, as mentioned above. A trial at the Anhui Academy of Agricultural Science in China (2007) clearly demonstrates the beneficial effect of SOP application on yield of cauliflower, compared to application of MOP. Compared to MOP, yield increased with 8 MT/ha after SOP application, at an application rate of 175 kg K_2O/ha.



Effect of K form on yield of cauliflower (Anhui Academy of Ag. Science, China, 2007)

CHAPTER 3

CUCUMBER & CUCURBITACEAE

MAIN NUTRIENT REQUIREMENTS

The rapid growth rate and the high yields of most of Cucurbitaceae explain the high demand in major mineral elements.

Crop	Yield	N	P_2O_5	K_2O	SO_3	MgO
	MT/ha	kg/ha				
Cucumber	100	300	100	450	40	70
Gherkin	20	160	80	220	30	50
Pumpkin	80	250	60	320	50	80
Zucchini	80	300	80	450	50	30

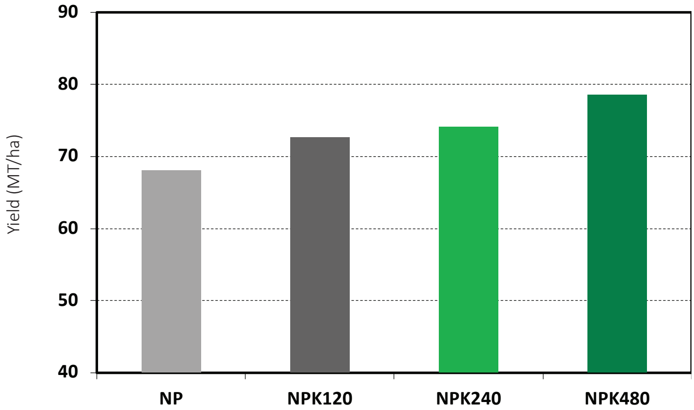
Nutrient requirements of cucurbitaceae

The daily requirement can reach 5 kg of nitrogen, 2 kg P_2O_5 for phosphorus and 6 kg K_2O for potassium per hectare. To satisfy the instantaneous nutrient requirements over a relatively short period of time is a real challenge in fertilization management. The key to success, therefore, is a sufficient dosage containing the correct balance of nutrients.

The potassium requirements of cucurbitaceae are important, exceeding their nitrogen requirements.

Potassium deficiency in cucurbitaceae

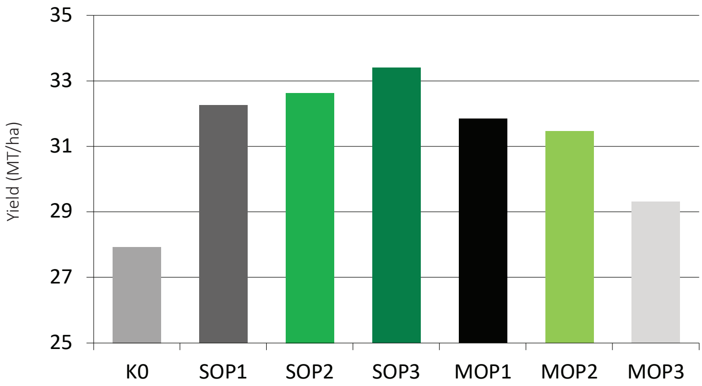
A potassium deficiency will lead to a lower growth rate and inefficient uptake and transformation of nitrogen, resulting in low productivity and poor product quality. A lack of potassium appears as leaf yellowing, and then a marginal necrosis.



Effect of potassium on pumpkin production (SAAS, China, 1997)

SENSITIVITY TO CHLORIDE

As a general rule, vegetables have a low chloride tolerance. It is therefore advisable to avoid accumulation of chloride in intensive production systems. Cucumber and zucchini are particularly sensitive, as shown in the graph below. The negative effect of chloride is clearly demonstrated in the experiment comparing the use of potassium sulfate (SOP) to that of potassium chloride (MOP) at 75, 150 and 225 kg K_2O/ha.



Effect of form of potash on cucumber yield (CAAS, China, 2001)

Chloride toxicity shows up as scorch on the edges of the leaves, which eventually fall off. The consequence of an excess of chloride is perturbation of water exchanges, as well as a competition between chloride and other elements leading to nutritional disorders. As a result both product yield and quality are affected.

It is vitally important to avoid the risk of chloride accumulation by choosing fertilizers without chloride – it is just as important as selecting the right combination of nutrients.

SULFATE OF POTASH BRINGS BOTH SECURITY AND QUALITY

The choice of sulfate of potash (SOP) as a potassium source is always preferable, notably for the beneficial role it plays in the formation of sugars and in nitrogen metabolism.

As a general fact, SOP provides a more regular calibre of produce with a larger average size, compared to other potassium fertilizers.

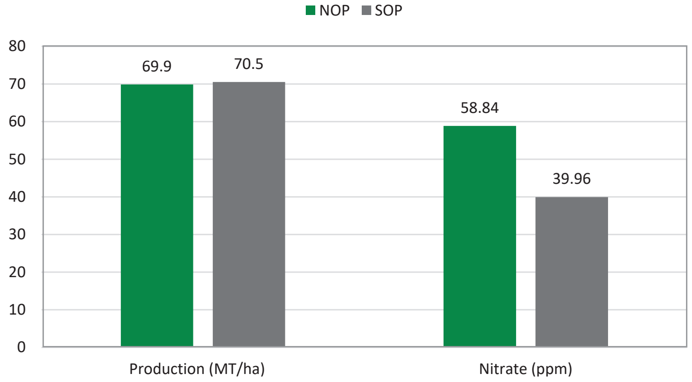
The production of dry matter is enhanced, so the vegetables are firmer and, consequently, more resistant to storage and transport. SOP increases the assimilation of nitrogen. Nitrate levels are therefore lower giving a healthier product that stores better. In addition, plants are less susceptible to disease.

VEGETABLES NEED SULFUR

The sulfur requirement of vegetable crops is generally greater than of field crops. Sulfur is taken up by plants as the sulfate form and a deficiency show up as a generalised chlorosis, with initial yellowing appearing on the young leaves.

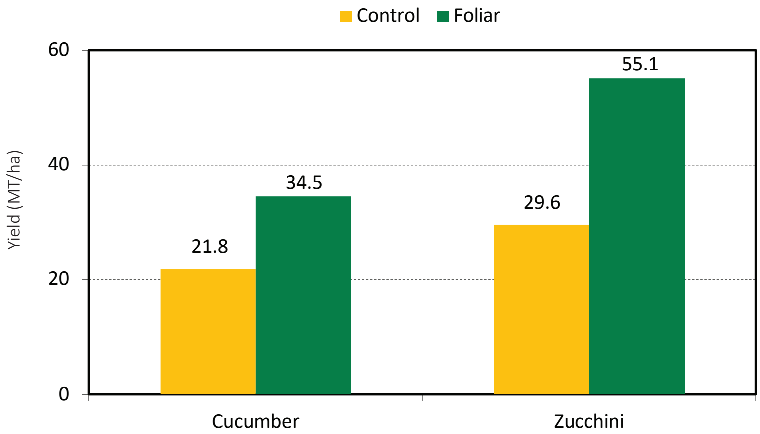
BENEFIT OF SOLUBLE SOP

SoluPotasse, the soluble SOP produced by Tessenderlo Kerley, is specially designed for fertigation whilst K-Leaf is designed for foliar spray. An experiment carried out using drip irrigation on zucchini shows the benefit of SoluPotasse, compared to NOP, with an increase in production and lower nitrate content.



Effect of potash form on zucchini (Pôle d'Aspach, France, 1999)

Foliar application of K-Leaf helps feed plants when their instantaneous requirement for potassium is high. It also contributes to plant growth and production when there are poor conditions at planting. It was the case in the example below where three foliar applications of K-Leaf at 4 % in 300 liters of water were used.



Effect of foliar spray of K-Leaf (Pôle d'Aspach, France, 2000)

Whatever the grade, SOP delivers both potassium and sulfur to the crop in a concentrated form and offers the security of a chloride-free fertilizer.

LEAF CROPS

NUTRITIONAL REQUIREMENTS

Although leafy vegetables come from a very wide variety of plants, most share similar cultivation practices. The most important crops in this category are lettuce and spinach.

Though these vegetables can grow in cool to warm climates, most types of greens prefer mean temperatures between 15 and 18°C and tolerate up to 24°C as well as mild frosts. Ideally, the soil should be loose, fertile and moist. These crops grow best in a soil with pH ranging from 6 to 7.

Leafy vegetables generally have quite high requirements for both phosphorous (P) and potassium (K) and rather low requirements for nitrogen (N). K requirement is often double the requirement of N, as indicated in the table below.

	N	P_2O_5	K_2O
Lettuce	100	50 - 100	150 - 200
Spinach	100 - 150	70 - 100	150 - 180

NPK requirements (kg/ha)

Usually, all P is applied at planting, while N and K requirements are often applied as split top dressings or via a fertigation system throughout the season.

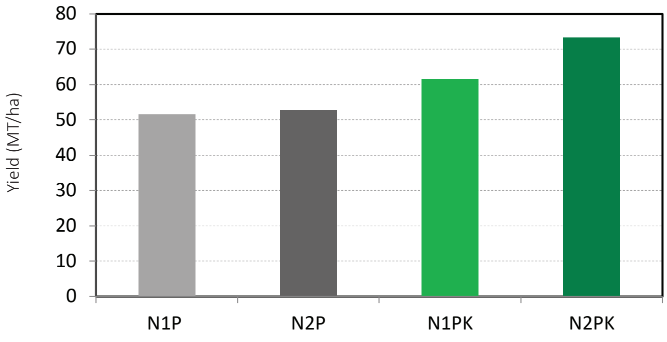
Spinach is also rather sensitive to magnesium and boron deficiencies.

IMPORTANCE OF BALANCED FERTILIZATION

In order to obtain maximum yield and quality, a balanced fertilization program is crucial. For leafy vegetables in particular, balanced fertilization is important to keep the nitrate levels in the leaves as low as possible.

Research has shown that increasing potassium application rates facilitates the uptake and transport of nitrate towards the aerial part of the plants, which in turn enhances the activities of the nitrogen assimilating enzymes, thereby improving nitrogen use efficiency (NUE) and ultimately reducing nitrate accumulation in these crops.

This effect is clearly demonstrated in a trial from China, where the effects on lettuce yield of treatments with or without 225 kg/ha potassium (K) combined with lower (150 kg/ha (N1)) or higher (225 (N2) kg/ha) doses of nitrogen (N) were compared. Results indicate that increasing the dose of N without applying K had little to no effect on yield, whereas combination of N and K increased yield by up to 21 MT/ha, as shown in the graph below.

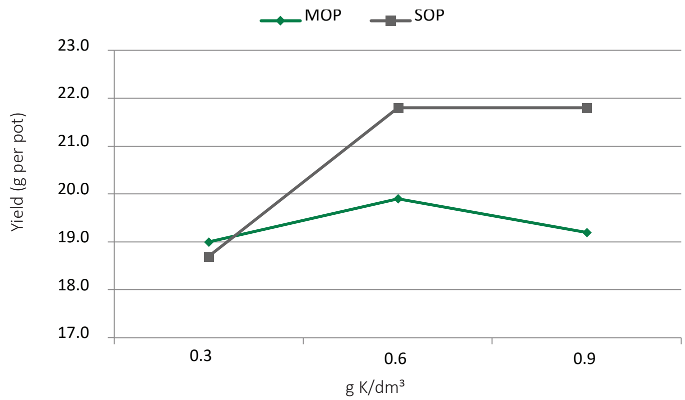


Effect of N and K on lettuce yield (CAAS, China)

Besides its role in preventing nitrate accumulation, potassium is also quintessential for the development of proteins, enzymes and vitamins in the plant, as well as plant photosynthesis. Potassium deficient plants show browning at the tips of the leaves.

SOP FOR HIGHER YIELDS

Because leafy vegetables generally require quite a high amount of potassium, as explained above, and because both potassium and sulfur contribute to improving nitrogen use efficiency, sulfate of potash (SOP) is a very good source of potassium for these plants. A comparison between two sources of potash, MOP and SOP, was done at the University of Life Sciences at Lublin, Poland in a pot experiment on rocket.

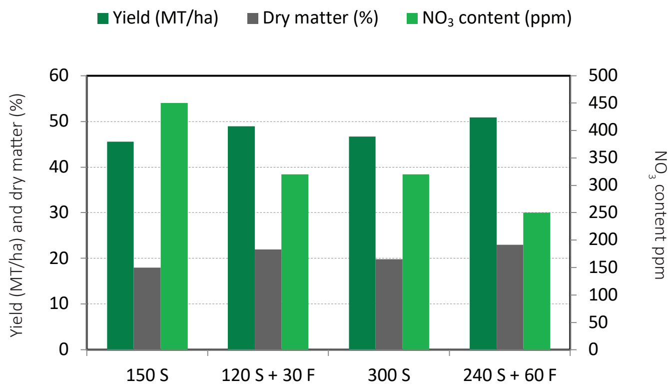


Effect of potash form on rocket production (Lublin University, Poland, 2009)

Results indicate that SOP improves the production of fresh matter (see graph above) as well as stomatal conductance, photosynthesis, transpiration and hence, increased leaf yield.

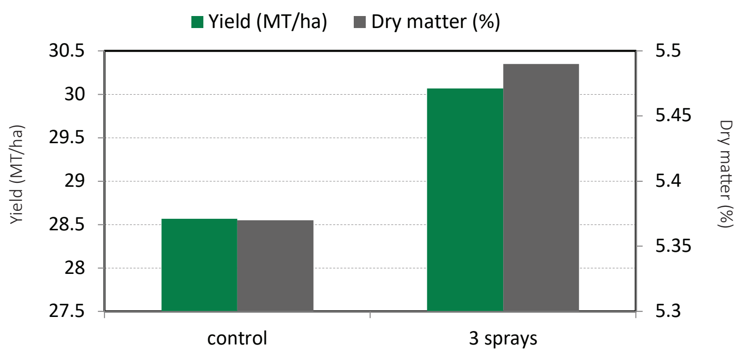
BENEFIT OF FOLIAR APPLICATION OF SOP

Many studies have focused on the benefits of supplementing a regular fertilization program with additional foliar sprays of SOP. A trial executed in cooperation with the Guangdong Academy of Agricultural Sciences (GAAS) in China clearly shows the benefits of foliar sprays of SOP on spinach. By applying 60 kg/ha as a foliar spray, combined with 240 kg/ha soil applied SOP, yield increased by over 4 MT/ha compared with 300 kg/ha soil applied SOP, as indicated in the graph below. Moreover, quality of the spinach improved as leaves treated with foliar sprays contained 3 % more dry matter and 70 ppm less nitrates.



Effect of foliar sprays of SOP on yield and quality of spinach (GAAS, China, 1998)

In Aspach le Bas in France a similar trend was noted for lettuce. Application of 3 foliar sprays, starting two weeks after transplanting, increased yield by 1.5 MT/ha, compared to no foliar sprays. Also, dry matter content increased with 0.1%, leading to a gain of 160 kg/ha dry matter.



Effect of foliar sprays of SOP on yield and quality of lettuce (Pôle d'Aspach, France, 2000)

POTATO

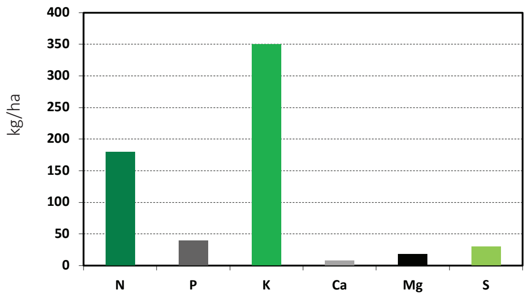
THE NUTRITIONAL EQUILIBRIUM

A good fertilization program for potatoes helps to guarantee that the nutritional needs of the crop are met throughout the season, including the periods of rapid growth.

Type of production	Yield	N	P_2O_5	K_2O
	(MT/ha)	kg/ha		
Seed Potatoes	30	80 - 100	150 - 200	150 - 200
Early Season	20-30	100 - 200	100 - 200	200 - 250
Main Season	50	150 - 200	120 - 150	300 - 400
Chips	50	150 - 180	80 - 110	250 - 300
Potato Flour	60	150 - 200	80 - 120	250 - 350

Fertilizer recommendations based on production type, requiring adjustment based on soil type and soil nutrient availability

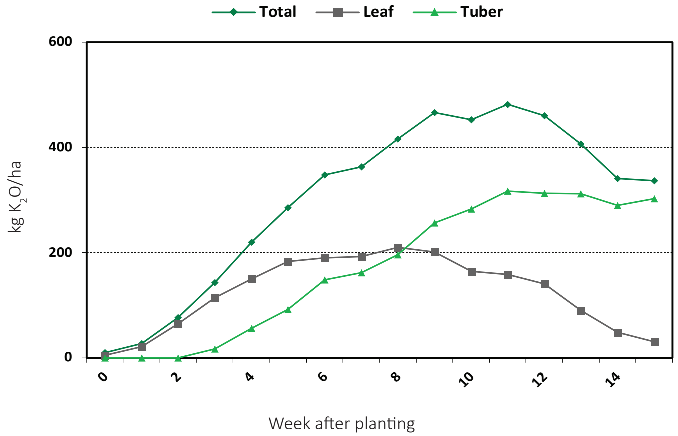
A balanced fertilization helps to ensure a better quality production: an under-supply of nitrogen will reduce the weight of the tubers, whereas an excess will deform them; a lack of phosphorus limits tuber production and consequently reduces the number of tubers; finally potassium acts on the process of tuber development and is hence critical to yield. Potasium is required by potatoes in greater quantities than all the other elements.



Mineral element requirements of potato

THE KEY ROLE OF POTASSIUM

The potassium requirement is particularly high during the period of tuber enlargement and starch accumulation.



Potassium requirements of potato

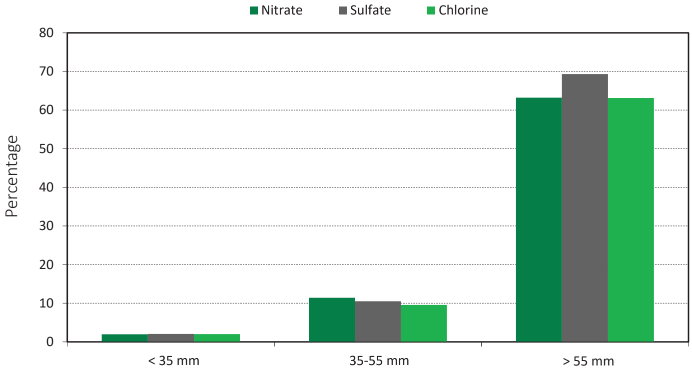
An adequate supply of potassium is important between 2 and 3 weeks after planting. The requirement can reach 10 kg/ha of K_2O per day.

Potassium deficiency in potato

THE IMPORTANCE OF POTASSIUM FORM

The choice of potassium fertilizer form has a direct impact on the quality of the potatoes. Sulfate of potash is the potassium fertilizer of choice when it comes to guaranteeing both the yield and quality of the production.

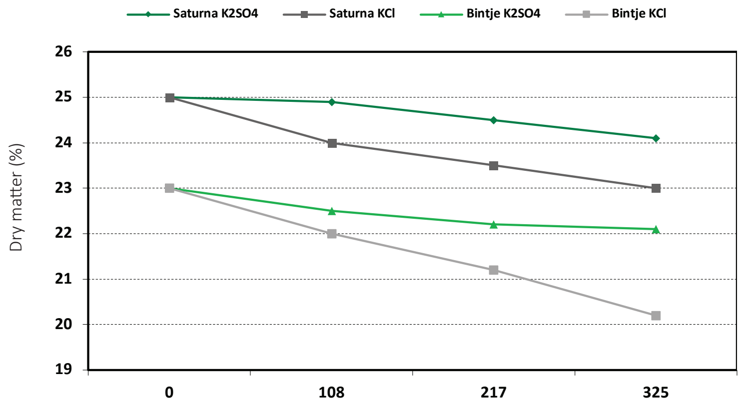
The size of the tubers is more regular with a higher average size compared to cases where other forms of potassium are used. Sulfate of potash increases the metabolism of nitrogen: consequently tubers content less nitrate and store better for longer periods of time and are less susceptible to diseases. In particular, it reduces internal darkening of the tubers.



Potato size resulting from use of different forms of potassium (Pôle d'Aspach, France, 2000)

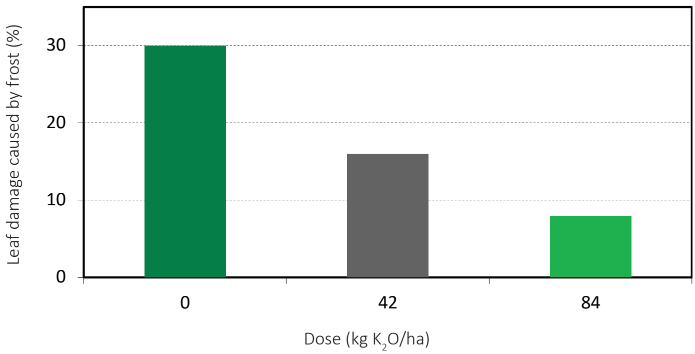
Potassium sulfate contains virtually no chloride, which can perturb transpiration and affect growth, supply of water is better regulated, and reducing the impact of dry periods.

SOP, in particular the granular form, can be applied during the early growth stages without any risk to the developing plants. Potassium sulfate improves dry matter: the tubers are more resistant to shock during grading and transport. It is also an important criteria for processing potato.



Effect of potassium sources on dry matter (SCPA, France, 1990)

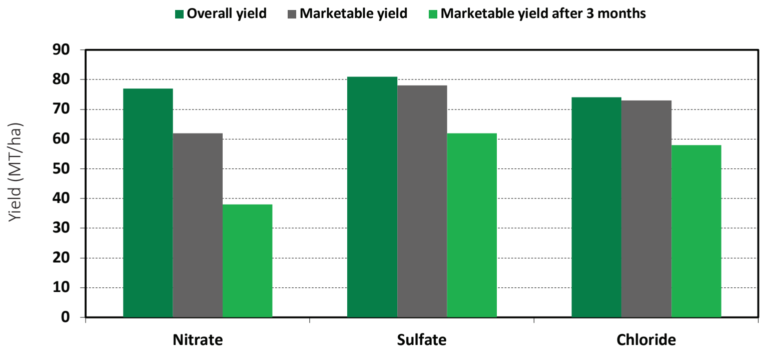
In addition, potatoes cropped with potassium sulfate have improved characteristics for cooking. In the case of chips, the colour is lighter and the retention of oil is reduced, giving a healthier product for the consumer. Finally, potassium sulfate improves plant resistance to frost as demonstrated in an experiment from India.



Effect of potassium on frost resistance (India, 1980)

THE USE OF SOLUPOTASSE

SoluPotasse, the soluble grade of SOP for fertigation, is widely used on potato grown under drip irrigation. The main advantage is to allow application when potassium is required and nitrogen would be detrimental for quality of the production.

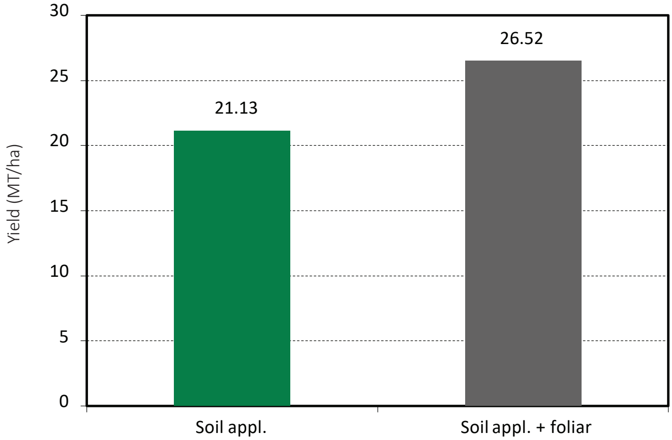


Potassium sources and storage capability (Pôle d'Aspach, France, 1996)

Of course, SoluPotasse brings all the advantages of SOP, particularly those concerning productivity and quality, as well as the advantage presented above concerning storage quality.

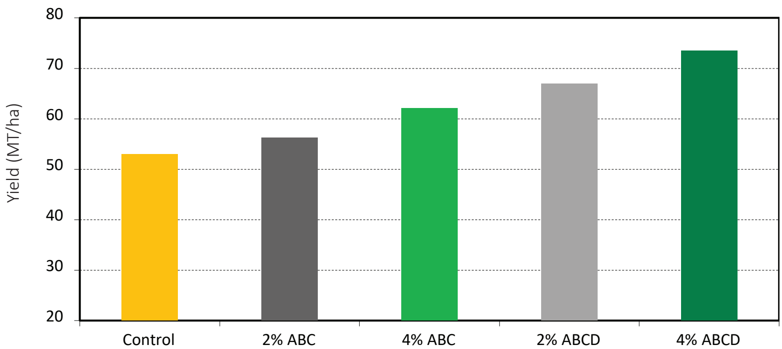
THE BENEFIT OF K-LEAF

K-Leaf is a high quality grade of SOP, designed for foliar applications. In an experiment carried out in Egypt, two sprays at a 2 % concentration in 400 l of water/ha show an interesting benefit on potato production.



Effect of foliar applications on potato yield (ARC, Egypt, 2007)

In a more recent experiment from Poland, three (ABC) or four (ABCD) sprays at 4 or 8 kg of K-Leaf per ha improve potato production dramatically.



Effect of foliar applications on potato yield (Staphyt, Poland, 2011)

Potassium sulfate also delivers the important nutrient sulfur in a form readily available to the potato plant. Sulfur is the most important secondary element required in potato crop.

ROOT & OTHER TUBER CROPS

MINERAL NUTRITION

Along with potato, many other root and tuber crops are important crops in human nutrition. The most popular crops belong to different families, but general requirements for potassium are relatively high.

Crop	Yield	N	P_2O_5	K_2O	SO_3	MgO
	MT/ha	kg/ha				
Beetroot	25	90	110	110	20	25
Carrot	30	120	100	220	10	25
Cassava	40	100	45	120	20	40
Crosne	15	80	30	100	25	15
Ginseng	25	80	45	120	10	75
Radish	20	100	50	150	10	70
Sweet potato	20	60	40	120	50	15
Taro	20	100	75	135	20	15
Turnip	45	100	70	150	80	15
Yam	40	150	40	200	20	50

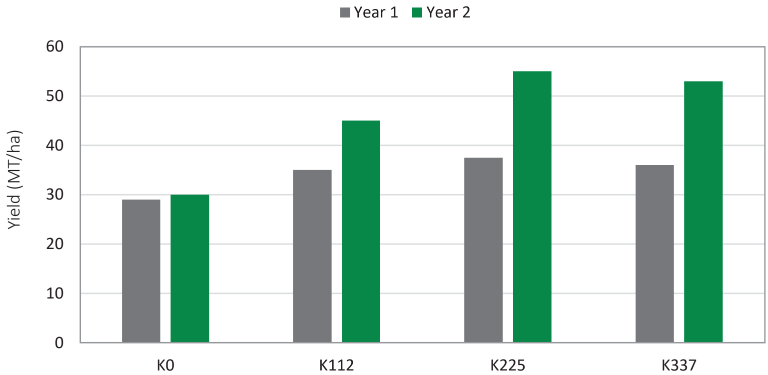
Recommendations for balanced fertilization

Typical deficiency symptoms are leaf yellowing and browning of leaf margins.

Potassium deficiency on yam

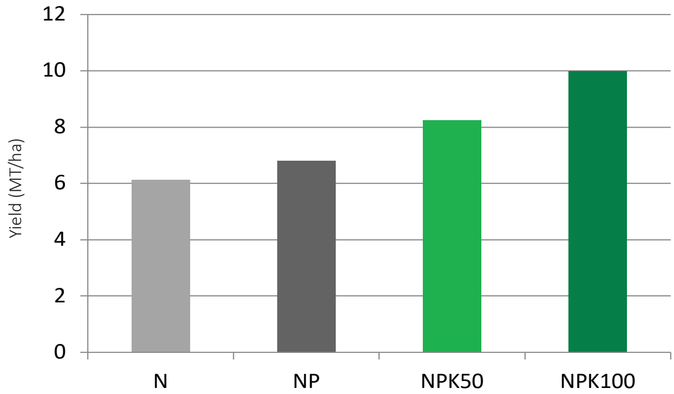
CHAPTER 3

An experiment was conducted on taro in China during two years at the Southwest Ag. University, comparing four doses of potassium in the form of potassium sulfate: 0, 112, 225 and 337 kg K_2O per ha. It can be easily concluded that 225 kg K_2O meet the plant's requirement for potassium. From the economic point of view, a slightly lower dose would be more appropriate.



Effect of different doses of SOP on taro production (Southwest Ag. University, China)

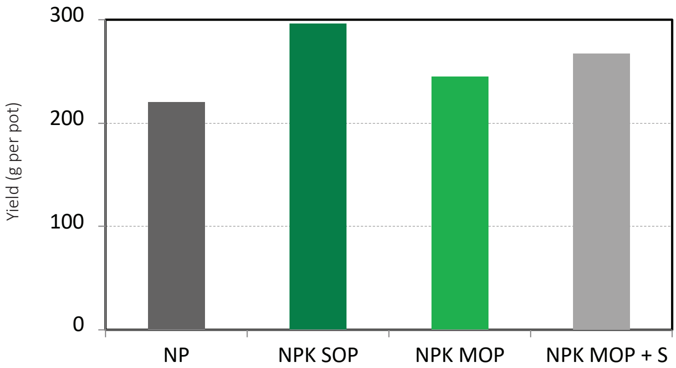
Another experiment on yam gives a second example of the benefit of potassium sulfate on tuber production. Four treatments were compared: N, NP and NPK with two levels of SOP (50 and 100 kg K_2O per ha). Yield is respectively increased by 21 % and 46 % over NP treatment for the two SOP doses.



Effect of different doses of SOP on taro production

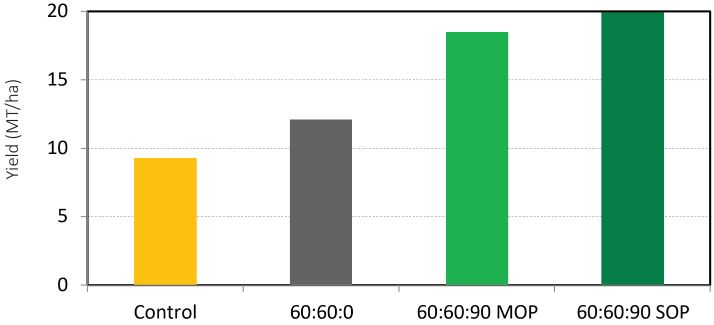
Taro field

Finally, a pot experiment carried out at the Shandong Academy of Agricultural Sciences in China shows the superiority of potassium sulfate over potassium chloride, even when adding sulfur to potassium chloride.



Effect of different forms of potassium on taro production
(Shangdong Academy of Agricultural Sciences, China)

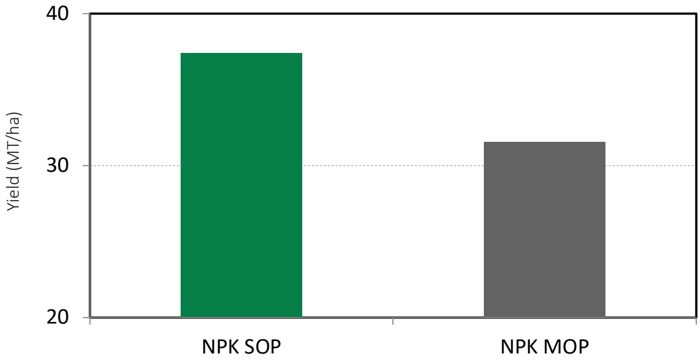
Staple foods such as root and tuber crops, followed the same response to SOP as potato in terms of productivity and quality. Another experiment from Ghana on cassava shows the benefit of potassium sulfate versus potassium chloride on tuber production.



Effect of different forms of potassium on cassava production

Potassium deficiency on sweet potato

The same result can be observed on sweet potato from the following experiment carried out in 2007 in Louisiana, USA. The basal dressing was applied as 50-135-135 NPK/ha as MOP or SOP and a side dressing of 34 K kg/ha as MOP or SOP. SOP plots show an increase of more than 18 % over MOP.



Effect of different forms of potassium on sweet potato production (USA, 2007)

TOMATO & SOLANACEAE

HIGH NUTRIENT REQUIREMENTS

Solanaceae have a rapid growth, and high yield levels make these crops amongst the most demanding in terms of instant nutrient requirements.

Crop (field)	Yield	N	P_2O_5	K_2O	SO_3	MgO
	MT/ha	kg/ha				
Eggplant	65	175	40	300	25	30
Bell Pepper	40	180	45	280	100	35
Chilli	25	140	100	200	70	40
Tomato	80	140	50	230	100	30

Nutrient requirements of Solanaceae

The daily requirement often reaches 5 kg of nitrogen, 2 kg P_2O_5 for phosphorus and 6 kg K_2O for potassium. To satisfy the instantaneous nutrient requirements over a relatively short period of time, rate, balance and timing of fertilization are the keys to success.

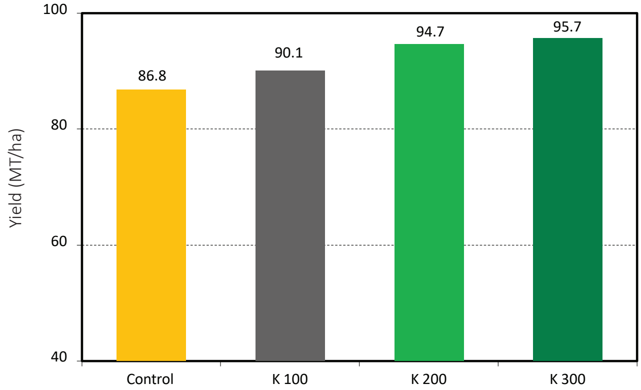
Potassium deficiency in tomatoes

The potassium requirement of vegetable crops usually exceeds the nitrogen requirement. Potassium deficiency will lead to a reduced growth rate, inefficient uptake and transformation of nitrogen, resulting in low yields and inferior quality. A lack of potassium in tomatoes or bell pepper shows up as zones with differing levels of maturity on the same fruit, as well as cracks. On the leaves potassium deficiency leads to marginal necrosis.

Potassium deficiency in pepper

VEGETABLES NEED SULFUR

The sulfur requirements of Solanaceae are always higher than those of the other crops, reaching levels of 100 kg SO_3 per ha and per year compared to 30 kg SO_3 per ha and per year on average for field crops. Sulfur is taken up by plants as the sulfate form. Sulfur deficiency shows up as a generalised chlorosis, with the initial yellowing appearing on the young leaves.

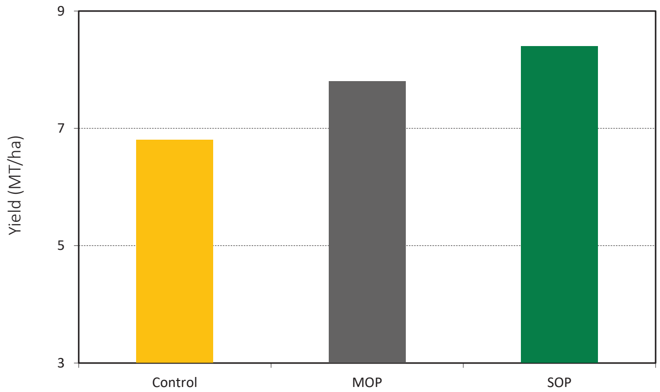


Effect of SOP on eggplant production (CAAS, China, 1999)

Sulfur deficiency in tomato

SENSITIVITY TO CHLORIDE

In general, fruits and vegetables do not tolerate chloride. Tomatoes are more tolerant, but it is advisable to avoid accumulation of chloride in covered production systems. Pepper and eggplant are more sensitive to chloride. The following graph illustrates the effect of NP (control) and NPK fertilization based on muriate of potash (MOP) and sulfate of potash (SOP) at 200 kg/ha on pepper.

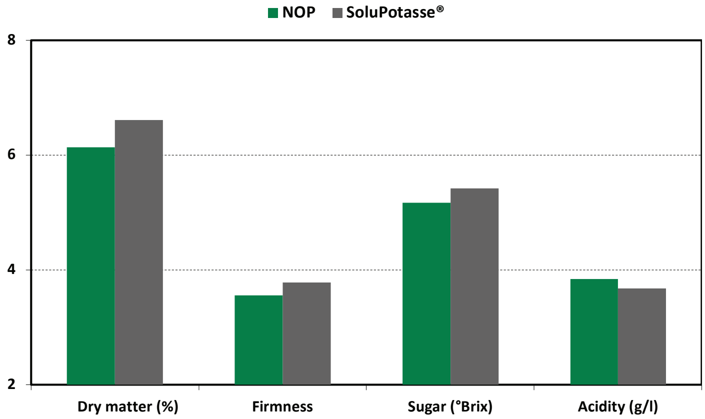


Effect of K sources on pepper production (IAS, Vietnam, 2000)

Chloride toxicity shows as scorch on the leaf edges, which eventually fall off. The presence of chloride also leads to a perturbation of plant transpiration and nutritional disorders resulting from competition of the chloride with other elements, affecting yield and quality.

SULFATE OF POTASH BRINGS SECURITY AND QUALITY

The choice of SOP as a potassium source is preferable for the beneficial role it plays in the formation of sugars and organoleptic components. Numerous experiments show the positive effect of SOP on fruit size, dry matter, firmness and pigments, as shown below in the comparison with potassium nitrate (NOP) in fertigated field tomato and in soilless greenhouse tomato, using SoluPotasse, the soluble grade of SOP produced by Tessenderlo Kerley.



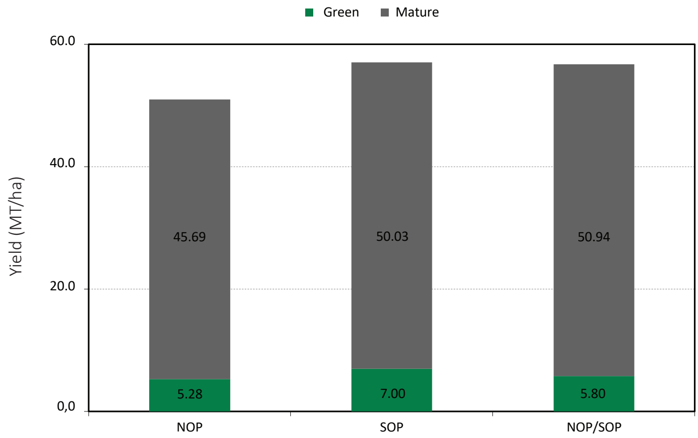
Effect of K sources on field tomato quality (Pôle d'Aspach, France, 1997)

Pôle d'Aspach France 2002	Program NOP	Program SoluPotasse
Yield (MT/ha)	73.028	82.611
Dry mater (MT/ha)	6.311	6.690
Fruits/plant	83	73.25
Size (g per fruit)	52.85	67.74
Sugar (° Brix)	7.29	7.33
Acidity (g/l)	4.93	4.50
S/A Ratio	1.48	1.63
K content in fruit	3.85	3.95

Soilless greenhouse tomato production

SOP increases the assimilation of nitrogen. Nitrate levels are therefore lower giving a healthier product, which preserves better. SOP fertilizer delivers to the crop both potassium and sulfur in a concentrated form that is free of chloride.

Another proof is coming from France in a trial on processing tomato, comparing a fertigation program based on either NOP, SOP or NOP until fruit setting followed by SOP from fruit formation to harvest. Each element is applied at the same dose (195 kg N/ha, 130 kg P_2O_5/ha, 390 kg K_2O/ha). The benefit of SOP alone or used at the end of the growing season is explained by the absence of nitrogen at a stage where it is detrimental.



Comparison of different sources of potassium on tomato production in fertigation (Staphyt, France, 2016)

PART 4

SPECIAL CROPS

COCOA

MINERAL NUTRITION

The management of the mineral nutrition in a cocoa plantation is largely dependent on soil conditions as well as the cropping system, particularly with or without shading. Cocoa tree prefers deep well drained soils with high organic matter and a pH range from 5.5 to 7.5.

Kg of nutrients in harvested pods per 1 ton of beans				
N	P_2O_5	K_2O	MgO	CaO
35	12	80	10	8

Potassium deficiency on cocoa leaf

As for many trees, leaf analysis is the best way to monitor cocoa fertilization. The table below gives an idea of the cocoa tree status according to the different levels of each element in leaf.

Element	% of dry matter		
	Deficient	Low	Normal
N	< 1.80	1.80 - 2.00	> 2.00
P	< 0.13	0.13 - 0.20	> 0.20
K	< 1.30	1.30 - 2.00	> 2.00
Mg	< 0.20	0.20 - 0.45	> 0.45
Ca	< 0.30	0.30 - 0.50	> 0.50

A long term experiment carried out in Colombia shows the role of potassium and the N:K interaction on cocoa bean yield. The highest fertilization rate doubles the production of cocoa beans versus control, providing also twice as much income for the farmer (taking into account the cost of fertilizers).

N	P_2O_5	K_2O	5-year yield (dry bean)
kg/ha			
0 (Control)	0	0	562
50	90	50	560
100	90	50	574
150	90	50	572
50	90	100	601
100	90	100	650
150	90	100	943
50	90	200	819
100	90	200	1,050
150	90	200	1,160

Concerning the prefered form of potash, some relatively old investigations in Trinidad, Ghana and Indonesia suggest that potassium sulfate (SOP) gives better yields compared to potassium chloride (MOP). Finally, SOP lowers cadmium accumulation in cocoa beans compared to MOP, which starts to be a real problem when it comes to cocoa quality.

Sulfur deficiency on cocoa leaf

COFFEE

PLANT NUTRITION MANAGEMENT

Fertilization of coffee prior to planting is aimed at promoting good rooting and rapid development. Phosphorus and organic matter are essential early on. Later, during the first two or three years, small but frequent applications of nitrogen, phosphorus and potassium are commonly recommended. Coffee cropping requires an NPK balance of 1-0.2-1. For mature coffee plants, 200 - 300 kg/ha N and K_2O, and 40 kg/ha P_2O_5 are generally applied per year, split in 3 or 4 applications. Fertilizers should be localized in an area close to the plant stem and not exceed the limit of the canopy.

POTASSIUM, THE KEY ELEMENT

Coffee plants have a high demand for potassium. This nutrient is an essential element for many plant functions such as enzyme activity, the transport of water, nutrients and sugars, and control of stomata cells.

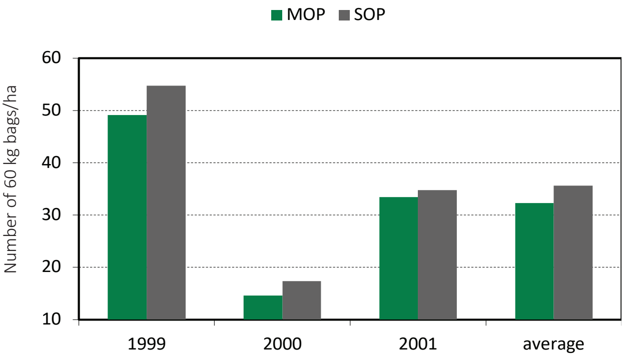
Potassium deficiency in coffee leaves

The early stage of potassium deficiency in plants is known as “hidden hunger”, in which no external visual symptoms develop but plant growth is nevertheless reduced. In advanced stages of potassium deficiency, coffee plants develop chlorosis and necrosis in leaf tips and margins. Development of visual symptoms begins in older leaves, as they provide their potassium to feed the younger ones. The net effect of a potassium deficiency is a decrease in crop yield and quality.

WHAT FORM OF POTASSIUM?

Coffee plants are not particularly sensitive to chloride, but a chloride accumulation affects the quality of the coffee. An experiment carried out in Brazil from 1999 to 2001 compared the effect of two sources of potassium - sulfate of potash (SOP) and potassium chloride (MOP) - on coffee yield and quality. Application rates of 120, 240, and 480 kg K_2O/ha were used.

Large yield variations between years were observed, due to differences in climatic conditions. Yield using SOP, averaged over the three application rates were 11.4 %, 19.8 % and 4.2 % higher, for the years 1999, 2000, 2001 respectively, compared to yield with MOP. The overall average yield for the three years with potassium sulfate was 10.2 % higher.



Effect of SOP and MOP on coffee (Brasil, 2002)

Beans produced with high quantities of chloride are more hygroscopic and more sensitive to the attack of microorganisms, which can damage them.

CHAPTER 4

SULFUR IN COFFEE PRODUCTION

Sulfur is an important nutrient for plant growth, and plays a key role in protein synthesis. For coffee, the normal leaf content is 0.15 to 0.25 % of the dry matter, with 70 % of S-protein contained in the chloroplasts (photosynthesis). Potassium sulfate contains 18 % S which largely covers the sulfur requirements of the coffee plant. Symptoms of sulfur deficiency are similar to those for nitrogen, however they first appear in new leaves, which develop a pale green colour. Plant stems become woodier and break easily and plant growth is stunted. The leaves develop chlorosis, falling prematurely, and the beans are less colourful, with tones of green and reach maturity later. In addition, they have low sugar and protein levels, and higher levels of non-protein nitrogen.

Sulfur deficiency in coffee leaves

In a 10 year field trial, average coffee yield increased from 1320 kg/ha to 2400 kg/ha in response to annual application of sulfate at a rate of 66 kg S/ha. A high correlation between soil sulfate content and coffee yield resulted from a two-year experiment. Coffee yield increased from 1890 to 2750 kg/ha when the sulfate S in the soil increased from 5 to 10 mg S/dm^3.

LOOKING FOR HIGHER QUALITY COFFEE

Sulfate of Potash (SOP) offers an excellent combination of potassium and sulfur, which allows production of a higher quality coffee. The higher quality is reflected in higher activity of the enzyme polyphenoloxidase, a better colour index, a higher concentration of total sugar, less acidity and less reducing sugar.

The high polyphenoloxidase activity level, resulting from the use of SOP, provides a beverage of fine quality ("soft" or "almost soft"). The level of activity corresponding to the use of MOP is associated with a beverage of only acceptable quality ("hard").

FLAX

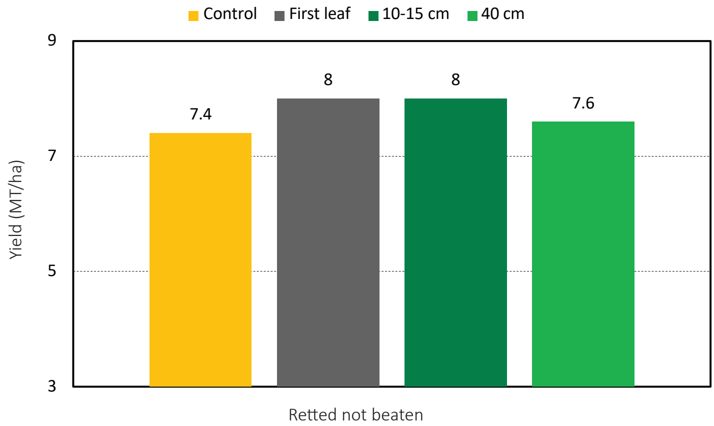
MINERAL NUTRITION

Flax is cropped in temperate regions, usually along shores as it needs rather wet conditions. Mineral nutrition can vary according to the production: oil or fibre.

Few studies are available concerning plant nutrition in general and mineral nutrition in particular. Usually 70 kg N/ha is needed, but this needs to be adjusted according to the previous crop and soil analysis, knowing that a large part can be returned to the field during processing. Mobilisation of P and K are estimated at 40 kg P_2O_5 and 140 kg K_2O per ha.

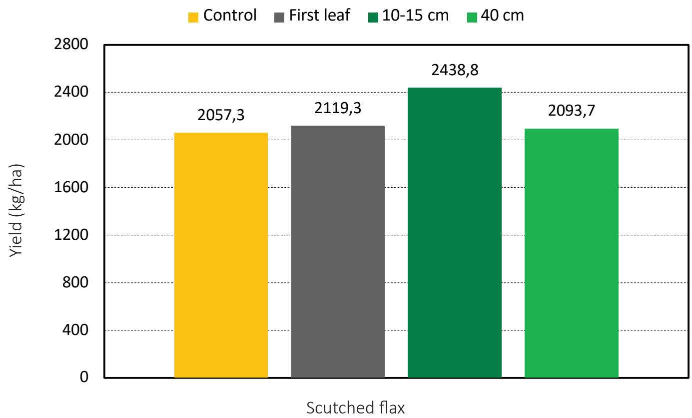
THE BENEFIT OF FOLIAR SPRAYS

In 2016, an experiment was carried out in the North of France. The basal dressing was as follows: 80 kg N, 40 kg P_2O_5 and 70 kg K_2O per ha. In addition, foliar applications of K-Leaf at 10 kg per ha (5 kg K_2O per ha) were sprayed at the first leaf stage, 10 - 15 cm stage or 40 cm stage.



Effect of foliar sprays of SOP on flax yield (Agrovision, France, 2016)

The results show that early or medium stage applications are more effective on retted yield than late application. When it comes to fibre production after processing, the application of K-Leaf at 10 kg per ha at 10 - 15 cm gives the best yield of scotched flax, with a production improvement of 18 % over control improving profit by 15 % for the producer.



Effect of foliar sprays of SOP on flax yield (Agrovision, France, 2016)

Flax plant left in the field for field retting

FLOWERS

MINERAL NUTRITION

Mineral nutrition depends on variety and a number of variables linked to cropping conditions. Nevertheless, some common parameters exist such as a pH from 5.5 to 7, a constant supply of water and nutrients and in an adequate ratio. 1:0.5:1 is usually considered as the optimal NPK basal ratio for a balanced fertilization.

Today, a large part of the cut flower production uses soilless cultivation and fertigation, which explains the popularity of soluble and liquid fertilizers. The EC of the solution in the media should generally not exceed 3 dS/m. Nitrogen is applied in nitrate and ammonium forms, respectively 75 % and 25 % usually. Potassium is an important element when it comes to quality and shelf life, and is sometimes required in higher quantities than nitrogen. Calcium is essential as part of the cell membrane, playing a role in the rigidity of the stalks.

IMPORTANCE OF POTASSIUM

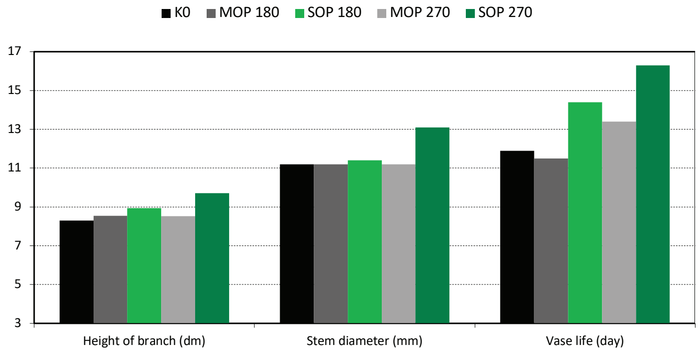
The key role of potassium on water regulation and on the transport of elements and assimilates in the plant is well known. Potassium is particularly important at the flowering stage. In case of potassium deficiency, margins of older leaves become chlorotic, quickly followed by necrosis.

Potassium deficiency on rose leaf

WHAT SOURCE OF POTASSIUM?

Sulfate of Potash (SOP) is more and more used as source of potash in cut flower production as well as for plants grown in pots.

Indeed, potassium nitrate (NOP), which is one of the main forms of potash applied, is more expensive, and use of potassium chloride (MOP) can be detrimental in a cash crop production, and an intensive cropping system, where the risk of chloride accumulation is high. This is well demonstrated in an experiment on marigold in India, in which SOP and MOP are compared to control at 180 and 270 kg K_2O/ha.

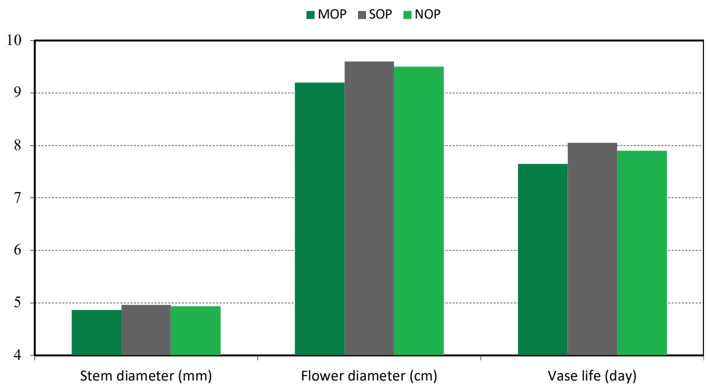


Effect of potash form on marigold (Pune College of Agriculture, India, 2006)

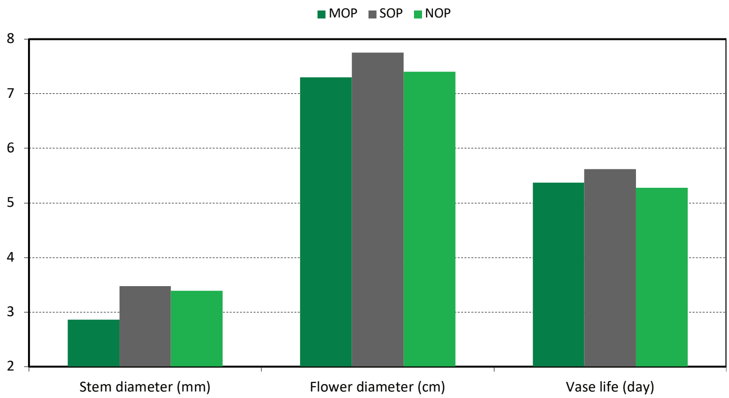
Regarding production and quality parameters, SOP shows better results compared to MOP and at least, equivalent or better than NOP.

SOLUPOTASSE USE IN CUT FLOWER PRODUCTION

An experiment carried out under drip irrigation shows the benefit of SoluPotasse, the soluble SOP, compared to NOP and MOP. Flowers fertigated with SoluPotasse have generally the strongest stems, larger flower diameter and a longer vase life.

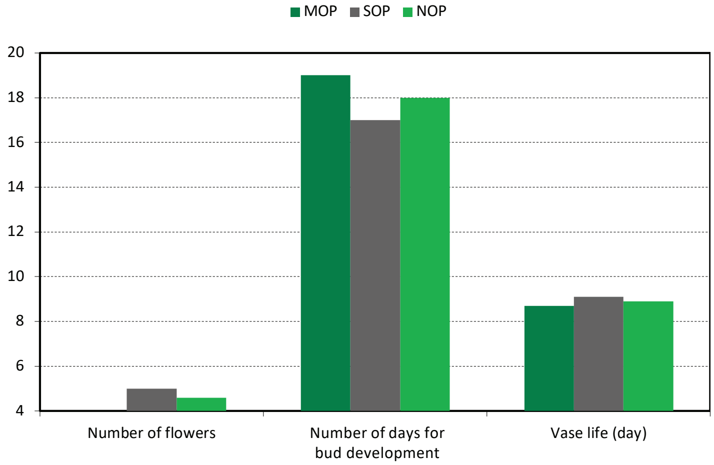


Results on gerbera (Pune College of Agriculture, India, 2006)



Results on carnation (Pune College of Agriculture, India, 2006)

CHAPTER 4



Results on rose (Pune College of Agriculture, India, 2006)

Thanks to the benefits of potassium and sulfur on quality and production, SOP is becoming the best investment for optimal fertilization management in cut flower cultivation.

MEDICINAL & AROMATIC PLANTS

A LARGE VARIETY OF SPECIES

Medicinal and aromatic plants represent at least 2000 species from most of the botanic families. A large part of these plants provides essential oils, obtained by distillation. It is impossible to give precise recommendations concerning fertilization for so many species, although some examples are presented below.

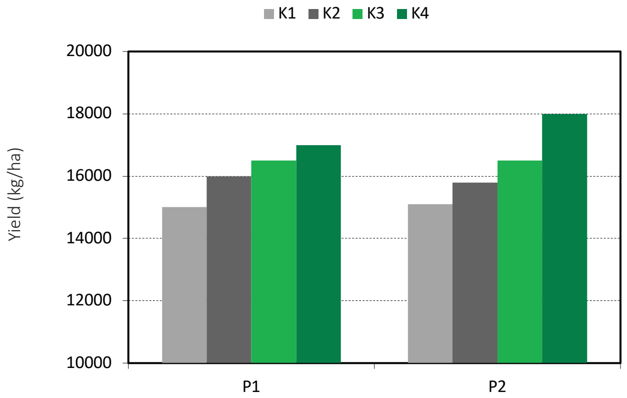
Crop	N	P_2O_5	K_2O
Arecanut	160	60	180
Black pepper	175	70	240
Cinchona	70	50	70
Clover	30	20	60
Cranberry	50	30	80
Ginger	30	30	60
Nutmeg	40	30	80
Poppy	110	45	160
Sage	80	60	180
Thyme	60	40	150

Example of NPK requirements per ha

The use of medicinal and aromatic plants is increasing and their production has evolved from traditional picking to industrial cropping. This allows an improvement in the quality of the plants, particularly those containing essential oils.

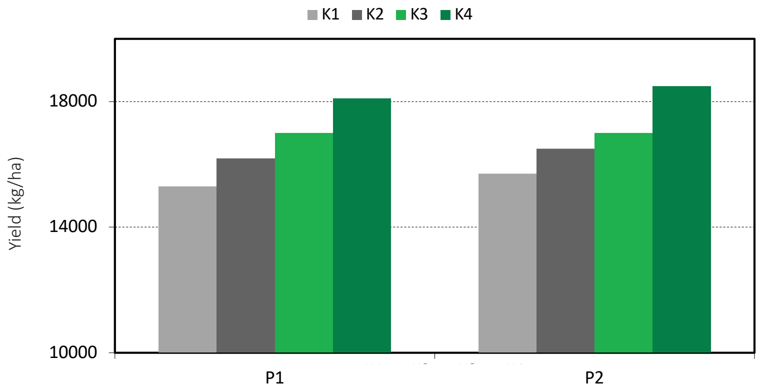
MINERAL ELEMENTS REQUIREMENTS

The difference in mineral nutrient requirements is dependent upon species, which are many when it comes to medicinal and aromatic plants. As a general fact, potassium needs are at least equal to nitrogen needs. Soil analysis is necessary to determine the fertilizer program, but in contrast to many other crops, fertilization strategy cannot be guided by foliar diagnosis, as few references are available.



Effect of SOP on thyme yield (Ege University, Turkey, 2007)

In a project carried out in Turkey with the Ege University, yield and quality of sage and thyme was investigated. Fertilizer program was 67 kg N/ha, 67 or 136 kg P_2O_5/ha (P1 and P2) and 67, 167, 267 or 367 kg K_2O/ha (K1 - 4) in the form of potassium sulfate. The positive effect of higher SOP doses is clear, whereas the second dose of phosphorus is only effective with the highest dose of potassium.



Effect of SOP on sage yield (Ege University, Turkey, 2007)

During the second year of the experiment, essential oils were analysed. The percentage of oil increases with potassium sulfate doses and no “dilution effect” is observed.

Amongst the other benefits of sulfate of potash, is the supply of sulfur in a form that is readily taken up by the plant. Sulfur plays a key role in amino acid and oil synthesis which explains its importance on the quality of medicinal and aromatic plants.

K_2O rate kg/ha	Thyme	Sage
67 (K1)	2.22	1.75
167 (K2)	2.27	1.87
267 (K3)	2.31	1.87
367 (K4)	2.44	2.16

Total oil contents of thyme and sage (%)

THE FORM OF POTASSIUM

A supply in the sulfate of potash form is always preferable, notably for its beneficial role in the formation of essential oils and organoleptic components. Sulfate of potash is also the best form in dry conditions which are prevailing in the Mediterranean area, a large region for medicinal and aromatic plant production.

A recent study, carried out by Dr Tomáš Lošák from Mendel University in Brno, illustrates the difference between potassium sulfate (SOP) and potassium chloride (MOP) on poppy in terms of production and quality. Two doses of potassium were tested: K1 (0.85 g per pot) and K2 (1.7 g per pot).

The production of morphine extracted from straw (empty capsule and 15 cm of stem) is increased by 8 to 10 % relative to the control with SOP whereas MOP shows only a slight increase or a negative effect. The same experiment demonstrates the role of potassium sulfate on yield and the negative effect of chloride.

	Seed yield	Straw yield	% of morphine in straw + head	
	g/plant		%	Rel. %
K0	5.96 a	12.41 a	1.37 a	100
K1 SOP	6.96 c	14.04 b	1.48 b	108.0
K2 SOP	6.42 c	14.83 c	1.51 b	110.2
K1 MOP	6.59 c	12.28 a	1.35 a	98.5
K2 MOP	6.88 c	13.54 b	1.40 a	102.2

Effect of SOP versus MOP on poppy yield (Mendel University, Brno, Czech Republic)

Finally, the sulfate form does not contain any chloride, which can perturb plant transpiration and growth. The supply of water is also better regulated, reducing the impact of dry periods for those plants largely produce in semi-arid conditions.

As few studies have been carried out on the mineral fertilization of medicinal and aromatic plants, it is of interest to examine research conducted in Egypt on caraway (also called Persian cumin). The experiment was carried out during two years (2007 and 2008) with three doses of potassium sulfate: 35, 70 and 105 kg per ha. Parameters measured were the seed yield, percentage of oil and oil production.

SOP K_2O/ha	Seed yield kg/ha		Oil %		Oil production kg/ha	
	2007	2008	2007	2008	2007	2008
35	1782	1819	1.90	1.89	33.86	34.38
70	1891	1900	1.92	1.93	36.31	36.67
105	1927	2018	1.95	2.03	37.58	40.97

Effect of SOP on caraway yield

The effect of the dose of potassium sulfate on yield and oil production is clear, as can be observed on many plants cropped for essential oil content.

MULBERRY

MINERAL NUTRITION

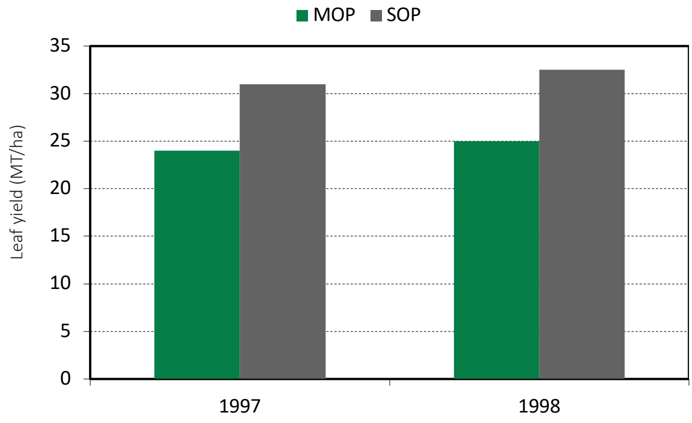
Mulberry trees are grown for the leaves that are the main nutritional base of silk worms. It is a very large business in many Asian countries. The selection and breeding for biomass production have widely changed during the last thirty years.

A leaf yield of 25 tons per ha/year and a cocoon yield of 1250 kg/ha/year require 240 kg N, 45 kg P_2O_5 and 210 kg K_2O per ha.

Silk worms feed on mulberry leaves

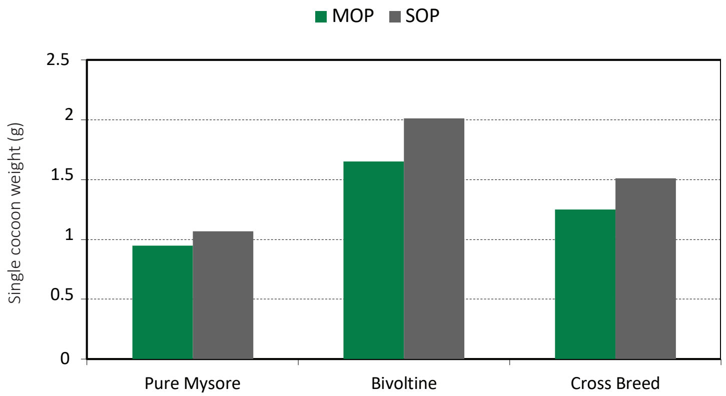
According to many references from India and China, the application of 300 kg of N per ha in combination with 120 kg P_2O_5 and 120 kg K_2O in the form of potassium sulfate recorded the highest fresh leaf yield per hectare each and every year.

This is illustrated in the following experiment carried out in India comparing potassium chloride (MOP) and potassium sulfate (SOP). Leaves were harvested 5 time per year.



Effect of potassium form on leaf production (UAS, India, 1997/1998)

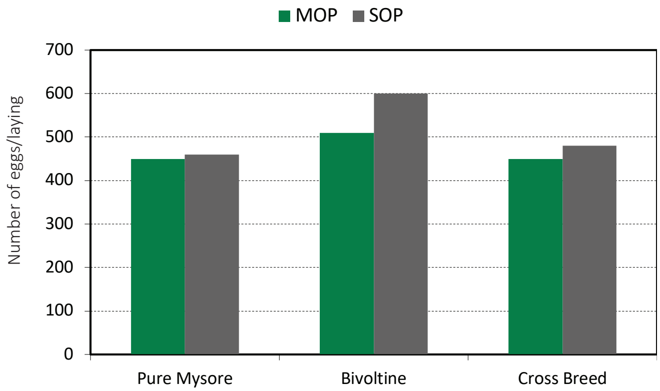
Then, in the same experiment, silk worms are fed with the leaves from the two treatments. Three different species of silk worms were considered.



Effect of potassium form on single cocoon weight (UAS, India, 1997/1998)

CHAPTER 4

For high quality silk production, single cocoon weight and fecundity are the main quality parameters. It appears that potassium sulfate shows a significant benefit over the same rate applied as potassium chloride.



Effect of potassium form on fecundity (UAS, India, 1997/1998)

From this experiment, it is clear that use of potassium sulfate produces more and better quality mulberry leaves. Consequently, silk worms are in a healthier condition to produce more silk and also to have more eggs.

TEA

THE BASIS OF BALANCED NUTRITION

The production of tea requires an NPK ratio of 1:0.4:0.5 (green tea from China) or 1:0.6:1.2 (black tea from India). Potassium is a major nutrient for the growth and development of tea plant and is also regarded as one of the key elements for tea quality. The tea plant has a particularly high concentration of K in the shoots and mature leaves. Potassium plays vital roles not only in maintaining the optimum turgor needed for cell elongation and division, but also for numerous biochemical and biophysical reactions, such as photosynthesis, respiration and translocation of minerals within the plant.

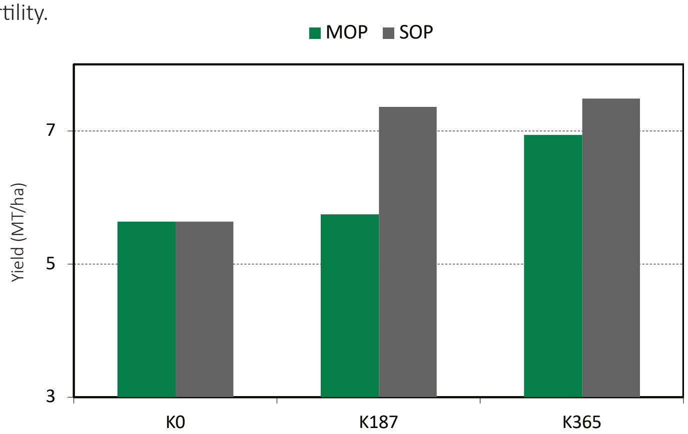
Potassium deficiency in tea leaves

In the case of potassium deficiency, plant growth rate and yield decline even though no visual symptoms are initially displayed.

Further reduction in available K results in visual symptoms in the following sequence: pronounced tip and marginal scorch on many of the mature leaves; leaves dropping prematurely leaving a crown of young foliage on top; development of thin and twiggy stems at the plucking surface; decline in new shoot growth and poor recovery after pruning; irregular and delayed shoot growth; and finally plant death.

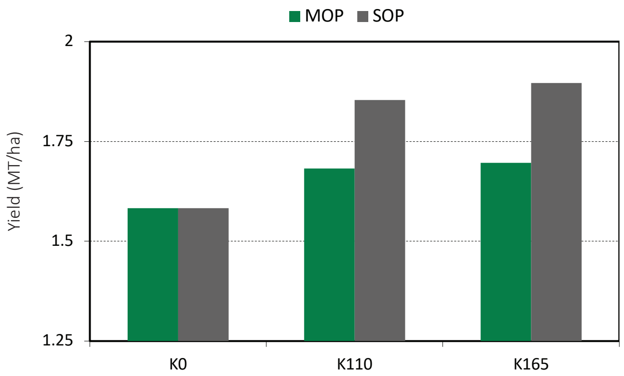
POTASSIUM SULFATE FOR HIGHER YIELD

Experiments carried out from 1999 to 2003 in China and India compared the effect of potassium sources on tea yield and quality at different application rates, according to soil fertility.



Effect SOP and MOP on green tea (China, 2002)

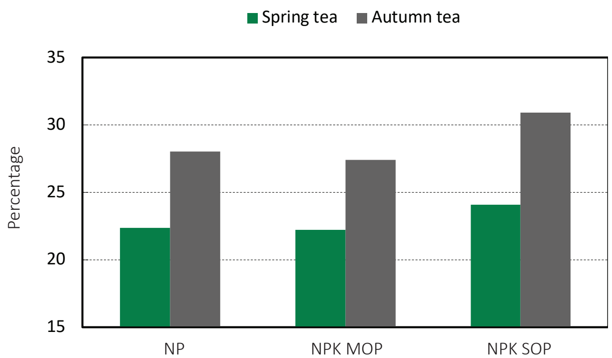
Although the effect of fertilization on yield is not the main objective in tea production, the yield is generally increased with potassium sulfate.



Effect SOP and MOP on black tea (India, 2003)

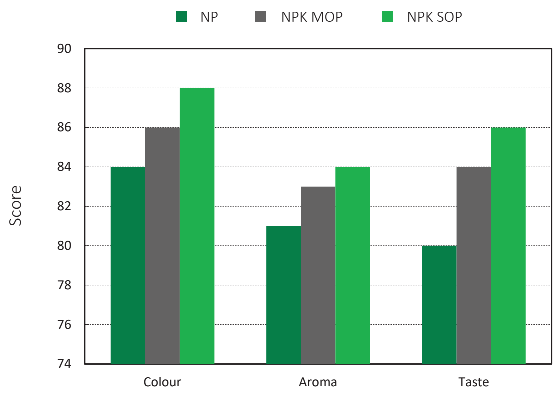
POTASSIUM SULFATE FOR QUALITY

An accumulation of chloride affects tea quality. Conversely, sulfur has a positive effect on amino acid production. The synergistic effect of potassium and sulfur produces an increase in polyphenols and caffeine in black tea and amino acids in green tea.
These are the main criteria of quality because of their effects on colour and taste, as well as human health.



Polyphenol production in black tea (Guangdong, China, 1999)

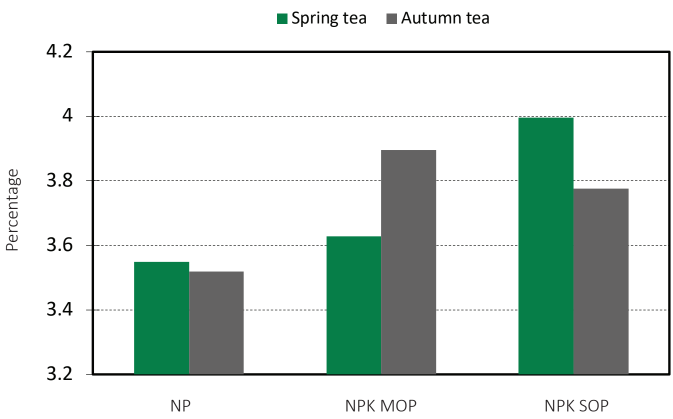
An experiment carried out on black tea in China showed the positive effect of SOP on polyphenols production, confirmed by observations regarding colour, aroma and taste.



Effect of SOP and MOP in black tea quality (Guangdong, China, 1999)

When using SOP, the overall score for all quality parameters showed an improvement of 25 % over NP fertilization and of 10 % over MOP based NPK fertilization.

In another experiment carried out on green tea, amino acid production was also increased when using SOP. Scores regarding colour, aroma and taste were also in line with results from experiments located in the main green tea production area in China.



Amino acid production in green tea (Guilin, China, 1999)

SULFUR IN TEA PRODUCTION

Sulfur plays a key role in amino acid synthesis. The normal leaf content for tea is 0.12 to 0.20 % of the dry matter, mainly contained in the chloroplasts. Potassium sulfate also contains 18 % S which largely covers the sulfur requirements of tea.

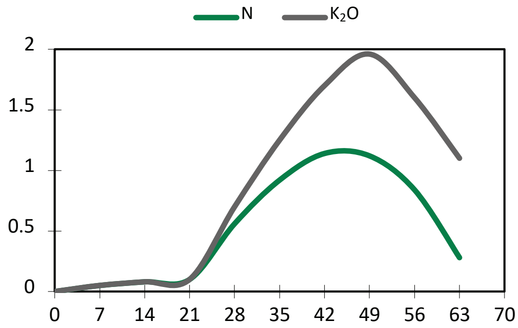
Sulfur deficiency on tea leaf

Thanks to the combined effect of potassium and sulfur, SOP is becoming the main fertilizer for production of high quality tea.

TOBACCO

SPECIFIC NUTRITIONAL REQUIREMENTS

Amongst all cultivated crops, tobacco stands out as a special case: during drying, the leaves undergo maturation and the final aim of the plant is to be smoked. The balance between the mineral elements plays a fundamental role in the chemical transformations that take place during the drying process and on the quality of the final product. The type of fertilizer used will have a profound effect on the combustibility of the tobacco, hence fertilization must satisfy the plant's nutritional requirements while respecting the mineral balance, thus allowing a high quality production, both from a taste and combustion point of view. Tobacco is a crop that needs significant amounts of potassium. It is a fast growing plant, between 80 and 150 days, with a high daily potassium requirement.



Daily absorption curves in kg/ha/day

While potassium and nitrogen are absorbed in a similar fashion during the first three weeks after transplanting, the total requirement and the daily uptake of potassium rise considerably after this time. A program of fertilizer applications on top of a base application enhances the potassium uptake, particularly during rainy years.

Potassium deficiency in tobacco

THE TYPE OF POTASH: A CRUCIAL CHOICE

The uptake of minerals is essential for a quality production. Potassium has an impact on important criteria such as size of leaves, specific weight, colour, elasticity and disease resistance.

Chloride toxicity in tobacco

For a good combustibility the potassium level in leaves must be superior to 2 % of the leaf dry matter. On the other hand combustibility will decrease with high levels of chloride and sodium. As well as disrupting plant transpiration, chloride also affects tobacco quality giving it a sour taste. The use of fertilizers containing chloride should be strongly discouraged, particularly from an economic point of view: a chloride level of greater than 2 % of the leaf dry matter, removes all the commercial value of the leaves. It is for this reason that sulfate of potash has always been considered as the best source of potassium for tobacco. It is not only a chloride-free fertilizer but also free of nitrogen, the supply of which after the third week can be detrimental to optimal maturation.

SULFUR: A NON-NEGLIGIBLE ELEMENT

Sulfur plays an important role not only in plant growth but also on quality. Tobacco growth is limited when the sulfur level in leaves drops to below 0.15 % of the leaf dry matter. At the same time one observes an accumulation of nitrates in the plant, which is detrimental to leaf maturation.

The control of atmospheric sulfur emissions, as well as a decrease in the use of sulfur bearing fungicides, has led to an increase in cases of sulfur deficiency. Sulfate of potash provides sulfur in a readily available form for tobacco.

Sulfur deficiency in tobacco

DIFFERENT METHODS FOR DELIVERING SULFATE OF POTASH

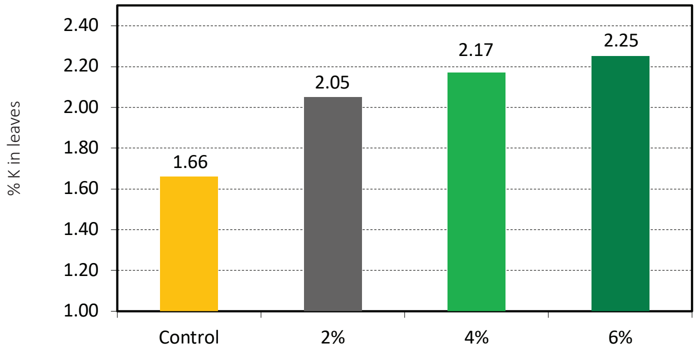
Sulfate of potash can be if necessary delivered in totality during transplantation either in a simple form or as part of a mixture. However a regular program of applications, based on granules, allows optimal uptake during a wet year or in irrigation.
SoluPotasse, Tessenderlo Kerley's soluble form of sulfate of potash, can also be used in nutrient solutions for fertigation using either drip or flood irrigation. For the production of cigars in Cuba and particularly wrappers, different fertigation programs were compared as shown in the following table. The objective of this 5-years experiment was to compare potassium sources as well as application timing concerning nitrogen and potassium and the impact on tobacco quality.

	Type	Comment
T1	Farmer's practice	Manure + N and K fertigation from 0 to 18 DAT*
T2	Recommended program, based on absorption curves	Basal dressing + K fertigation from 0 to 28 DAT, N fertigation from 0 to 21 DAT
T3	Standard program	N and K fertigation from 0 to 21 DAT
T4	Program based on NOP	Basal dressing + N and K fertigation from 0 to 28 DAT
T5	T5 = T2 without basal dressing	K fertigation from 0 to 28 DAT, N fertigation from 0 to 21 DAT

*DAT: Days after transplanting

	Production (kg/ha)			
	Wrapper		Other leaf	Total
	Export quality	National quality		
T1	674	396	621	1697
T2	899	508	834	2241
T3	662	343	765	1770
T4	444	449	913	1806
T5	499	444	874	1817

Foliar applications with K-Leaf give an equally good result, stimulating plant activity at the potash absorption peak during the second month after transplantation.

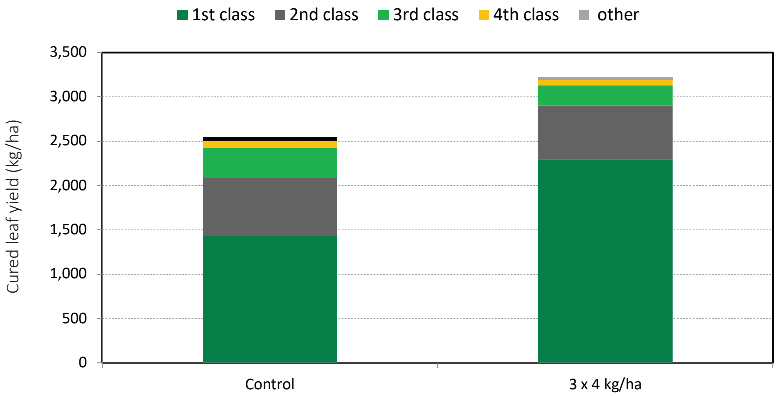


Potassium level in tobacco leaves after three foliar sprays (Guangzhou University, China, 1997)

The experimental results above demonstrate the benefits of a complimentary program of foliar sprays on tobacco quality. The sprays were applied at 30, 40, and 50 days after transplanting with 2, 4 and 6 % concentration based on a 300 l/ha solution. The four plots received the same basal fertilization.

Whatever the means of application, sulfate of potash provides tobacco with the best product quality.

Results from an experiment in Argentina confirm the benefit of foliar applications of K-Leaf. Three foliar applications at 4 kg/ha improve yield and first class leaf production over the control without foliar spray.



Effect of foliar applications of K-Leaf on tobacco production and quality (Expt. St. La Posta, Argentina, 2014)

PART 5

FIELD CROPS

ALFALFA

SPECIFIC NUTRITIONAL REQUIREMENTS

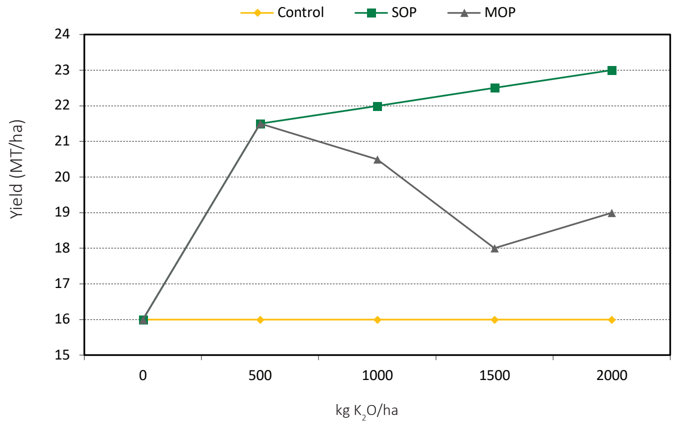
Alfalfa is able to fix nitrogen and so mineral fertilization concerns mainly potassium and phosphorus. Alfalfa production requires a large amount of potassium: 28 kg K_2O are removed per harvested ton. Potassium is required to develop plants and enable them to resist low temperature during winter time.

Alfalfa is a perennial plant (usually cropped during 3 years) which must store carbohydrates for spring re-growth and after each cutting. The maintenance of a sufficient K level is necessary to allow carbohydrate production.

Potassium deficiency on alfalfa

Typical K deficiency symptoms of alfalfa are small chlorotic spots clustered near the margins of the older leaves. With increasing severity of K deficiency these small spots form chlorotic areas.

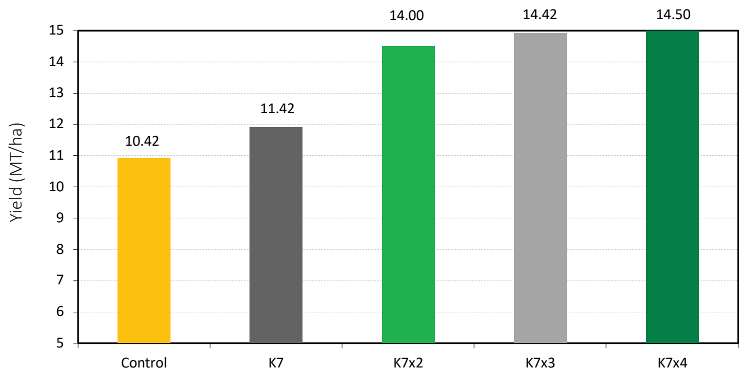
Several experiments show the response of alfalfa to potassium. In the trial presented below carried out in the USA, two forms of potash fertilizer were compared: potassium chloride (MOP) and potassium sulfate (SOP).



Effect of potassium form on alfalfa production (LAWR Dept.,UC Davis, USA, 1995)

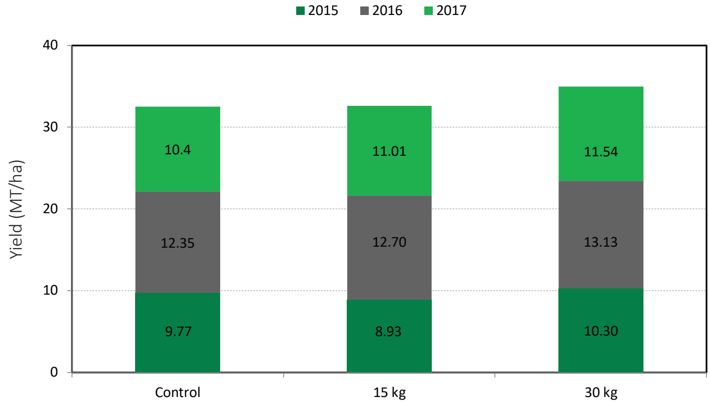
Alfalfa production is improved when increasing K_2O dose with SOP and decreased with MOP due to the negative effect of chloride. The concentration of potassium in the leaves of alfalfa was slightly higher in SOP fertilized treatments than in MOP treatments.

In another experiment carried out in Iran in cooperation with the Soil & Water Research Institute, it was found that application of foliar sprays (7 kg/ha of K-Leaf, or 3.5 kg K_2O/ha) improves production. Treatments are as follows: the control is without foliar application, K7 is one application after the first cut, K7x2 is applications after cut 1 and cut 2, K7x3 is applications after cut 1, cut 2 and cut 3, K7x4 is applications after cut 1, cut 2, cut 3 and cut 4. All plots received the same basal dressing.



Effect of K-Leaf on alfalfa production (SWRI, Iran, 2016)

This is confirmed in a three-year trial carried out in France where 15 or 30 kg of K-Leaf per ha (7.5 or 15 kg K_2O/ha) were applied a few days after each cut. The cumulated dry matter yield is increased by 7.5 %, improving by more than 6 % the income for the farmer.



Dry matter production over 3 years (Staphyt, France, 2013-2015)

CEREALS

FERTILIZATION UNDER SEMI-ARID CONDITIONS

Cereals represent one of the most important staple crops in the world and can be cropped in various conditions. Potash fertilization is traditionally done with potassium chloride when chloride can be easily leached. However, under semi-arid conditions, particularly in Northern Africa and in the Middle East, it is vital to consider the risk of salinization and to use alternative sources of potassium.

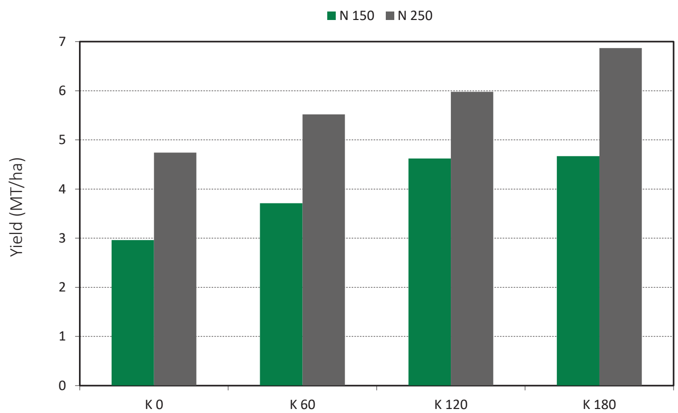
Field experiments in research centres in this area show that potassium sulfate has a place in cereal production.

Potassium deficiency on wheat

SOP TO PROTECT THE YIELD POTENTIAL AND SOIL QUALITY

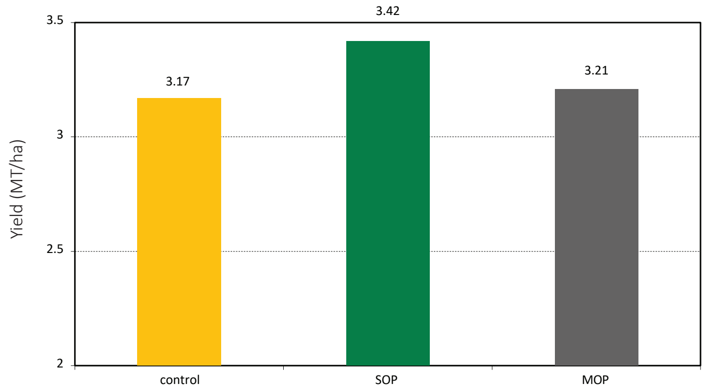
A wheat production of 6 - 7 tons of grain per hectare requires 150 - 175 kg N, 55 - 75 kg P_2O_5 and 100 - 125 kg K_2O. Nitrogen demand is regular from early spring to midsummer while potash demand is highest at the end of spring. Other nutrients are also required such as calcium (50 kg CaO/ha), magnesium (25 kg MgO/ha) and sulfur (50 kg SO_3/ha).

Under semi-arid conditions, sustained high yields are only achievable with balanced fertilization and control of soil salinity. In an experiment conducted in Algeria under desert conditions in co-operation with the Ouargla University in Southern Algeria, an increase in the nitrogen rate must be also accompanied by an increase in the potassium sulfate rate. This trial was conducted using 150 or 250 kg N/ha and 0, 60, 120 or 180 kg K_2O/ha.



Effect of N and K on wheat production (Ouargla University, Algeria, 2004)

Another experiment from Egypt, illustrates the effect of potash on yield at two application rates and with two sources (MOP and SOP). The three treatments received the same NP dressing and the recommended dose of potassium (60 kg K_2O/ha).



Effect of potash form on wheat production (ARC, Egypt, 2009)

In semi-arid conditions, leaching of chloride is not possible and high levels of evaporation can lead to accumulation of salts on the soil surface. Chloride from MOP has a detrimental effect on yield, whereas SOP application safeguards the yield potential.

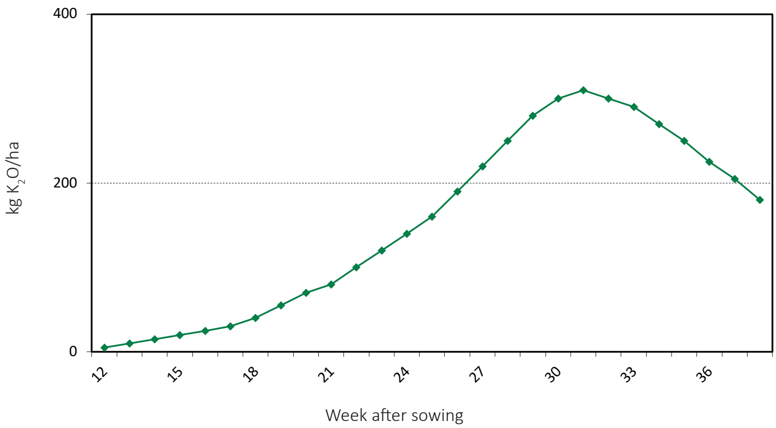
Sulfur deficiency on wheat

IMPORTANCE OF SULFUR

In the last 30 years, a better control of industrial emissions, a reduction of sulfur based pesticides and better quality of fertilizers on the market have induced sulfur deficiencies in many crops, including cereals.

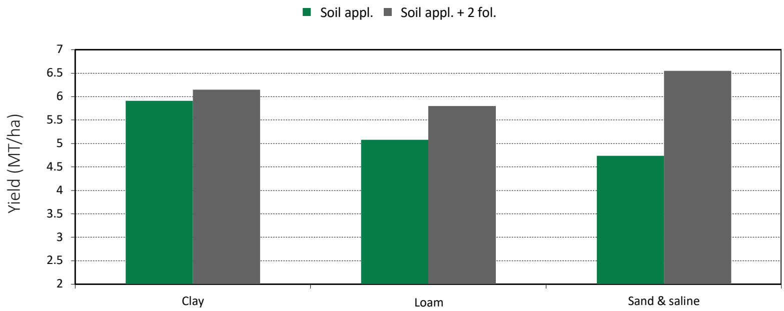
THE BENEFIT OF FOLIAR APPLICATIONS OF K-LEAF

Foliar sprays of SOP can be very effective when they are used during the critical stages of the plants growth, with respect to potassium uptake as well as that of other mineral elements. Concerning wheat, the highest potassium requirement is at grain filling.
It is a very short period: 7 to 12 days as shown in the graph below. Foliar applications of SOP become very popular to complement mineral nutrition in intensive production systems. In the case of potassium, it allows the plant to have a better metabolism and transport of assimilates to the grains. Finally, the number of grains per head and the specific weight are improved resulting in higher yields.



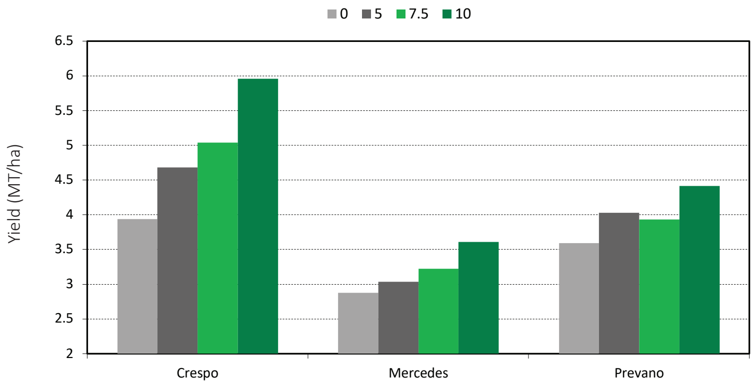
Potassium absorption in winter wheat

A field experiment, carried out in Egypt at 3 different locations with different soil textures and qualities shows the benefit of foliar sprays of K-Leaf on wheat production. 8 kg K_2O/ha were applied twice. Application timing is very important due to the short critical stage for potassium uptake in wheat. Foliar application must be done at the end of stem elongation or just before the flowering stage. In the case of two applications, consider an interval of a week.



Effect of foliar sprays of Leaf® on yield in different soil conditions (ARC, Egypt, 2009)

From this experiment, it can be concluded that in limiting conditions (light sandy soil), foliar applications of SOP help to express the full potential of wheat. In an experiment from Argentina, where soils are very rich in potassium, foliar applications at 5, 7.5 and 10 kg/ha of K-Leaf improved significantly yield in 3 different locations, without any potassium fertilizer as basal dressing.



Effect of foliar application of K-Leaf on wheat yield (INTA, Argentina, 2011)

In this case, foliar applications enhance root absorption of potassium during the critical stage, at grain filling. Potassium in the soil is not a limiting factor, the liming factor is the capability of roots to absorb elements from the soil. Foliar applications stimulate plants and boost the uptake of nutrients via the roots, resulting in better yields.

COTTON

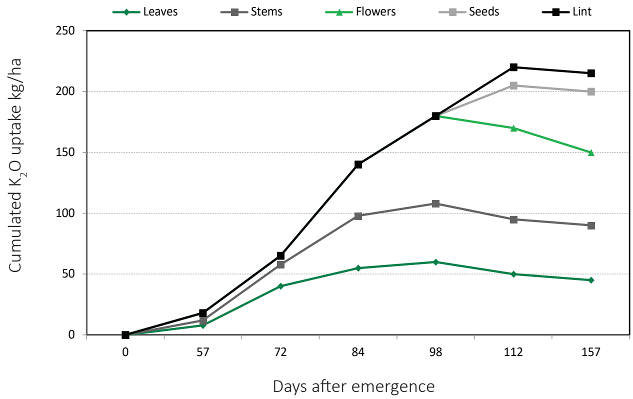
NUTRITIONAL REQUIREMENTS

In cotton, growth and dry matter production follow a sigmoidal curve and nutrient uptake shows a similar pattern. Often, phosphorous (P) is applied as a starter fertilizer, though placement of P fertilizer is not as important as in the production of many other crops. In contrast, split application is used for both nitrogen and potassium application throughout the cropping period.

Ideally, the pH of the soil should be between 6.0 and 6.5, with 6.5 being optimum. The amount of fertilizers required for optimal cotton growth, varies from 55 to 280 kg/ha for potassium, 110 to 225 kg/ha for nitrogen and 20 to 45 kg/ha for phosphorous, depending on soil properties. It is therefore recommended to perform soil analysis prior to fertilizer application.

POTASSIUM, A QUINTESSENTIAL NUTRIENT

Potassium deserves special attention in cotton production because of its high uptake rate, the relative inefficiency of the cotton root system as a K^+ absorber, and the diversity of soils in which it is cultivated. 110 to 120 days after planting, the shape of the K uptake curve is similar to those of dry matter production, N and P uptake.
But after that stage of maximum accumulation, the total K uptake drops, the decrease being the result of a translocation from leaves and stems to reproductive organs as well as movement of K back to the soil. Therefore, extra potassium should be applied at this stage.



POTASSIUM DEFICIENCY SYMPTOMS

Potassium deficiency symptoms usually occur at the bottom of the plant on the lower, older leaves. Leaf colour first changes to light yellowish-green.

Potassium deficiency in cotton leaf

Later, numerous brown specks occur at the leaf tips, around margins and between veins. Tips and margins break down and begin to curl. Eventually, the leaves become reddish-brown, dry and finally rust coloured and brittle. Cotton bolls fail to develop properly and may fail to open or only partially open. The fibre is of poor quality.

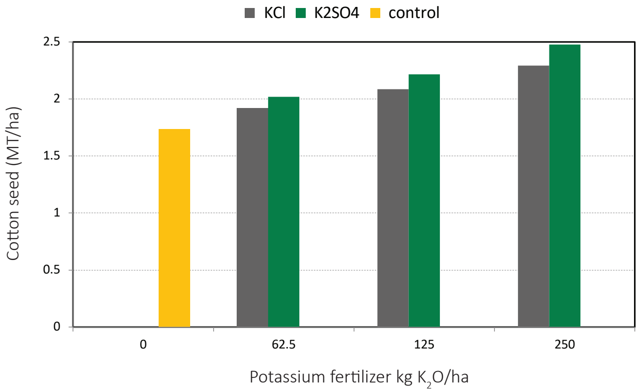
SULFUR REQUIREMENT

Since cotton seeds are rich in protein, cotton is a crop that utilizes relatively large amounts of sulfur. Usually, cotton contains more sulfur than phosphorous. The uptake of sulfur ranges from 7 to 33 kg S/ha. According to the amount contained in the seed, the sulfur removal can be estimated to be half the uptake. In case of sulfur deficiency leaves are lighter green and smaller than normal, similar to nitrogen deficiency. Chlorosis and leaf death occur in the most severe cases of sulfur deficiency.

Sulfur deficiency in cotton leaf

SOP: BENEFICIAL FOR YIELD

Cotton crops are often grown in semi-arid or arid conditions. As there is a great risk of salinity in this type of cropping conditions, chloride toxicity symptoms might occur. These symptoms include scorched leaf margins, excessive abscission, as well as reduced leaf and overall reduced plant growth. Therefore, it is highly recommended to use potassium sulfate (SOP) as a source of potassium, as opposed to potassium chloride (MOP).

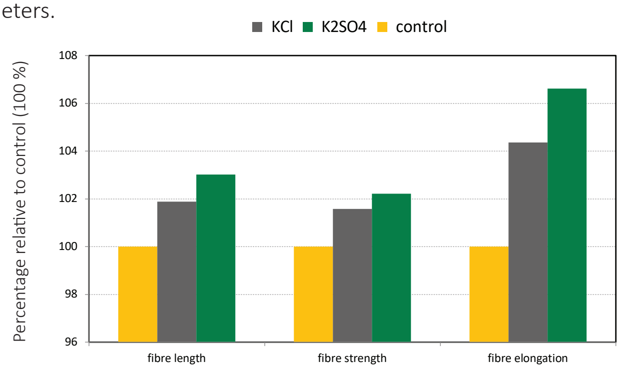


Effect of potash form on cotton production
(Bahauddin Zakariya University, Multan, Pakistan, 2003)

An experiment from Pakistan (see graph above) comparing the use of SOP and MOP shows a clear increase in yield when SOP is used. This is due to an increase in the number, size as well as the weight of the bolls. This effect is even more pronounced in saline conditions, with a 25 % increase in yield when SOP is used compared to MOP, due to the detrimental effect of chloride.

SOP: BENEFICIAL FOR QUALITY

Besides its beneficial effect on yield, SOP also has a positive influence on quality parameters.



Effect of SOP on quality of cotton (Bahauddin Zakariya University, Multan, Pakistan, 2003)

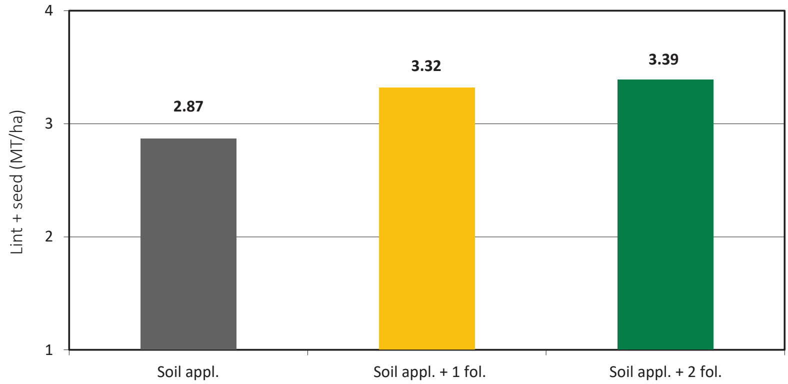
CHAPTER 5

Fibre length, strength and elongation all increase when SOP is used. SOP also increases water use efficiency and thus plant resistance to drought conditions. Finally, SOP helps to reduce the incidence and severity of pest and disease attacks, such as the cotton leaf curl virus.

SOLUBLE SOP IN COTTON PRODUCTION

Potassium uptake requirements during growth can be difficult to maintain. SoluPotasse is a soluble grade of SOP especially prepared for fertigation. Being able to adapt nutrition to the plant's requirements at different growth stages is the main benefit of fertigation. SoluPotasse, providing potassium without nitrogen, is particularly efficient during the boll development stage.

Foliar application of potassium enables the correction of deficiency more quickly and efficiently than soil application. Thus, foliar application prevents yield loss. K-Leaf has been designed for this purpose. The graph below illustrates the beneficial effect of using K-Leaf in foliar application at 6 kg K_2O/ha applied applied twice: the first application at stem elongation and the second a week after; soil application is following local recommendations, i.e. 60 kg K_2O/ha.



Foliar application on cotton: response to K-Leaf (ARC, Egypt, 2004)

This is confirmed in another trial from Turkey (Bati Akdeniz Agricultural Research Institute, Turkey, 2017), in which K-Leaf was applied at 7.5 or 15 kg per ha in 250 liters of water at 70 or 90 days after sowing (DAS).

Treatments	Number of bolls/ plant	Cotton seed yield (kg/ha)	Lint (%)
T1 control	16.3	4337 b	41.0
T2 3 %; 70 DAS	18.6	4831 ab	41.1
T3 6 %; 70 DAS	17.2	5244 a	40.5
T4 3 %; 90 DAS	18.1	5060 a	40.8
T5 6 %; 90 DAS	16.3	4848 ab	40.1
LSD 0.05	ns	250	ns

Effect of K-Leaf on cotton seed yield and yield components
(Bati Akdeniz Agricultural Research Institute, Turkey, 2017)

All plots received the same basal dressing. The percentage of lint is not changed, but cotton seed yield increased by 20 % with 15 kg/ha of K-Leaf applied 70 days after sowing (T3) compared to control (T1).

Treatments	Fibre fineness (micronaire)	Fibre length (mm)	Maturity	Uniformity (%)	Strength (%)
T1 Control	4.56	28.3 b	87.1	84.8 b	33.4 b
T2 3 %; 70 DAS	4.69	30.5 a	87.8	86.7 a	36.6 a
T3 6 %; 70 DAS	4.73	30.8 a	87.6	85.9 a	37.5 a
T4 3 %; 90 DAS	4.81	31.2 a	87.9	86.8 a	36.4 ab
T5 6 %; 90 DAS	4.77	30.7 a	87.9	86.9 a	38.2 a
LSD 0.05	ns	0.57	ns	0.49	1.24

Effect of K-Leaf on cotton fibre quality
(Bati Akdeniz Agricultural Research Institute, Turkey, 2017)

Results of this trial revealed that foliar K-Leaf applications as a complement to soil fertilization increase cotton seed yield. The highest yield was obtained from the NPK soil + 6 % SOP foliar sprays at early bloom stage treatment.

Fibre length, fibre uniformity and fibre strengths were also significantly improved by foliar SOP applications. According to cotton quality assessment in practice in Turkey, fibres of this study were evaluated as “long” in general, being longest in the T4 treatment. The fibres were highly uniform and were evaluated as “very strong” in terms of strength.

GROUNDNUT

GROUNDNUT NUTRITION

Groundnuts should be grown in rotation with cereals such as maize or sorghum, which have been well fertilized, because groundnuts respond better when fertilizer is applied to the previous crop rather than to the groundnuts themselves. Since groundnut is a leguminous crop, atmospheric nitrogen is fixed in root nodules. Therefore, nitrogen fertilization is usually not required. Nevertheless, where the soil is known to be infertile or deficient in some nutrients, additional fertilizer may be applied.

Usually, basal applications of fertilizers are broadcast prior to planting. Depending on soil tests, recommended application rates vary from 10-30 kg N/ha, 40-90 kg P_2O_5/ha and 40-90 kg K_2O/ha. 250 kg CaO/ha are often applied at bloom to prevent the formation of empty shells. A loose sandy soil with good drainage and a pH ranging from 5.3 to 6.5 is preferred.

IMPORTANCE OF POTASSIUM

Potassium is a key element for the plant's healthy functioning. Amongst other elements, potassium contributes to the development of proteins, enzymes and vitamins as well as plant photosynthesis. Furthermore, potassium plays an essential role in transport systems within the plant and it improves water use efficiency. It is necessary to ensure adequate potassium availability in the field through soil testing.

Potassium deficiency in groundnut leaves

If soil testing reveals that there is little potassium available, it will be necessary to apply additional potassium fertilizer. In light soils, to minimize the loss of potassium due to leaching under heavy rainfall conditions, it is recommended to apply potassium in two splits doses.

Lack of potassium causes stunted plants with small branches and little vigour. Leaves of potassium deficient plants do not grow normally and appear irregular in shape. In mature leaves a yellowish-green colour can be observed, spreading from the leaf apex, along the leaf margins, to the middle of the leaf, while the areas around the vein remain normal. In severe cases, the leaves appear dry and scorched at the edges and the leaf surface is irregularly chlorotic. Symptoms usually appear within five weeks after planting. Due to leaching, potassium deficiency is particularly prevalent in light soils.

SULFUR REQUIREMENT

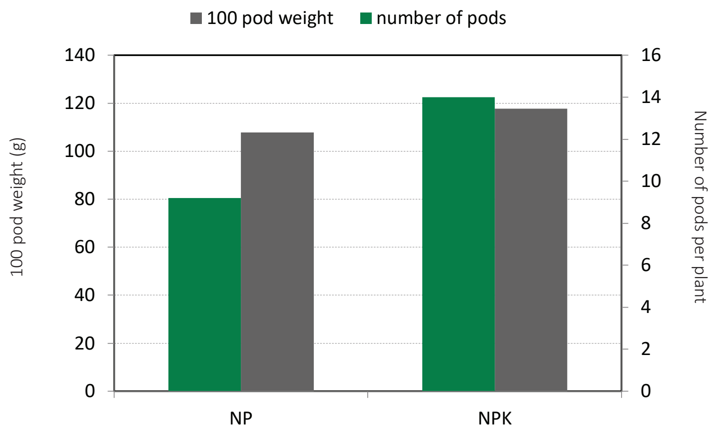
Sulfur plays an important role in the metabolism of groundnut plants. It is essential for the synthesis of proteins, plays a key role in chlorophyll formation and assists in biological oxidation-reduction processes. In recent years, sulfur deficiency in groundnut production has become an issue due to the use of high quality fertilizers like di-ammonium phosphate (DAP) and organic pesticides containing very little sulfur, as well as the low presence of sulfur in the soil in regions of groundnut production. Sulfur deficiency is characterized by stunted growth. Young leaves are small and yellowish-green. Nodulation and pod formation are restricted and maturity of seeds is delayed. In cases of severe sulfur deficiency, leaves become papery.

Sulfur deficiency in a groundnut plant

SOP FOR HIGHER YIELD AND IMPROVED QUALITY

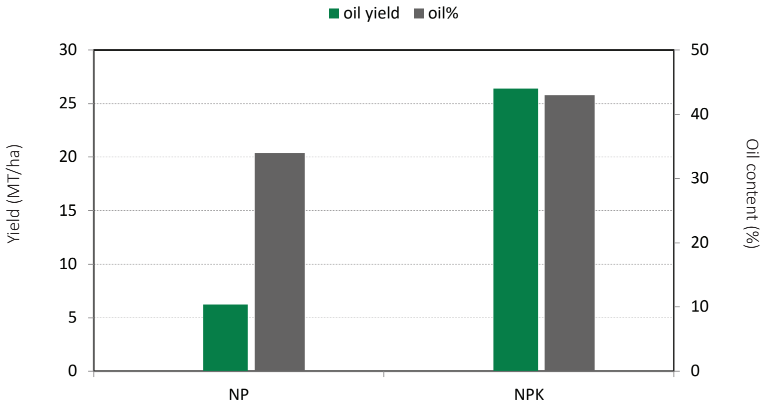
Groundnut is known to be a chloride sensitive crop. Excessive chloride may therefore impede growth and decrease yield. Thus, use of MOP as a source of potassium is best avoided. Additionally, SOP provides the plant with sulfur, thereby improving both yield and quality.

Experiments in China on sandy soil with low sulfur content, for example, indicated an 8 % higher yield when SOP was used compared to MOP. Sufficient potassium fertilization not only improves the number of pods per plant, but also their size and pod filling, as shown in the graph below. Fertilization was 75 kg N/ha and 90 kg P_2O_5/ha, potassium was 0 or 180 kg K_2O/ha.



Effect of SOP on groundnut quality (Northern China, 1995)

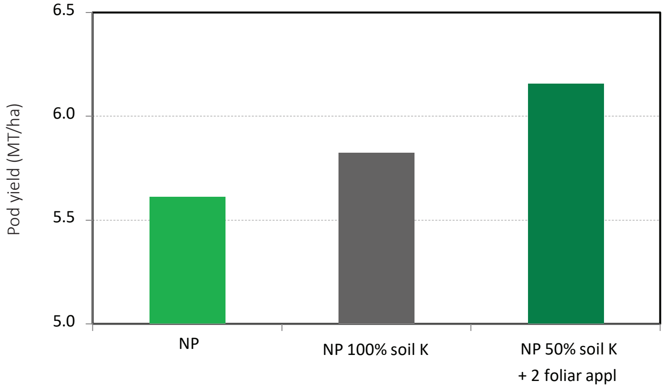
Trials conducted in Egypt in 1999 indicated that SOP not only improves yield, but that the oil content in the pods is higher as well. As illustrated in the chart below, additional application of 180 kg K_2O/ha as SOP to NP fertilization increased oil content by 20 %.



Effect of SOP on groundnut yield and oil content (Egypt, 1999)

COST-EFFECTIVE IMPROVEMENT: K-LEAF FOLIAR APPLICATION

Although a single basal application of fertilizers before planting is common practice in groundnut production, recent studies demonstrate the benefits of foliar application. K-Leaf, the fast dissolving SOP, is designed especially for foliar application. Foliar application of K-Leaf not only allows curing or prevention of potassium and sulfur deficiency efficiently, but it also enhances potassium uptake by the roots. Consequently, the efficient absorption of both potassium and sulfur through the plant's foliage improves yield.



Effect of foliar SOP sprays on groundnut yield (ARC, Egypt, 2011)

Interestingly, a higher yield can be achieved by applying only half the usual dose of SOP (115 kg K_2O/ha) on the soil, in combination with 2 foliar applications at 2 % SOP (equivalent to 10 kg of K-Leaf/ha), compared to a full dose applied to the soil, as demonstrated by trials in Egypt.

MAIZE

BASICS OF MAIZE FERTILIZATION

Maize is adaptable to a wide range of climates, but summer temperature must be above 20°C. Regarding soil, the main issue is a good drainage for the maintenance of sufficient oxygen for good root growth and activity, and enough water-holding capacity to provide adequate moisture throughout the growing season. Optimal pH is from 6.0 to 7.

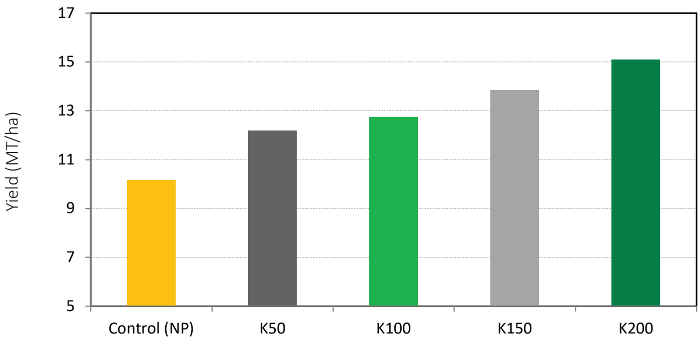
Mineral fertilizers can be broadcasted or banded along the seedling row for a better efficiency. Split applications are generally possible only at early stages because of the height of the stalks which can reach 2.5 meters, or when using fertigation.

Plant nutrient requirements of maize (yielding 12 MT/ha) during the growing season			
Plant age (days)	Nutrients absorbed (kg/ha per day)		
	N	P_2O_5	K_2O
20 - 30	1.7	0.39	1.7
30 - 40	6.7	1.55	9.95
40 - 50	8.3	2.32	11.56
50 - 60	5.3	2.06	4.42

A standard 12 tons production of grains per ha, requires 240 kg N/ha, 90 kg P_2O_5/ha, 270 kg K_2O/ha, 60 kg CaO/ha, 40 kg MgO/ha and 65 kg SO_3/ha.

Potassium deficiency on maize leaf

The symptoms of potassium deficiency in maize begin at the leaf tip and progress down to the leaf base. Potassium deficiency on the ear is characterized by missing grain at the top. Potassium is an important mineral element particularly during rapid vegetative growth and seed formation. Potassium deficiency symptoms appear on the lower leaves. Leaf symptoms are a yellowing to necrosis of the outer leaf margins. The other main deficiencies commonly observed are phosphorus, zinc and sulfur.

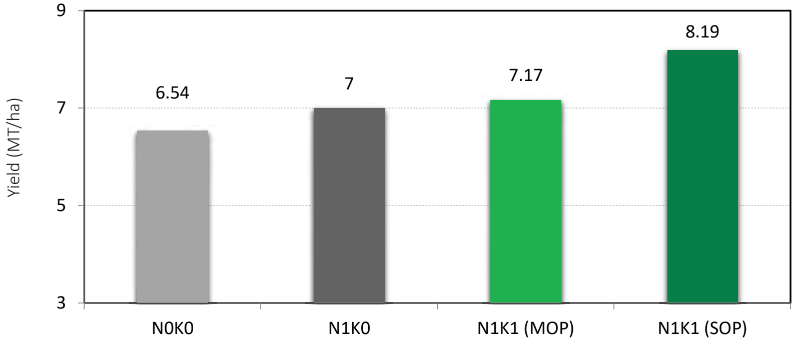


Maize response to potassium (Tabriz University, Iran, 2011)

Sulfur deficiency on maize

SOP: BENEFICIAL FOR YIELD

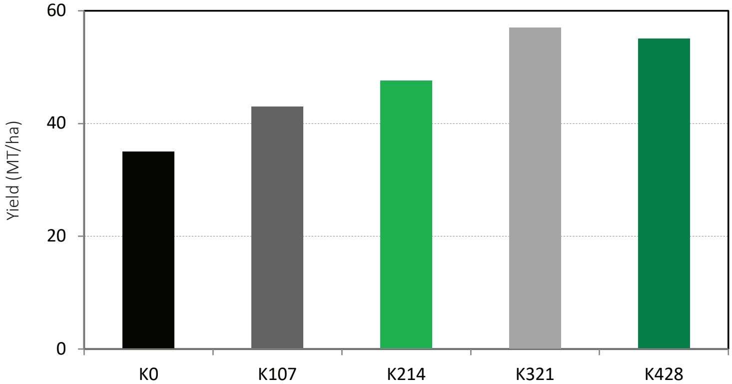
Although potassium chloride is the main source of potassium applied on maize, there are some benefits if potassium sulfate is used, such as when high level is required or in the case of band application to avoid chloride toxicity on the roots, as maize is considered as a salt sensitive crop. Saline conditions, either from the soil or irrigation water, are another reason to apply potassium sulfate in order to manage the electro-conductivity of the soil solution. The benefit of SOP is illustrated in an experiment comparing the use of SOP and MOP at 0 or 125 kg K_2O/ha, when nitrogen is applied at 0 or 120 kg N/ha. An increase of 1 ton is observed with SOP over MOP.



Effect of K forms on maize production (Mendel University, Czech Republic, 2010)

SOLUPOTASSE IN MAIZE PRODUCTION

SoluPotasse the special grade of soluble SOP can be used on light soils in fertigation. A recent experiment carried out in Morocco proves the efficiency of this technique on silage maize. The nutrients applied via fertigation throughout the season is 270 kg N/ha, 168 kg P_2O_5/ha and 0, 107, 214, 321 or 428 K_2O/ha.

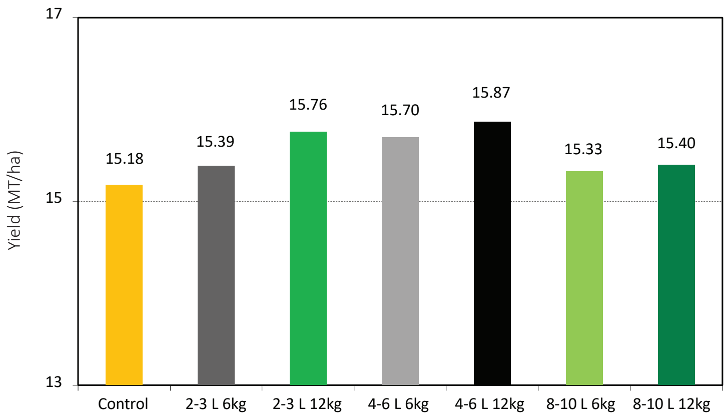


Maize response to SoluPotasse (IAV Hassan II, Morocco, 2011)

K-LEAF IN MAIZE PRODUCTION

K-Leaf the special grade of soluble SOP for foliar applications can be used to correct potassium deficiency more quickly and efficiently than soil application. Thanks to its role in enhancing root absorption, K-Leaf also increases grain production. This is illustrated in the graph below from an experiment carried out in France.

Results show an average yield increase of more than half a ton of grains when applying 12 kg/ha of K-Leaf, in good soil and climatic conditions, as the productivity was over 15 MT/ha. As for all foliar applications, timing of application is the key when it comes to plant response. Basal dressing was 367 kg N/ha, 69 kg P_2O_5/ha and 69 kg K_2O/ha; foliar: 6 or 12 kg K-Leaf/ha at 2-3 leaves, 4-6 leaves or 8-10 leaves stages.

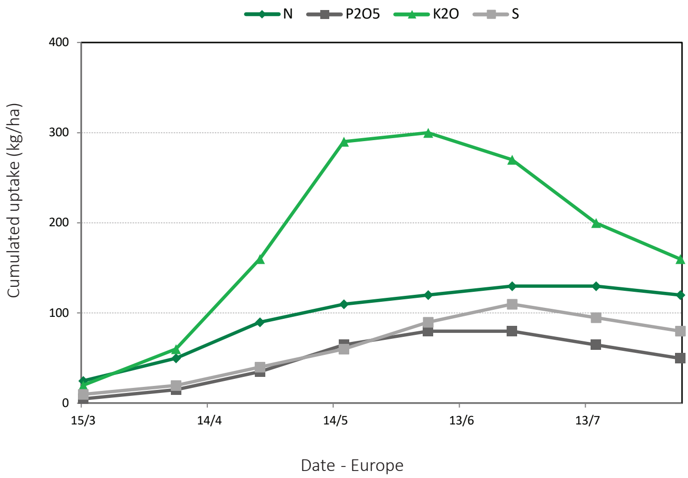


Effect of K-Leaf on maize yield (GRCETA-SFA, France, 2012)

RAPESEED

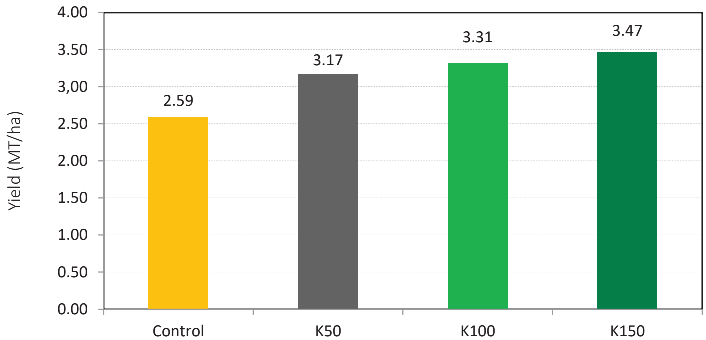
NUTRITIONAL REQUIREMENTS AND FERTILIZATION

Rapeseed is an important source of oil for human consumption, after palm and soybean. More recently, it is also used to produce bio-fuel.



Absorption curves of major elements

Yield and oil content are affected by mineral nutrition along with water management. A production of 3-4 tons of grain yielding 1.3-1.7 tons of oil per hectare requires 130-150 kg N, 90 kg P_2O_5 and 120-130 kg K_2O, but potassium uptake reaches 300 kg K_2O throughout the entire season. The following experiment compares the control to three doses of SOP: 50, 100 or 150 kg K_2O/ha, showing the role of potassium and sulfur in oil crops.



Rapeseed response to potassium (University of Faisalabad, Pakistan, 2004)

For winter varieties, phosphorus is applied at sowing, whereas nitrogen and potassium are applied in part at sowing, with the remaining part applied in early spring. For spring varieties, fertilization is usually done at sowing.

Sulfur is also an important element in oil production. 75 kg S as the sulfate form are necessary for a high oil content.

SOP TO PROVIDE POTASSIUM AND SULFUR

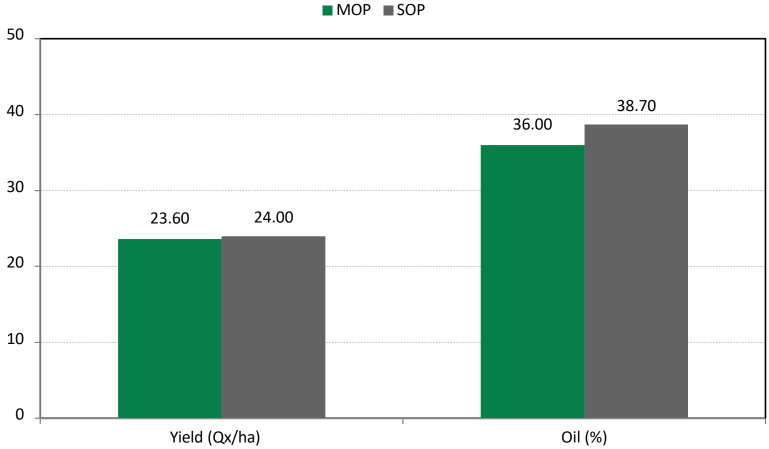
Potassium sulfate contains two important elements for oil production, particulary sulfur as sulfate, the only absorbable form by rapeseed.

Potassium deficiency on rapeseed

The main potash deficiency symptom is leaf yellowing, whereas sulfur deficiency is characterized by intervenial yellowing. Sulfur deficiency leads to lower oil concentration in the seeds.

Sulfur deficiency on rapeseed

An experiment conducted in India shows the benefit of SOP versus potassium chloride (MOP), particularly with respect to oil content.



Effect of K source on rapeseed production (India, 1997)

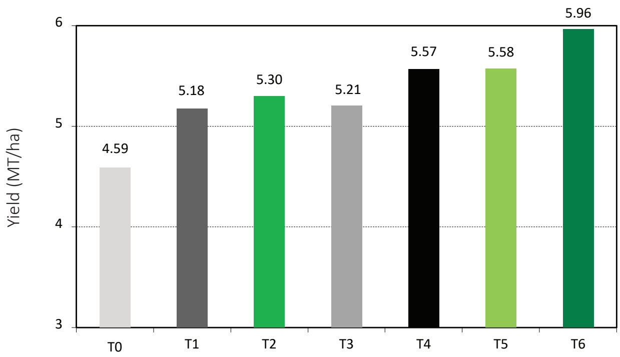
A slight improvement in yield combined with a higher percentage in oil content leads to a higher oil production. As for all oil crops, sulfur is essential in the oil synthesis, this explains the benefit of SOP over MOP.

Qx = Quintal (100 kg)

THE BENEFIT OF FOLIAR APPLICATIONS OF SOP

Foliar sprays can be used as a complement to soil application for a wide range of crops. Usually, it is recommended to spray potassium sulfate when potassium demand is high, which is, in the case of rapeseed, after flowering. However, due to rapeseed morphology, better results are obtained with earlier applications, starting at late rosette stage.

A field experiment, carried out in Poland, provides an illustration of the benefit of foliar sprays of K-Leaf foliar grade SOP on rapeseed production.



Foliar spray of K-Leaf (Staphyt, Poland, 2013)

T0 is the control (no foliar SOP sprays), T1 and T2 are 5 and 10 kg/ha of K-Leaf at rosette stage, T3 and T4 are 5 and 10 kg/ha of K-Leaf at bud stage, T5 and T6 are 5 and 10 kg/ha of K-Leaf applied at both stages. The basal dressing is the same for all treatments. Foliar applications favour root absorption of potassium and all elements during the high demand stage, when pods are growing. Nevertheless, early applications are also effective, showing that potassium must be in the plant before the critical stage.

Potassium sulfate, providing two important elements to produce high oil content seeds, is the best choice in rapeseed cropping. By combining soil application of granular SOP and foliar applications of K-Leaf, rapeseed growers secure both seed production and oil content.

RICE

MINERAL NUTRITION IN RICE PRODUCTION

Because rice is mostly cropped under traditional methods, it is frequent to observe imbalanced fertilization. Rice can be cropped on various soil types. In flooded systems, soils are generally deep clay soils with a high CEC, whereas in rain-fed cultivation soils are often poor.

A standard production (5 to 6 MT/ha) requires 120 kg N/ha, 35 kg P_2O_5/ha and 160 kg K_2O/ha. Phosphorus is applied before planting. For a better efficacy, nitrogen and potassium are applied in split applications, throughout the cropping period.

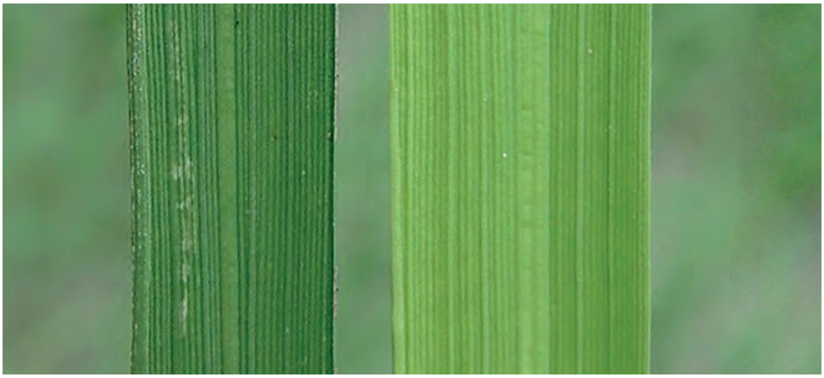
POTASSIUM, A YIELD COMPONENT

In flooded systems, rice benefits from the high availability of potassium from the soil. However, under intensive cropping or in light soils, potassium can be easily exhausted.

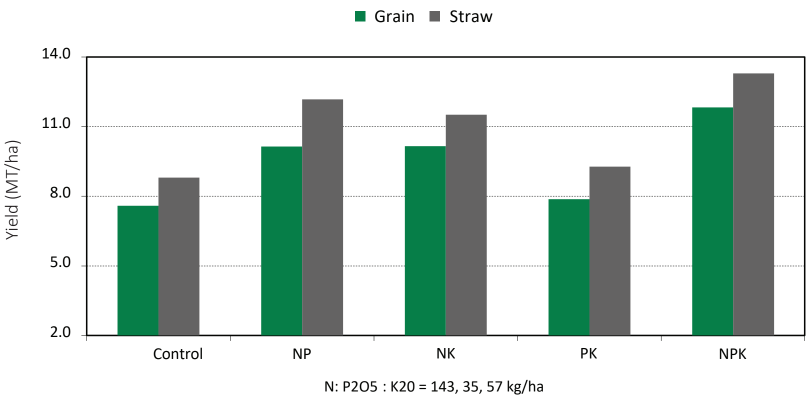
Potassium deficiency in rice

Potassium content in the leaf should not drop below 2 % at the booting stage in order to ensure enough grains per panicle and a high 1000 grains weight. Because the critical stage is in the later part of the generative phase, potassium deficiency often remains undetected by farmers.

The deficiency symptoms include stunted plants with dark green leaves and short stem, dark rusty brown spots starting from the leaf tip spreading later over the whole leaf, drying up of the leaf tips and margins and early senescence of old leaves.



Sulfur deficiency on rice (right) compared to normal leaf (left)



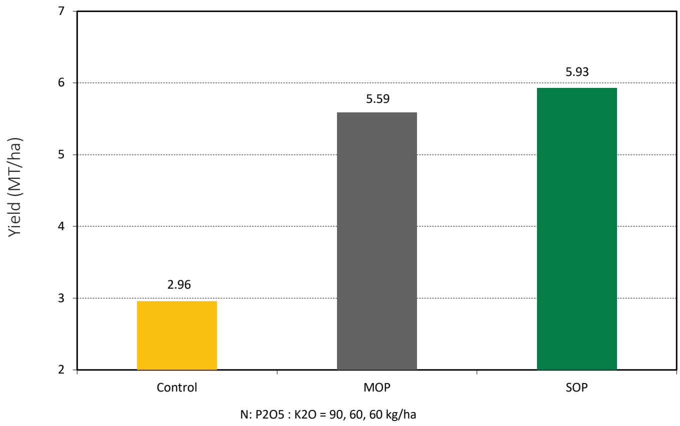
Effect of balanced fertilization on rice (ARC, Egypt, 2008)

The graph above shows the role of the major elements on grain and straw yield. Using the technique of the missing element, this experiment is a perfect example of the benefit of balanced fertilization. The yield is improved by 56 % with NPK application compared to the control. Rice production under balanced fertilization reaches 11.8 MT/ha while the control yield is only 7.6 MT/ha.

POTASSIUM SULFATE TO CONTROL SALINITY

Rice is extremely sensitive to salinity as a seedling and during the early stages of development. Yields are reduced by a decrease in seedling stand and poorer plant growth. Crop yields are reduced 12 percent for every unit of electrical conductivity above 3.0 dS/m in the soil solution. Irrigation water may also be a source of salinity. Although potassium chloride is widely used as source of potassium in rice cultivation, in case of a risk of salinity, it is advisable to apply potassium sulfate.

Comparing potassium sulfate (SOP) and potassium chlorine (MOP) treatments at the same dose of potassium illustrates the benefit of potassium as well as the advantage of SOP over MOP (see chart below). In addition, potassium sulfate provides sulfur that covers the sulfur requirements in standard rice production.

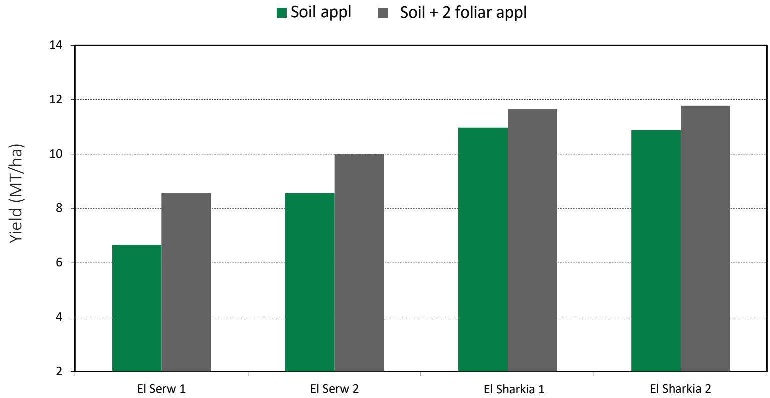


MOP and SOP effect on rice production (Indonesia, 1973)

THE BENEFIT OF FOLIAR APPLICATION OF K-LEAF

Due to its fast growth, rice is sensitive at the critical growth stage, when roots cannot absorb enough potassium in a short time. Foliar application of K-Leaf, Tessenderlo Kerley's soluble grade of potassium sulfate, contributes to improve production and a better efficiency of basal dressing.

An example from Egypt is given below. In addition to the basal fertilization of 57 kg K_2O per ha, 2 foliar applications of K-Leaf at 12 kg K-Leaf (6 kg K_2O/ha) were applied at flowering and 10 days later.

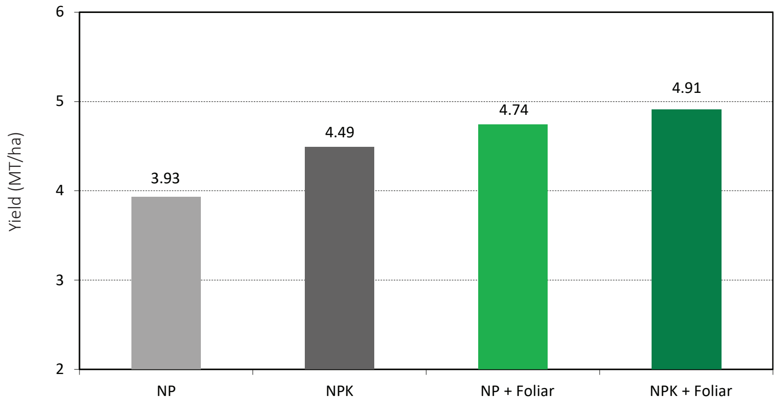


K-Leaf foliar spray on rice production in Egypt (ARC, Egypt, 2007)

Results from the 4 different locations show an increase in the rice yield ranging from from 6 to 28 % when foliar sprays are applied. These increases are relative to the control yields in plots without foliar sprays. This means that foliar applications of SOP can help to express all the potential of rice particularly in poor conditions. When the potential is low, the improvement is high (+ 28 % in El Serw 1) and of course, when the potential is high, improvement is limited (+ 6 % in El Sharkia 2).

Rice is an essential food in many developing countries, especially in Asia. On a local scale, rice production plays an important role in the economy. Potassium can help to increase rice production through more balanced fertilization.

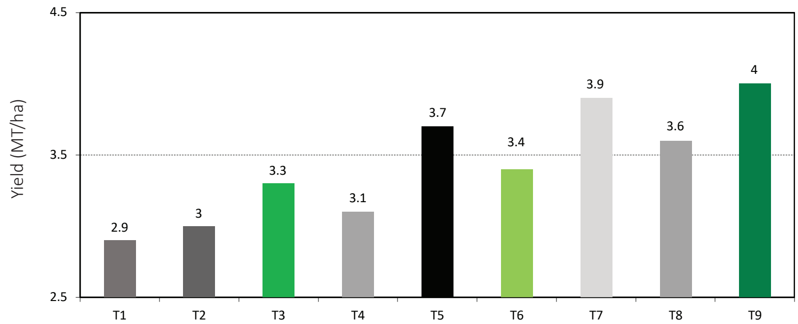
Another example from Vietnam confirms the Egyptian results. In the experiment presented below, the potassium applied to the soil was 60 kg K_2O as MOP, complimented by foliar application of 1 kg of K-Leaf applied 3 times.



K-Leaf foliar spray on rice production in Vietnam (IAS, Vietnam, 2009)

This trial shows that efficiency of foliar sprays compared to soil application and that the combination of both can improve production significantly compared to the control.

A third example from India expresses the same trend. In the experiment presented below, T1 was the control (no fertilizer), T2 with only NP fertilization, T3 NPK with 50 kg K_2O (MOP) split in 4 applications, T4 the same as T3 plus foliar application of K-Leaf at 1 % at heading, T5 is T3 plus foliar application of K-Leaf at 2 % at heading, T6 is similar to T4 but only 75 % of MOP was applied, T7 is similar to T6 with 2 foliar applications of K-Leaf at 2 % (panicle initiation and heading), T8 is with only 50 % of MOP applied and 2 foliar applications of K-Leaf at 1 % (panicle initiation and heading), T9 is 50 % of MOP and 2 foliar applications of K-Leaf at 2 % (panicle initiation and heading).



K-Leaf foliar spray on rice production in India (TNAU, India, 2010)

Results suggest that potassium can improve yield by 10 % and that foliar applications help to increase yield only at 2 % concentration and with 2 applications. When using two foliar applications at 2 %, it is apparently possible to reduce soil application of potassium.

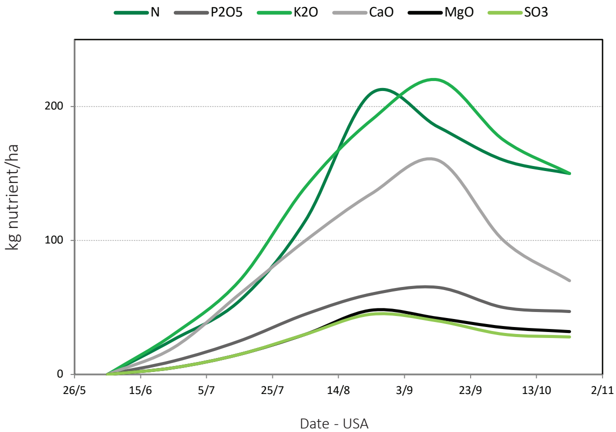
In saline conditions and for foliar application, potassium sulfate contributes also to a higher yielding and better quality rice production, which is essential to help feed the global population.

SOYBEAN

NUTRITIONAL REQUIREMENTS

Soybean grows in warm and moist climates, similar climatic conditions to those for maize. The minimum temperature for effective growth is about 10°C. A lower temperature tends to delay the flowering. Soybean cultivation requires well drained loamy soils with a pH from 6.0 to 7.5. Sodic and saline soils inhibit germination of seeds and must be avoided.

Soybean is a legume able to fix adequate atmospheric N to produce yields of 3000 - 4000 kg/ha, if nodules are well developed. Phosphorus is taken up throughout the growing season in the range of 30 to 60 kg P_2O_5/ha. The period of greatest potassium demand starts just before the pods begin to form and continues until about 10 days before the seeds are fully developed.



Nutrient uptake during growth

Potassium remains the most important mineral element particularly during rapid vegetative growth and seed formation. Deficiencies of micronutrients are more common than on most other field crops. Shortages of Fe, Mn, Mo and Zn can often be observed.

POTASSIUM DEFICIENCY SYMPTOMS

Potassium deficiency shows up as chlorosis starting along the outside edges of leaves, especially the older leaves. Depending on soil fertility, soybean needs 50 to 180 kg K_2O/ha to produce 3 to 4 MT/ha.

Potassium deficiency in soybean leaf

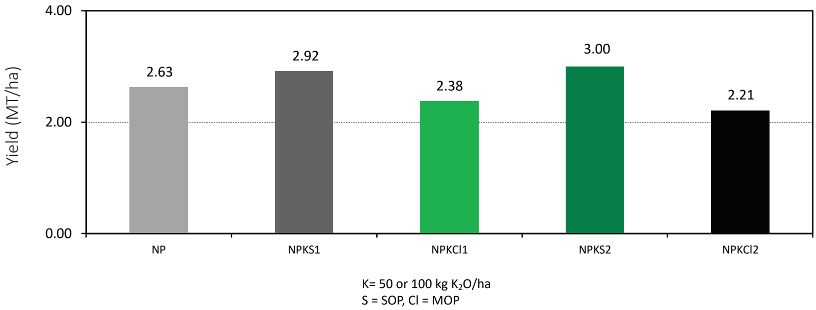
SULFUR REQUIREMENT

As for all oil crops, soybean needs a relatively large amount of sulfur. Sulfur requirement ranges between 20 and 25 kg S/ha. In case of S deficiency young leaves are light-green and symptoms can look like nitrogen deficiency. Flowers are decoloured and severe deficiency leads to empty pods.

Sulfur deficiency in soybean leaf

SOP: BENEFICIAL FOR YIELD

On soils which are prone to leaching and low in organic matter, potassium should be applied preferably in the sulfate form. As soybean is sensitive to sodicity and salinity, potassium sulfate is also recommended in these conditions. An illustration of this sensitivity is demonstrated in an experiment comparing the use of SOP and MOP, carried out in soil with an EC of 1.4 dS/m (see below).

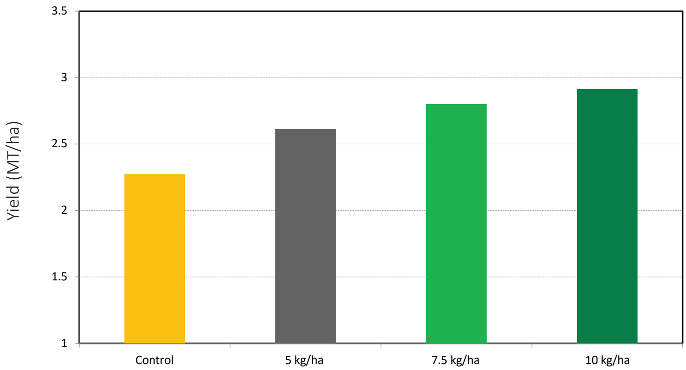


Effect of potash form on yield in saline conditions (SWRI, Iran, 2003)

The detrimental effect of chloride is clearly demonstrated, particularly when applying a higher dose of MOP which leads to lower productivity.

K-LEAF IN SOYBEAN PRODUCTION

K-Leaf is designed specifically for foliar applications. It can be used to correct potassium deficiency more quickly and efficiently than soil application. Another interesting effect is its potential to enhance root absorption of nutrients, consequently improving the mineral nutrition of the plant. This is illustrated in a series of experiments carried out recently in Argentina on soils rich in available potassium.



Effect of foliar application of K-Leaf on soybean production (INTA, Argentina, 2011)

Results show an average yield increase of 10 to 15 % when spraying 7.5 to 10 kg/ha of K-Leaf. As, in these soil conditions, potassium is not a limiting factor, the additional yield is due to a better assimilation through the roots stimulated by a better metabolism of the plant.

This new approach in mineral plant nutrition requires the identification of the optimum stage of application: In this case the R3 stage (corresponding to the beginning of pod formation) is the one giving generally the best yield improvement.

SUGAR BEET

MANAGING FERTILIZATION UNDER SALINE CONDITIONS

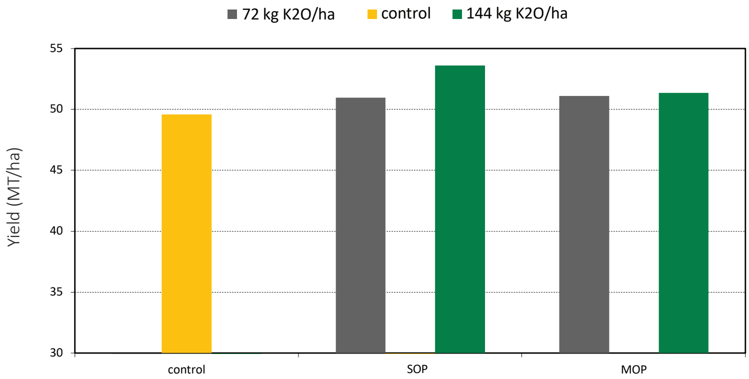
The sugar beet cropping area has steadily increased during the past 20 years under semi-arid conditions, particularly in Northern Africa and in the Middle East. The sugar beet crop is known for its chloride and salt tolerance. It even needs a certain amount of sodium to achieve the best yield potential. Potash fertilization is traditionally done with potassium chloride. But field experiments in research centres in Egypt, France and Eastern Europe show that SOP may also have a place in sugar beet production.

Potassium deficiency on sugar beet

SOP SAFEGUARDS THE YIELD POTENTIAL

A production of 10 tons sugar per hectare necessitates about 200 kg N, 75 kg P_2O_5 and 400 kg K_2O. Nitrogen demand is highest during the 3rd and 4th months after planting while potash demand is highest from the 3rd to 6th month. Other nutrients are also required such as calcium (250 kg CaO/ha), magnesium (65 kg MgO/ha), sulfur (50 kg SO_3/ha), and sodium (100 kg Na_2O/ha).

Under semi-arid conditions, sustained high yields are only achievable when there is no increase in soil salinity, as shown in the experiment conducted in Egypt under desert conditions in co-operation with the Desert Research Centre. This experiment illustrates the effect of potash on yield at two application rates and with two sources (MOP and SOP), after four seasons of production. The five treatments received the same NP basal dressing.

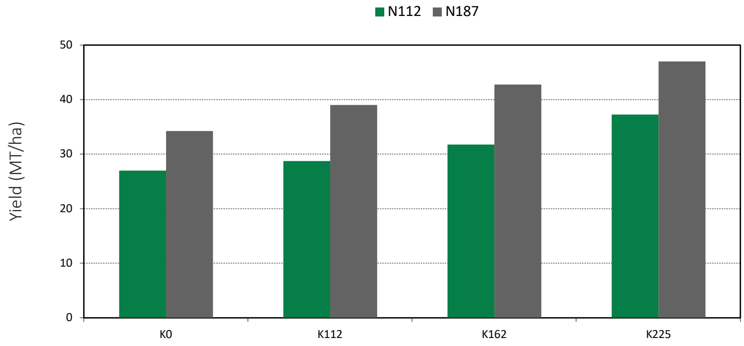


Effect of the form of potash on sugar beet (DRC, Egypt, 2001)

It is clear that chloride accumulation through high MOP application has a cumulative detrimental effect on yield, whereas SOP application safeguards the yield potential.

The following graph illustrates the dose effect and the interaction between nitrogen and potassium. It is an excellent example of the necessity to increase potassium dose along with nitrogen dose. SOP doses are 0, 112, 162 or 225 kg K_2O/ha and N doses are 112 or 187 kg N/ha.

CHAPTER 5

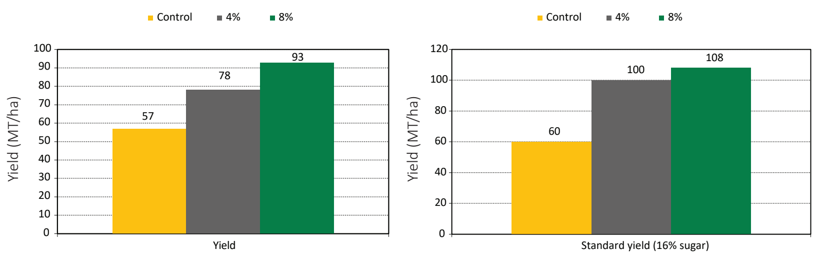


Effect of N and K as SOP on sugar beet production (DRC, Egypt, 2008)

FOLIAR SPRAYING WITH K-LEAF: A CLEAR ADDED VALUE

Foliar spraying is very effective and thus is becoming very popular as a complement to mineral nutrition in intensive production systems. In the case of sugar beet, the first consequence of foliar potash sprays is a better metabolism for sugar concentration and transport of assimilates to the roots.

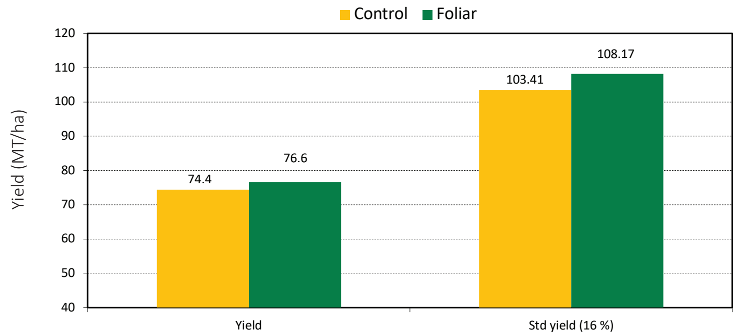
In a field experiment carried out in France, we found that foliar sprays of K-Leaf enhanced yield and sugar content. Sprays at 4 and 8 % (in 300 litres of water/ha) were made six times, respectively at 44, 51, 65, 73, 83 and 93 days after sowing. The best yield was obtained with 8 % concentration (total application: 72 kg K_2O/ha).



Foliar spray at different concentrations, six applications in 300 l of water per hectare (Pôle d'Aspach, France, 1999)

The results show the benefit of foliar applications on yield, without any dilution effect on sugar content, which is also enhanced. The yield converted in standard yield on the base of a 16 % sugar content is significantly increased.

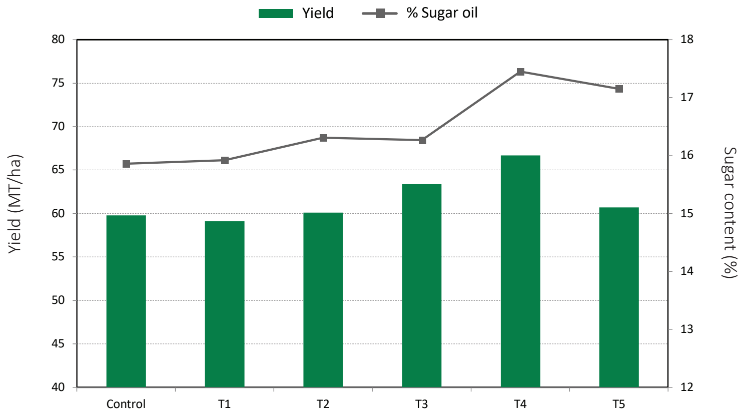
Following experiments at the research station, it was important to confirm the results in practical conditions. A field test was carried out in the Reims area of France, where a solution of K-Leaf at 3 % was applied in 300 l/ha of water, three times from beginning of June to mid-July.



Effect of K-Leaf on sugar beet production (Tessenderlo Kerley International, France, 2007)

From this field test, it is clear that 3 applications at 3 to 4 % concentration are enough to increase significantly sugar production.

This is confirmed by an experiment carried out in Lithuania in 2017 in which 10 kg per ha were applied at the 6 - 8 leaves stage (T1), 10 - 12 leaves stage (T2), a combination of both these foliar applications (T3), 3 applications as T1, T2 and at the growth stage when the crop has reached total coverage of ground (T4) and finally a single application at the growth stage corresponding to total coverage of ground (T5). T4 with 3 sprays shows the highest yield as well as sugar production.



Effect of K-Leaf applications on sugar beet yield and sugar content in roots (Aleksandras Stulginskis University, Lithuania, 2017)

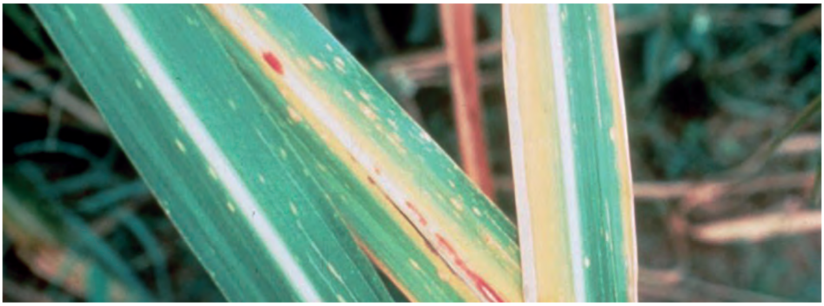
This last example demonstrates the importance of the number and timing of applications. Three sprays of K-Leaf, from 6 - 8 leaves to total coverage of the ground by the sugar beet leaves, improves yield by 11.5 % and sugar production by 22.8 %, thanks to the role of potassium in sugar production, transport and accumulation in the roots.

SUGAR CANE

MINERAL NUTRITION IN SUGAR CANE PRODUCTION

Sugar cane can be cropped on various soil types, although it is ideally suited for cultivation in a well-drained soil with a pH around 6. Outside of industrial plantations, sugar cane cropped under traditional methods frequently shows imbalanced mineral nutrition.

A standard mineral fertilization is 100 to 150 kg N/ha, 50 to 60 kg P_2O_5/ha and 120 to 200 kg K_2O/ha. It can be more in some locations or in irrigated cropping systems.

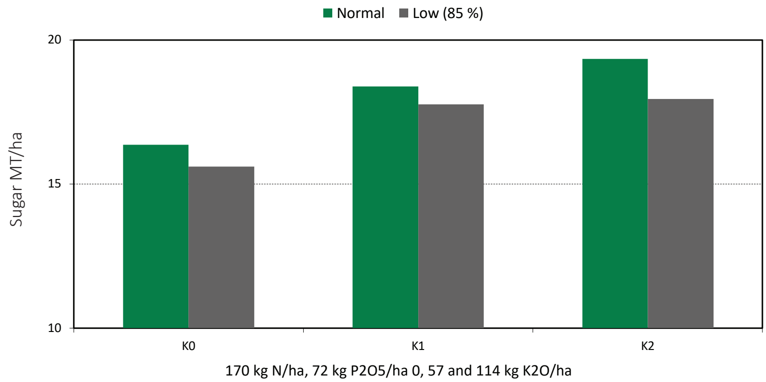


Potassium deficiency on sugar cane

POTASSIUM, A YIELD COMPONENT

Most of the potassium is taken up during shoot development when dry matter is accumulated and when leaf area is at its maximum. Potassium is the most abundant cation accumulating in the cell sap of sugarcane. Potassium in sugarcane acts as an enzyme activator in plant metabolisms such as in photosynthesis, protein synthesis, starch formation and translocation of proteins and sugars. Because of the high mobility of potassium in the plant, early symptoms of potassium deficiency are first seen in the older leaves. Leaf borders and tips will show yellow-orange chlorosis with chlorotic spots which turn later into brown, reducing photosynthesis activity. A normal potassium content in leaf remains in the range from 1.7 to 2 % of the dry matter.

As far as sugar synthesis is concerned, the potassium and nitrogen interaction is important. Water supply is also a key factor in sugar cane production. An experiment carried out in Egypt, combining 2 irrigation regimes and 3 levels of potassium, shows the effect of the dose and water on sugar production.



Effect of potassium and water regime on sugar production (ARC, Egypt, 2009)

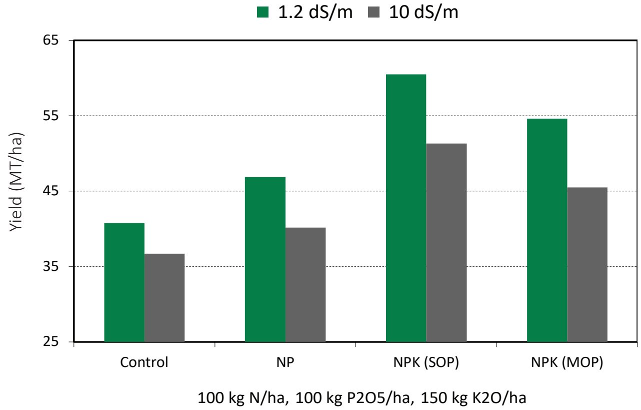
A low supply of water means a lower production of sugar, but better water use efficiency as shown in table below. In terms of water management, this experiment helps to identify the best practice, which is the combination of the lower level of irrigation and the second dose of potassium in the table below.

	Normal water supply	Low water supply (85 %)
K0	1.36 kg	1.48 kg
K1	1.47 kg	1.66 kg
K2	1.52 kg	1.62 kg

Effect of potassium on water use efficiency of sugar cane in kg of sugar per m^3 of water

POTASSIUM SULFATE TO CONTROL SALINITY

Sugar cane is considered as medium sensitive to salinity. Crop yields are reduced 6 % for every unit of electrical conductivity above 1.7 dS/m in soil solution. Although potassium chloride is widely used as source of potassium in sugar cane cultivation, in cases where there is a risk of salinity or when using fertigation, it is advisable to apply potassium sulfate, as demonstrated in the experiment conducted in Pakistan in 2004.



Effect of potassium sources on sugar cane production in saline conditions (NIAB, Pakistan, 2004)

Comparing potassium sulfate (SOP) and potassium chloride (MOP) treatments at the same dose of potassium illustrates the advantage of SOP. In addition, potassium sulfate provides sulfur that covers the sulfur requirements in standard sugar cane production. A lack of sulfur may decrease sucrose production by 50 %. The benefit of potassium sulfate is confirmed in another experiment carried out in China.

	NPK (MOP)	NPK (SOP)
Yield	67.50 MT/ha	75.87 MT/ha
Sugar (%)	14.77 %	16.06 %
Purity (%)	87.85 %	90.40 %

Effect of potassium sources on production and quality of sugar cane (Academia Sinica, China, 1994)

SOLUPOTASSE FOR HIGH-TECH PRODUCTION

In industrial sugar cane plantations, pivot or sprinkler irrigation is more and more replaced by sub-soil drip irrigation. SoluPotasse, Tessenderlo Kerley's soluble grade of potassium sulfate, contributes to improving production thanks to its quality and the possibility to split potassium applications.

Sulfur deficiency on sugar cane

Sugar cane is a successful crop thanks to the increasing consumption of sugar in Asia and to the production of bio-fuel. As potassium and sulfur are indispensable in sugar synthesis, potassium sulfate can contribute to a profitable production of sugar.

SUNFLOWER

NUTRITIONAL REQUIREMENTS

Balanced fertilization offers a new perspective for fine tuning genetically fixed quality properties of sunflower crops by farmers and growers. The amount of NPK fertilizer needed to achieve this equilibrium is highly dependent on the type of soil and the nutrients therein as well as the target yield. Because sunflower plants are deep rooted crops and N requirement is at its highest for initial growth, the main focus when making a fertilization plan, is the starter effect. Besides application of NPK fertilizers, it is recommended to apply sulfate sulfur at 20 kg S/ha on well-drained soils. Care should be taken with respect to the right timing and placement of fertilizers, as sunflower crops are sensitive to fertilizer salts.

Yield goal (kg/ha)	Soil N plus fertilizer N required	Soil test phosphorous (ppm)				Soil test potassium (ppm)			
		VL	L	M	H	VL	L	M	H
		0-5	6-10	11-15	16-20	0-40	41-80	81-120	121-160
		P_2O_5 (kg/ha)				K_2O (kg/ha)			
1120	56	22	17	11	0	39	28	17	0
1680	84	34	22	17	0	62	45	28	11
2240	112	45	34	22	11	78	56	34	11
2800	140	56	39	28	11	101	73	45	17

VL = very low, L = low, M = medium, H = high

Sunflower is not very sensitive to soil pH. Depending upon other properties of the soil, a pH range from 6.0 to 7.2 may be optimal for many soils.

HIGH POTASSIUM DEMAND

Potassium exerts a wide range of physiological functions in sunflower plants. Amongst others, potassium improves the resistance of the plant to diseases and environmental stresses, but it also plays a crucial role in the activation of enzymes during the conversion of assimilates to oil. Therefore, sunflowers absorb large amounts of potassium during the growing season. Critical K levels are often stated to be around 280 kg/ha or 112 ppm in the top 15 cm of the soil.

POTASSIUM DEFICIENCY SYMPTOMS

Potassium deficiency reduces stem diameters and overall growth. Potassium deficient sunflowers exhibit slightly reduced plant height and leaf number, but a highly reduced root length. Since K is mobile within the plant, deficiencies are first visible in older leaves. The edges and areas between veins of older leaves tend to turn pale green or yellow, followed by withering. At the bolting to flowering stages, the yellowing may start to show on the middle leaves first. Younger leaves may form a rosette-like pattern and eventually develop dark brown necrotic patches. In severe cases, plant leaves die, but remain attached to the stem.

Potassium deficiency in sunflower

The plants have a characteristic tendency to wilt on hot and sunny days, even if no other symptoms can be seen.

SULFUR REQUIREMENT

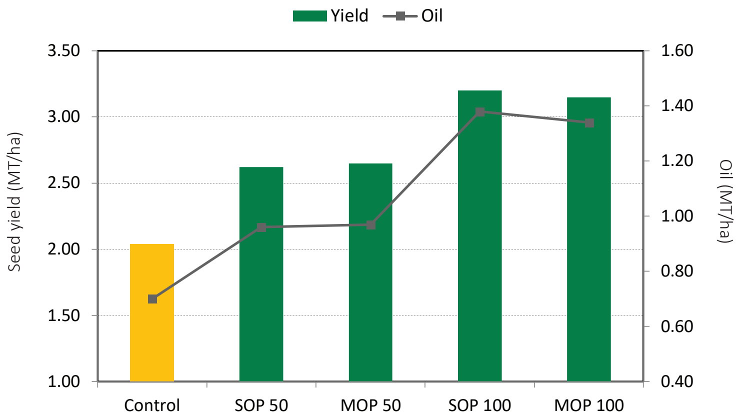
Besides potassium, sulfur also plays a vital role in the plant, as it is a key element for protein synthesis. In case of sulfur deficiency, the plants typically show a paling and yellowing of (primarily young) leaves, the number and size of the leaves is reduced and overall growth of the plant is retarded. Other symptoms include a restriction in the size of the head, delay in flower maturation and stem elongation.

SOP: BENEFICIAL FOR YIELD

Since sunflower is a chloride sensitive crop, use of MOP should be avoided. Excessive chloride in the plant causes leaf burn or drying of leaf tissue. Normally, plant injury occurs first at the leaf tips and progresses from the tip back along the edges as severity increases.

Deficiency of potassium reduces the number of achenes per sunflower head and the percentage of oil in seeds. Upon addition of sulfate of potash (SOP), the two parameters are improved leading to higher yield and oil production.

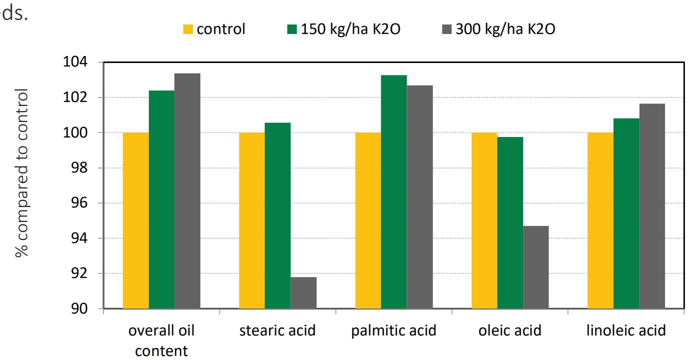
A trial from Pakistan illustrates the effect of potassium on sunflower production and particularly the benefit of SOP on seed yield and oil content compared to MOP. Two doses of potash were applied: 50 and 100 kg K_2O per ha. The advantage of SOP is higher at the higher dose due to the role of sulfur on oil production and the negative effect of chloride for MOP.



Effect of the grade of potash on seed and oil production (University of Agriculture, Faisalabad, Pakistan, 1999)

SOP: BENEFICIAL FOR QUALITY

As sunflower is an oilseed crop, an important quality characteristic is the composition of the oil in the seed. Experiments indicate that, besides an overall increase in achene oil content, application of SOP results in a significant increase in palmitic acid as well as linoleic acid while reducing the oleic acid and stearic acid contents. Since linoleic acid is an unsaturated fatty acid beneficial for human health, application of SOP to sunflower crops might improve the quality of the oil from the seeds.



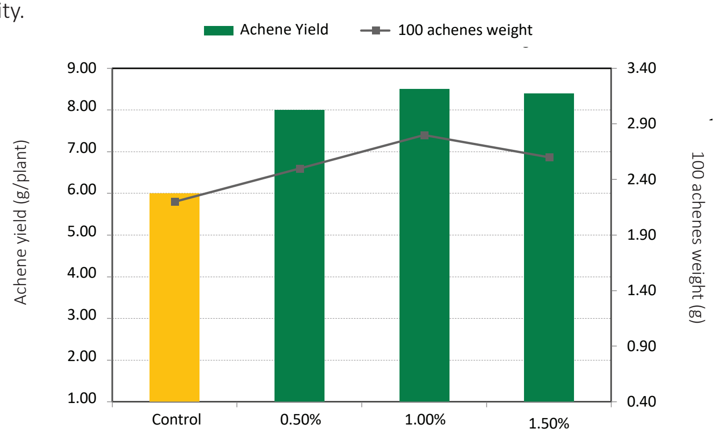
Effect of SOP on sunflower oil composition (University of Agriculture, Faisalabad, Pakistan, 1999)

K-LEAF IN SUNFLOWER PRODUCTION

Foliar application of SOP enhances growth by increasing the rate of photosynthesis and transpiration, thereby improving dry weight and yield of sunflower plants. Research in Pakistan demonstrated that additional application of two soluble SOP foliar sprays resulted in a yield increase as well as an increased 100 achenes weight.

This research is a pot trial with the following treatments: control, two foliar sprays at 0.5 % of SOP, two foliar sprays at 1 % of SOP, and two foliar sprays at 1.5 % of SOP. 1 % solution of SOP improves yield by 40 % and 100 achenes weight by 27 %. Water use efficiency is also improved, which is of a great importance in certain sunflower cropping areas, mainly in the Middle East region.

Additionally, a greater concentration of potassium at root level was observed, indicating improved nutrient absorption via the roots. As K-Leaf is a soluble grade of SOP especially developed for foliar application, it proves to be not only a good source of potassium in sunflower production, but acts as a stimulant of plant metabolic activity.



Effect of foliar application of SOP on sunflower
(University of Agriculture, Faisalabad, Pakistan, 1999, 2008)

PART 6

SOP FERTILIZATION IN PRACTICE

APPLICATION METHODS OF FERTILIZERS

Generally 4 methods are used for the application of fertilizers.

1. Broadcasting: uniform distribution over the whole cropped field.
2. Placement: application in bands or in pockets near the plants or plant rows.
3. Fertigation: application though an irrigation system, dissolved in water. It can be also considered as placement of fertilizers.
4. Foliar application: using low or high volume sprayers, the fertilizers are sprayed covering the plants.

The method of application has to be chosen to suit the particular nutrient, the crop, as well as method of cultivation. Nitrogen is generally applied as broadcast to crops. Phosphorus needs to be placed near the plant rows, because of its low mobility. Potassium is also usually applied as broadcast.

Broadcasting of fertilizers is practiced:

- On all crops with a dense stand and not sown in rows.
- In the case of plants whose roots spread widely in the soil.
- On very fertile soils.
- When high rates of fertilizers are used.
- When readily soluble nitrogenous fertilizers are applied.
- When potash fertilizers are applied in light soils.

There are some disadvantages with broadcast application: it may stimulate weed growth and fertilizers may come in contact with a large volume of soil and and may be fixed, becoming unavailable for that crop. This is particularly true in the case of super phosphate application.

The different methods of placing the fertilizers are:

- Banding i.e. placing fertilizers in bands on one or both sides of the rows. This is also known as side dressing.
- Drilling in between the rows.
- Spot placement i.e. by placing in between the plants. This is mostly practiced for vegetable crops.
- By placing in a circular band away from the base of the plants as in the case of fruit trees.

No single method can be considered best for all the crops. The method of placement varies with the crop, fertilizer, and weather. It is advisable to use placement of fertilizers when small quantities of fertilizers are to be distributed, in cases of crops sown in wide rows, in cases of shallow rooted plants and on soils with low fertility.

The principle of fertigation is to apply fertilizers through the irrigation water, usually using a drip irrigation system. The advantages of fertigation are:

- The possibility to split the supply of fertilizers throughout the growth of the plant.
- The adaptation of the ratio between elements to the requirements of each growth stage.
- The placement of fertilizers close to the roots, together with water.

As a result, loses by leaching are reduced and efficiency of fertilizers is enhanced. To be used in fertigation, fertilizers must have a special quality: high purity, solubility and low pH, in order to prevent drippers clogging and to promote better availability of elements for the roots. Special grades of potassium sulfate such as SoluPotasse and Solucros® are specially designed for fertigation.

The use of foliar application of fertilizers

Fertilizers are dissolved in water and these diluted solutions are sprayed directly on the plants' foliage. Hand operated sprayers are used for smallholdings. On individual farms tractor drawn medium or low volume sprayers can be used while on a large scale aircrafts are sometime used for foliar spraying. Concerning soluble SOP, it can be applied to correct deficiency or to improve the yield and quality of the production.

FEATURES AND BENEFITS OF TESSENDERLO KERLEY'S SOP

Tessenderlo Kerley has been producing its sulfate of potash (SOP) products for one hundred years. This range of high grade products helps growers produce high quality crops with maximum export value, while helping protect sensitive environments.

A NITROGEN-FREE SOURCE OF POTASSIUM

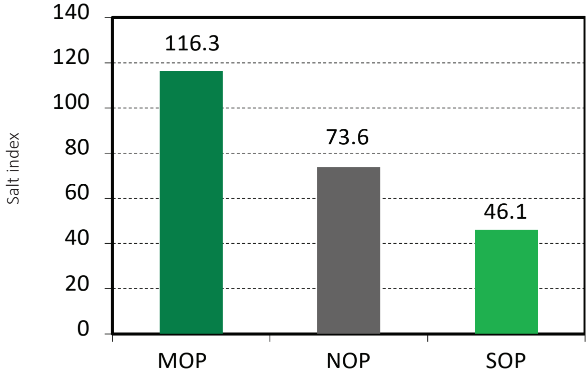
Evidence suggests that an excessive supply of nitrate when fruit is forming can be detrimental to quality. SOP allows growers to develop fertilization programs that exactly match crop requirements.

VIRTUALLY CHLORIDE-FREE

Chloride makes a significant contribution to soil salinity and an excess can be detrimental to the quality of many cash crops with poor chloride tolerance.

EXTREMELY LOW SALT INDEX

Salinity can destroy agricultural land by seriously reducing soil and water quality. Of the three most common potash fertilizers - potassium nitrate (NOP), potassium chloride (MOP) and potassium sulfate (SOP) - SOP has by far the lowest salt index and is the best product to use in areas at risk from salinity.



Base index: 100 = sodium nitrate

IMPROVES THE YIELD AND QUALITY OF FRUIT AND VEGETABLES

The use of SOP provides high quality produce with outstanding flavor. In many cases, size and consistency, as well as yield, are improved. Increased pigment content gives better color and appearance. Higher levels of sugar and juice, combined with a reduced acidity, provide better flavour and aroma.

ENHANCES NUTRITIONAL VALUE

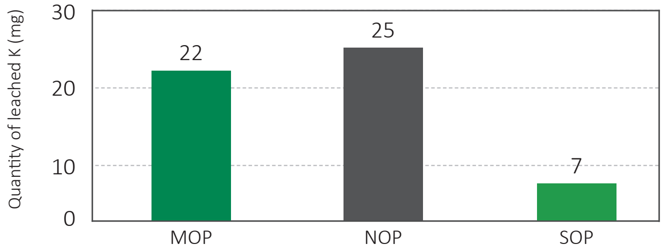
SOP has a positive effect on the plant's production of vitamins, starch and sugar, the basic factors for high nutritional value.

PROVIDES DURABILITY AND RESISTANCE

The use of SOP provides firmer fruit and vegetables with a better resistance to bruising. It can also increase the suitability of fruit and vegetables for canning or processing.

CONSISTENT PERFORMANCE ACROSS A RANGE OF SOIL TYPES

In alkaline and salt-affected soils, SOP helps lower the pH level at the root surface, improving the availability of phosphorus, iron and most other micronutrients. In acidic soils (mainly light or sandy) SOP reduces cation leaching and is considerably less prone to leaching than other potash fertilizers.



Quantity of leached K (University of Florida, USA)

CONTAINS THE IMPORTANT SECONDARY NUTRIENT SULFUR

Sulfur is delivered in the sulfate form, which is easily taken up by the plant, sulfur is an important constituent of amino acids and proteins and is also required for photosynthesis.

THE IMPORTANCE OF CHOOSING A HIGH GRADE SOLUBLE SOP PRODUCT

1: INTRODUCTION

When choosing a soluble potassium sulfate (SOP), the choice is often driven by price, without taking product characteristics, benefits and disadvantages for fertigation into consideration. Yet, the physical and chemical properties of the product are paramount to ensure safe and easy handling as well as optimal plant nutrition, whilst preserving soil quality.

Thanks to Tessenderlo Kerley’s 100 years of experience in producing SOP, we have been able to develop a special production process for our high quality water soluble SOP, SoluPotasse, and, in parallel, have introduced a unique quality control system based on the most important quality parameters of soluble SOP, whilst at the same time respecting the strict European legislation.

2: PRACTICAL EVALUATION OF SOLUBLE SOP IN THE FIELD

Besides reviewing the properties declared on the specification sheet or bag, an easy first test is to prepare a solution of the product to check the level of insolubles (all insoluble material) and the speed of dissolution.

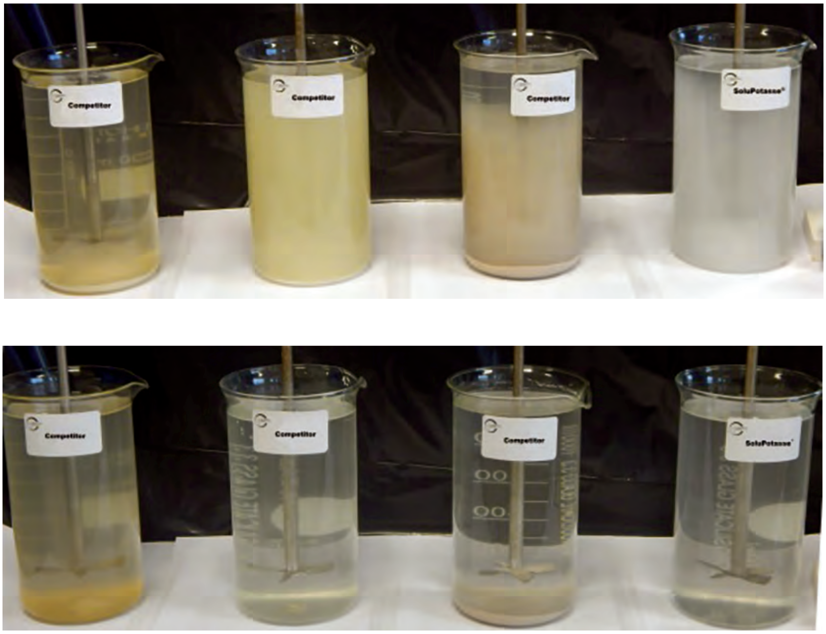


Figure 1: Different samples in solution, compared to SoluPotasse as the rightmost reference sample on the pictures (left after 1 minute of stirring; right after 15 minutes of stirring); (Tests shown were conducted using de-ionised water for consistency)

3: THE CONCENTRATION OF CROP NUTRIENTS

High concentrations of the key nutrients K_2O and SO_4 are of direct benefit to the farmer, who, in the end, is getting better value for money with more nutrients for each kilogram of product. Growers generally look for a minimum potassium content of 51 % K_2O and figure 2 demonstrates a big variability between different soluble SOP products available in the market, including a large set of samples with less than 51 % K_2O. SoluPotasse sample score in 2018 on average was 51.7 % and never lower than 51.4 %.

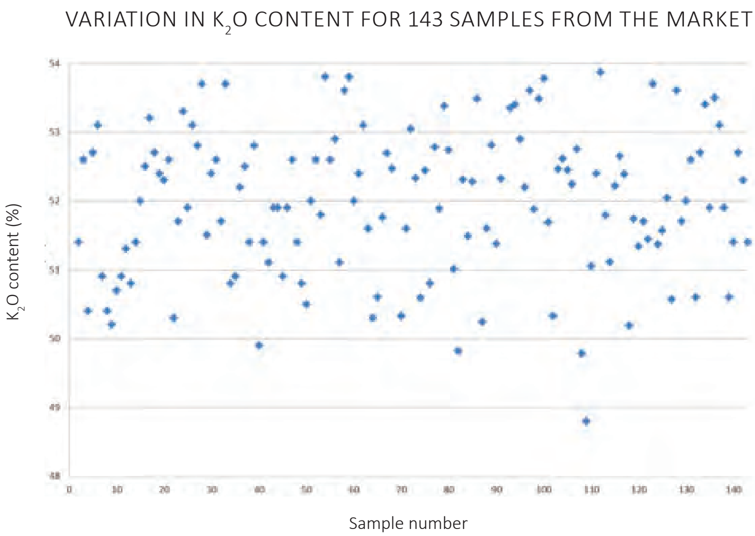


Figure 2: K_2O content in 143 SOP samples

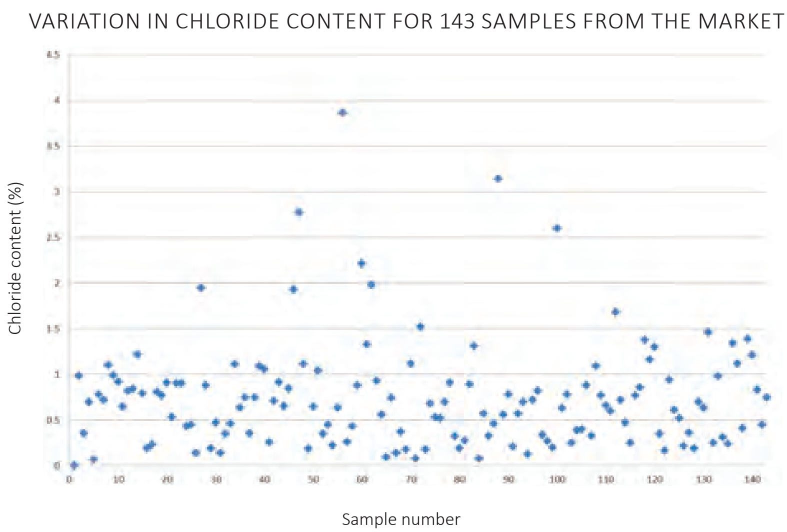


Figure 3: Chloride content in 143 SOP samples

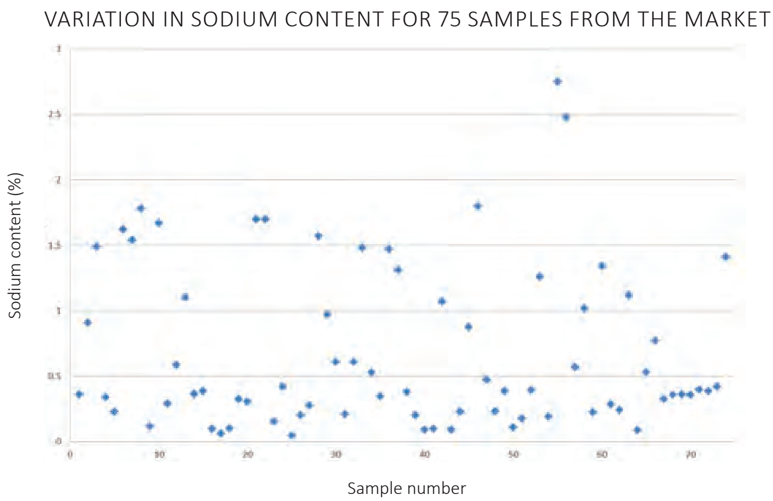


Figure 4: Sodium content in 75 samples

4: THE NEGATIVE IMPACT OF CHLORIDE AND SODIUM

The chloride (Cl^-) content, which is a very important characteristic of soluble SOP, also appears to vary quite significantly (figure 3). Only about half of the samples analysed have a chloride content below 0.6 %. There are even quite a few products with a value above 1 %. SoluPotasse average sample score in 2018 was 0.53 % and never scored above 0.70 %. The content of sodium (Na^+), which is a good indicator of purity, varies from around 0 to over 2 % (figure 4). For SoluPotasse, the sodium level in the 2018 samples never exceed 0.36 %, with an average value of 0.31 %.

A high content of chloride or sodium or a lower level of K_2O can result in a notable difference in performance, both in economic and agronomic terms. Additionally, the presence of heavy metals in the product is becoming a bigger issue each day, so analysis of these elements should also be considered.

5: THE NEGATIVE IMPACT OF INSOLUBLE MATERIAL

Measuring the quantity of insolubles in a soluble SOP product is paramount in determining whether or not that product can be used for fertigation. The presence of insolubles is highly undesirable and can lead to clogging of both the filters and the drippers. To be acceptable, the level of insolubles should be below 0.05 %. SoluPotasse samples are well below this value and have an average score of 0.02 % (based on 2018 samples). In contrast, almost 50 % of the analysed samples were above the 0.05 % limit and 12 % were even above 1 % (figure 5)! The latter should obviously not be used in fertigation for technical reasons, without even mentioning the economic consequences.

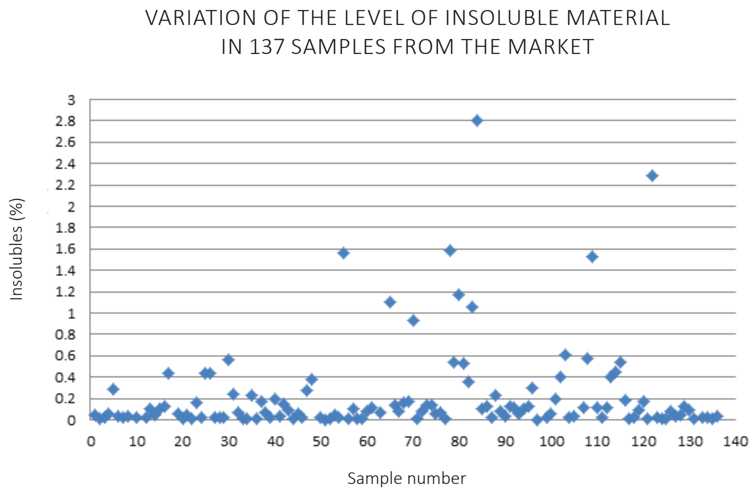


Figure 5: Content of insolubles in 137 SOP samples

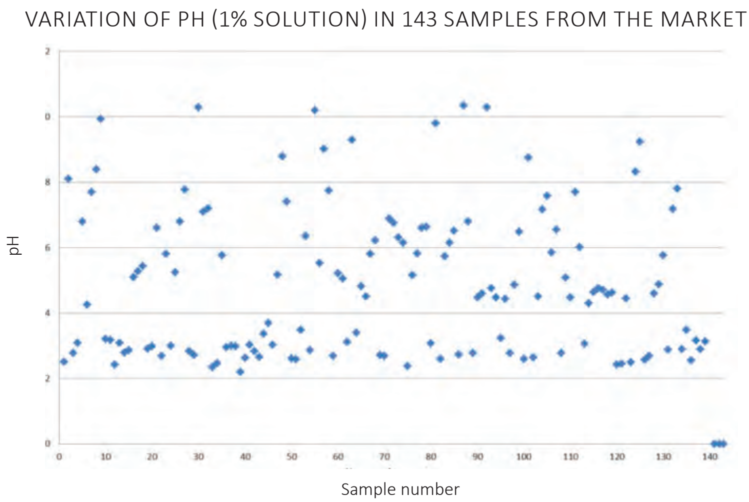


Figure 6: pH at 1 % in 143 SOP samples

6: THE PH OF THE SOLUTION - ACIDITY

Acidic products, like SoluPotasse, are beneficial for the quality of the nutrient solution and optimal uptake by the plant of a wide variety of nutrients. Figure 6 demonstrates great variability in pH, ranging from very alkaline to acidic, the latter being recommended. An acidic product also helps prevent the drippers from clogging.

7: DISSOLUTION SPEED

The speed of dissolution is another aspect that affects the usability of a product in fertigation systems. Figure 7 shows that there are some forms of SOP (masquerading as "soluble") which won't dissolve to more than 90 %, even after 10 minutes of stirring. The use of these products is obviously not recommended! Our laboratory defines a good quality product as one that is 90 % dissolved after 3 minutes with stirring, a result realized with SoluPotasse.

DISSOLUTION SPEED IN WATER FOR SEVERAL DIFFERENT WATER SOLUBLE SP PRODUCTS

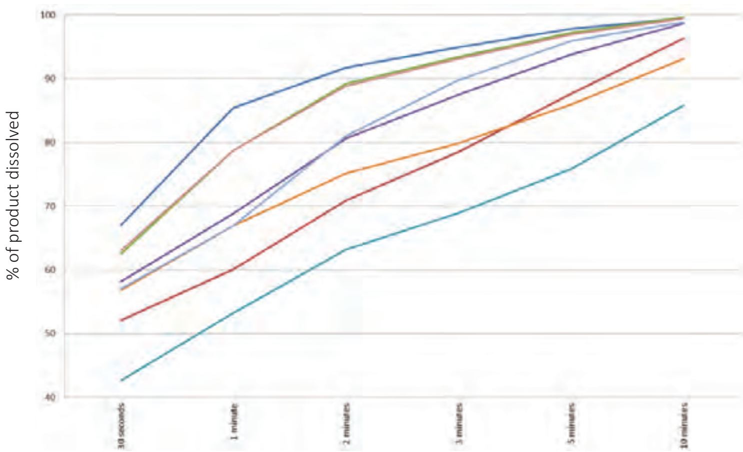


Figure 7: Dissolution speed at 10 % concentration in water

8: MAXIMUM SOLUBILITY

Besides the speed of dissolution, the quantity of SOP that can be dissolved in a certain volume of water is also important to the grower, since it implies that a higher concentration of nutrients in the solution can be achieved. Yet again, the range of values for this parameter varies widely. The best products, like SoluPotasse have a maximum solubility of 12 kg/100 l, while the worst barely even reach 11 kg/100 l. Bear in mind that maximum solubility is also impacted by water quality and temperature.

9: DUST

For reasons of security and ease of use, the dust content of the product can also be an important factor. Products containing a higher fraction of dust are more difficult and unpleasant to handle, whether using the product in fertigation or for the manufacturing of liquid or water soluble NPK’s. A wide range if values are observed for dust content in the market: between 0.01 % and 0.8 %. Also here, SoluPotasse scores very well generally staying below 0.1 %.

10: THE IMPORTANCE OF HAVING A QUANTITATIVE SCORING SYSTEM TO MONITOR QUALITY

There are four main reasons why it is important to have such a system:

1. Simplification: by selecting the most important soluble SOP quality parameters users are able to reduce the total number of variables that need to be evaluated.
2. Unification: using one global scoring system allows distributors and growers alike to compare various qualities of soluble SOP and thus make an informed choice of product.
3. Precision: laboratory tests for each of these parameters are standardized and our knowledgeable lab technicians always execute all analyses exactly the same way, thus allowing precise comparison between results of different samples. Also, by having one simple system to determine product quality, the risk of erroneously choosing a bad quality SOP for the end-user is greatly reduced.
4. Universality: this objective scoring system can be applied to any water soluble SOP independently whatever its source.

11: THE SCORING SYSTEM OR QUALITY INDEX (QI)

Based on workshops and surveys with distributors and their growers globally, eight important quality parameters were independently identified and ranked according to their importance. The following order of importance was agreed:

	Chemical	Physical
Priority 1	K_2O	Insolubles
Priority 2	Cl	Dissolution speed
Priority 3	pH	Maximum solubility
Priority 4	Na	Dust

Each of these parameters was then weighted by the distributors & users according to its importance for use in fertigation systems. For each criterion, a spectrum of vales was defined, based on the ranges of values observed in real samples collected in the market. The upper and lower levels correspond to a maximum and minimum score. So, on a scale from 0 to 200, the quality index (QI) for each sample is calculated as the weighted sum of the 8 parameters (see later).

Combining all these parameters, gives a total maximum score of 200 points. The priority along with minimum and maximum values for each of these parameters is summarized in the table below.

	Priority	Scoring range		
	1-4	high	average	low
	CHEMICAL			
K_2O (%)	1	52	51	50
Cl (%)	2	0.3	0.65	1
pH (1 % solution)	3	2.5	3.5	4.5
Na (%)	4	0.2	0.6	1
	PHYSICAL			
Insoluble H_2O (%)	1	0.01	0.055	0.1
% Dissolved after 3 mins	2	95	90	85
Max solubility (%)	3	12	11.5	11
Dust (%)	4	0.03	0.1	0.17

% K_2O – priority 1

It goes without saying that any high grade water soluble SOP should have a high level of K_2O. Any sample with a K_2O value below 50 is scored 0 in this system. These products are best avoided. Products with a very high K_2O content of 52 % or above are assigned the maximum score. The guaranteed minimum K_2O content is 51% for SoluPotasse, but the average value is about 51.5 %.

Chloride – priority 2

Excess chloride can be detrimental for the environment as well as the plant and the quality of its produce, which is why it is important to check the level of chloride in the product. Products with chloride levels of over 1 % should therefore not be used in fertigation, hence a score of 0 for these products. A chloride content of 0.3 % or less is extremely low and such products receive the maximum score. SoluPotasse scores well, with only 0.6 % chloride on average. At Tessenderlo Kerley, we guarantee a maximum of 1 % chloride in SoluPotasse.

pH – priority 3

For optimal nutrient absorption by the plant as well as prevention of blocking of drippers, the pH of the solution should be slightly acidic. To achieve this goal, the chosen water soluble SOP should have a low pH. Hence, products with a pH around 2 or 3, like SoluPotasse, receive a high score, whereas neutral to basic products (pH > 4.5) receive a score of 0.

Sodium – priority 4

High salt concentrations near the roots of the plant have a negative effect on the plant's ability to absorb the necessary nutrients. Hence, high levels of sodium should be avoided. Sodium is also an indicator of the pureness of the product. The higher the content of sodium, the lower the purity of the product. Products with sodium levels above 1 % are clearly of inferior quality and thus don't score on this aspect. 0.2 % of sodium or less on the other hand generates a maximum score. In 2018, SoluPotasse never contained more than 0.4 %. *

** Based on our monthly average analysis of production samples.*

% Insolubles – priority 1

From a grower's perspective, the level of insoluble components in a water soluble SOP is of critical importance to prevent the drippers from being blocked. Also in liquid NPK manufacturing, insoluble material causes problems, such as blocking of filters. To be acceptable, the product should have less than 0.1 % insolubles. SoluPotasse is well below this value, with only 0.02 % of insolubles on average. Products with 0.01 % insoluble material receive a perfect score on this parameter.

Dissolution speed – priority 2

For practical purposes and to save costs, whether using the product in a fertigation system or as a raw material for liquid NPK manufacture, the speed of dissolution of the product is a key criterion.

A product that dissolves slowly, implies a higher cost for the user. Improperly dissolved material may even clog the dripper system, thus resulting in even higher costs. After 3 minutes of dissolution a clear distinction can be made between fast-dissolving and slow-dissolving soluble SOP products. Products that are more than 95 % dissolved after 3 minutes receive maximum score on this criterion, whereas products that are less than 85 % dissolved score 0. SoluPotasse is a fast dissolving water soluble SOP, which is usually more than 90 % dissolved after 3 minutes.*

** In pure water at ambient temperature. Poor quality water and/or lower temperature will reduce speed of dissolution.*

Maximum solubility – priority 3

From an economical point of view, the maximum solubility of a product should not be overlooked as higher solubility implies a higher potential concentration of nutrients in the solution. At room temperature, maximum solubility of SOP is around 11 to 12 kg/100 l. SoluPotasse's maximum solubility is at the high end of this range, around 12 kg/100 l, thereby receiving maximum score. Obviously, the maximum solubility of the product also depends on the quality and temperature of the water. Products with a maximum solubility below 11 kg/100 l are of inferior quality and thus receive no points for this parameter.

Dust – priority 4

Products with a high level of dust are more difficult to handle and incidentally, more difficult to dissolve. High quality products with dust levels around or below 0.03 % receive excellent scores, whereas products with dust levels above 0.17 % are of poor quality and hence, do not score. Again, SoluPotasse scores well on this parameter, with average values at about 0.05 %.

Other factors

Although not incorporated at present into the scoring system, the heavy metal content of water soluble fertilizers is coming under increasing scrutiny. Heavy metals include a large range of elements present in various levels in water soluble fertilizers, making it difficult to assign a clear value to this parameter. Nevertheless, most people agree that some important heavy metals to exclude from water soluble SOP are cadmium (Cd) and mercury (Hg), both of which are below detection limit in SoluPotasse. High levels of aluminum and other metals can also sometimes be found in SOP coming as a by-product from aluminum production. SoluPotasse is also free of perchlorates (below detection limit).

12: SOLUBLE SOP PRODUCT ANALYSIS

Over the past five years, Tessenderlo Kerley's quality and R&D teams have analysed more than 200 soluble SOP products against the criteria and we continue to do so. Products include Tessenderlo Kerley's SoluPotasse water soluble SOP, which was developed in the 1990's as the first product of its type specifically for fertigation, as well as many other products on the market. Product samples were collected from growers, distributors and retailers and the quality index (QI) of each was then determined. QI values varied widely, demonstrating significant differences in the eight parameters, and confirming that QI value really defines different quality categories.

Based on feedback from our customers and the expertise of the SOP Plant Nutrition's Technical and Sales teams, we were able to define three different grades of soluble SOP:

- QI < 110: these products are not suitable for any type of fertigation and merely resemble standard grade powder SOP.
- QI between 110 and 140: these products could possibly be used in fertigation, but carry serious precautions in terms of composition and solubility; certain conditions may limit their use (e.g. in drip or hydroponics irrigation, water hardness, crop growth stage, other components in the mixing tank, etc.).
- QI > 140: suitable for use in all types of fertigation and particularly in drip irrigation or hydroponics. High quality products generally score around 150 or above.

13: INFLUENCE OF PRODUCTION PROCESS ON SOLUBLE SOP QUALITY

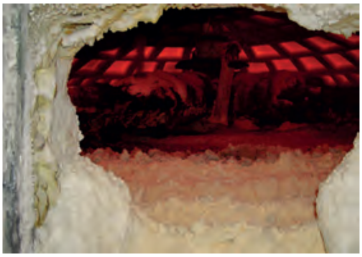
Part of the variability in the quality of products is due to the different production methods used. The three principal methods for SOP production are the evaporation and crystallization of surface or subsurface brines into SOP, an ion exchange process based on the mining of an ore known as Hartsalz, which is transformed into SOP via electrostatic separation, and the Mannheim process, in which potassium chloride reacts with sulfuric acid to produce SOP in a furnace. These three processes are summarized in the tables below. For many of the samples, we were able to identify the production process used, making a link between the product characteristics and the production process.

Evaporation and crystalization of brines

- Solar evaporation; harvesting; purification
- SOP products are pH neutral – not ideal as soluble grade

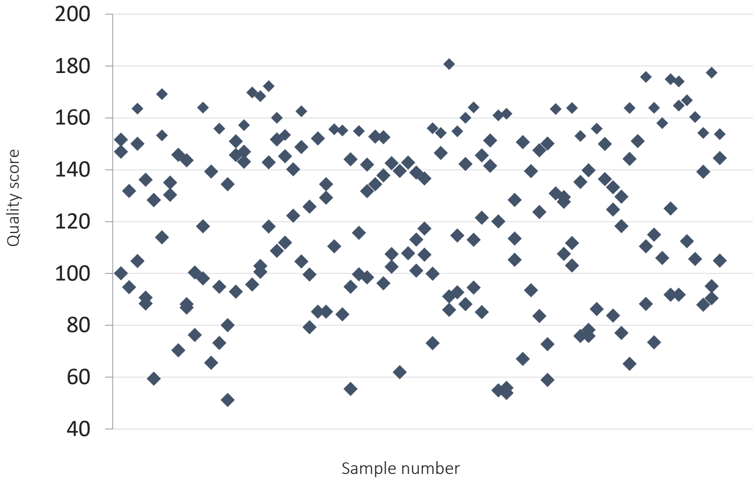
Mining of mineral ores (e.g. Hartsalz) followed by ion exchange

- Ion exchange between KCl and $MgSO_4$ via double salts (leonite and schoenite)
- SOP products are pH neutral – not ideal as soluble grade

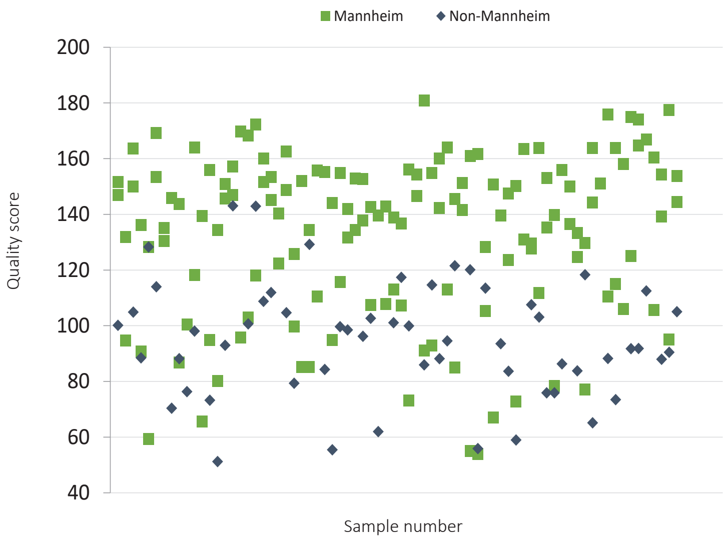


The Mannheim Process

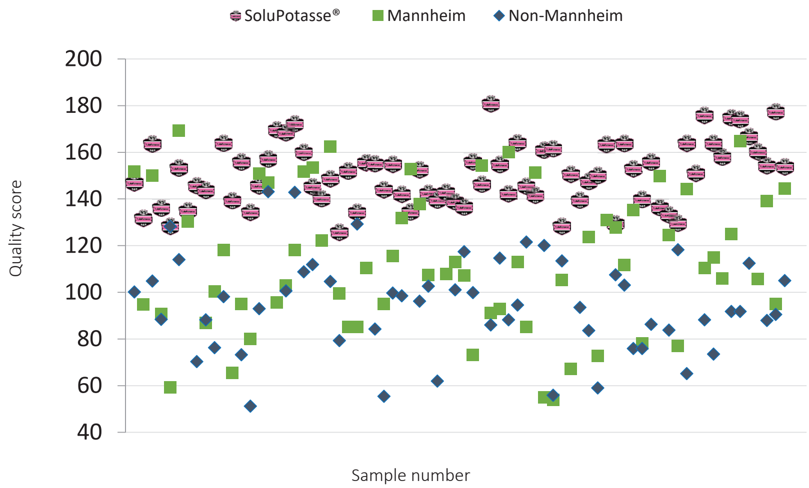
- Potassium chloride reacted with sulfuric acid at high temperature
- By-product is hydrochloric acid used in other processes
- SOP products have acidic pH – better for soluble grade



Graph 1: QI of soluble SOP samples from different producers



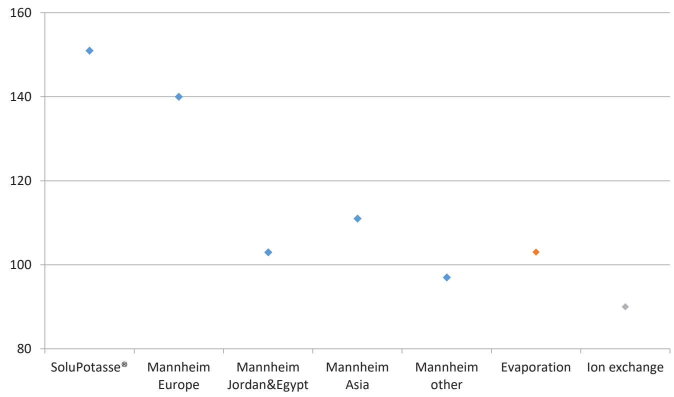
Graph 2: QI of soluble SOP samples per production process



Graph 3: QI of SoluPotasse is consistently high

Graph 2 clearly demonstrates that the Mannheim process is preferred for a good quality soluble SOP. It is also the only process that will give an acidic product – one of the important parameters for fertigation. As previously stated, products with a QI greater than 140 have the required characteristics for use in all types of fertigation and offer maximum security and efficiency. The Mannheim process as such, however, does not guarantee a good quality soluble SOP - many Mannheim products score below 140, or even below 110. In environments where these lower quality products may pose a risk, for example in greenhouse fertigation, they should really be avoided. In addition, a significant number of products on the market with a QI below 110 are sold as water soluble, but are not suitable for this use. The graph overleaf shows the average values of soluble SOP obtained from Mannheim producers from different regions of the world; the average values for products obtained by either evaporation or ion exchange are also included for illustration. The graph indicates that not only the production process influences product quality, but, surprisingly, also the origin and producer of the product have an impact. The Mannheim process is used in many regions around the world, but it is clear that this is not a guarantee for high grade products. The best forms of water soluble SOP can be found where there is a long tradition of Mannheim production.

Tessenderlo Kerley's production process at its factory in Ham is computer controlled and regular sampling by our in-house quality control lab guarantee consistent quality. We can ensure our customers that SoluPotasse is a product of a consistently high quality.

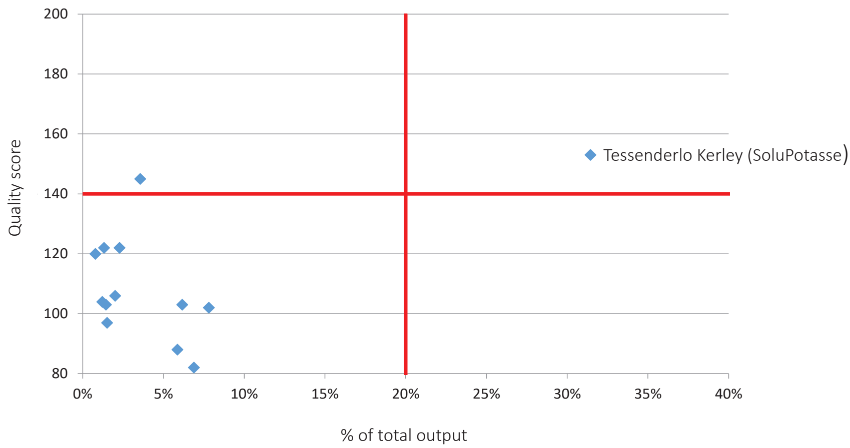


Average QI of soluble SOP samples per product origin

14: PRODUCTION CAPACITY OF SOLUBLE SOP

Soluble SOP is usually applied at specific stages throughout the crop growth cycle. Hence, it is critical that product is available at the right time during the cropping season. So, in addition to looking for high quality soluble SOP, growers must look for a reliable supplier who can offer the right quality when it is needed.

Does a high product quality also imply high availability? Other high quality soluble SOP producers have been identified in addition to Tessenderlo Kerley, but their outputs remain low (see graph). Even if high quality were not a requisite, no other producer with a large capacity could be identified.



Tessenderlo Kerley is the only supplier combining both a consistently high quality and the capacity to secure worldwide demand. Only a high grade product such as SoluPotasse, therefore, guarantees growers the best performance and peace of mind.

15: CONCLUSION: QUALITY MATTERS AND SOLUPOTASSE REMAINS THE BEST

Fertigation involves supplying fertilizers via the irrigation system. This could be either flood (furrow), overhead pivot or drip irrigation. Sulfate of potash (SOP) is an important source of potash for fertigation as it is free of both chloride and nitrate and also contains sulfur. Various products exist on the market but, unfortunately, the quality of these varies widely and many of them are not suited to all types of fertigation. Product quality cannot be judged solely on the specification sheet or the declarations on the product bag.

There is great variability in the different soluble SOP's available on the market for fertigation. High quality products clearly make a difference to generate higher returns and give a more safe and easy handling of products.

The 8 parameters highlighted here are all important and should be considered together, since they are largely interdependent.

Most soluble SOP producers don't control all of these quality parameters in a systematic way.

Tessenderlo Kerley has gathered hundreds of samples worldwide throughout the years and as demonstrated, consistent and precise evaluation of the characteristics of these samples clearly demonstrates very big differences in quality of water soluble SOP products available in the market. Products with a score below 110 should not be used in fertigation systems, whereas products with a score up to 140 are best avoided in high-tech irrigation systems. Products with a score above 140 can generally be considered the best reference products as they combine the best of all criteria simultaneously.

Only reliable partners with considerable experience in the production of water soluble SOP, such as Tessenderlo Kerley, can offer high grade water soluble SOP of a consistent quality. For us, producing high grade fully water soluble SOP for fertigation is a top priority: we use these parameters to strictly control the quality of SoluPotasse and constantly update our extensive database of samples of different products in the market. The Mannheim technology combined with Tessenderlo Kerley's unique production process guarantees we can maintain a very high standard of quality for SoluPotasse, resulting in a clearly superior quality index for SoluPotasse, with an average of around 150/200 over the last 5 years, a score that cannot be consistently equaled by our competitors. It is for this reason that SoluPotasse remains the reference for soluble SOP in the market, even after more than 20 years.

THE IMPORTANCE OF QUALITY FOR FOLIAR SPRAYING OF SOP

It is very important that growers wishing to apply foliar sprays of SOP use a product that is compatible with the application methods and equipment used for foliar spraying.

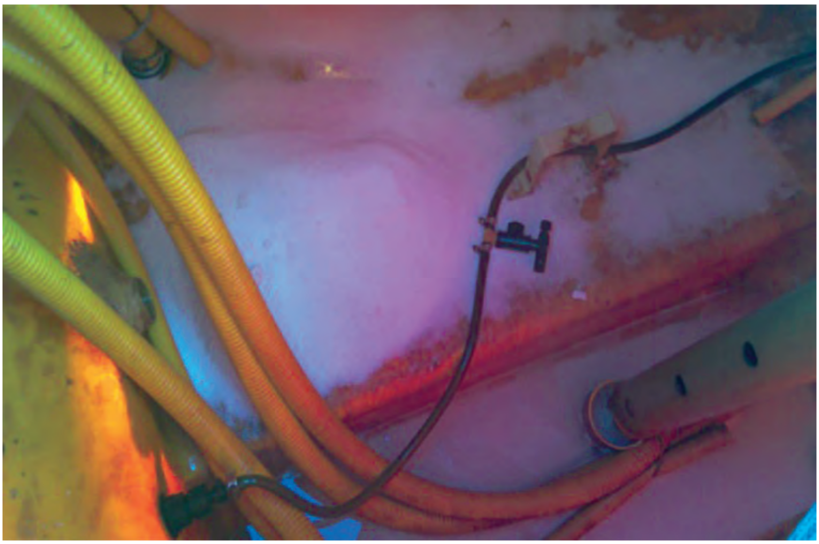
In fertigation systems, regular water soluble fertigation grade products are dissolved in large tanks with continuous stirring. Once a homogeneous solution has been formed it is introduced into the irrigation system. These systems are widely used in modern greenhouses and also in open field drip irrigation on technically advanced farms.

In contrast, for foliar application in field crops, modern tractor sprayers are now used in many parts of the world. In such systems, product is introduced directly into the spray tank often by means of suction (via an induction bowl) and dissolution is by means of circulation of water and agitation in the sprayer tank rather than by mechanical stirring. These differences can have a profound effect on the performance of a soluble SOP product in the two systems. A trial with a foliar sprayer in France highlighted the potential constraints when not using SOP specifically developed and formulated for foliar application:

A typical foliar sprayer

CHAPTER 6

Regular water soluble SOP is introduced into the 'bowl' for transfer into the spray tank by means of suction



Results from an 8 % solution after spraying - much of the product did not dissolve and remains in the tank

Results from an 4 % solution after spraying – better but still some product remains un-dissolved

The test shown above clearly demonstrates that unfortunately regular fertigation grade SOP is far from ideal as a foliar product for modern sprayers. Farmers cannot accept such performance since firstly product may be 'wasted' if it remains in the tank and secondly they have the additional work of cleaning the tank after spraying. There is also the serious risk that undissolved product could actually block the sprayer nozzles and damage the equipment. It is for these reasons that growers wishing to make foliar applications of SOP should only use a product market for this specific application, such as K-Leaf from Tessenderlo Kerley.

K-LEAF FOR OPTIMAL FOLIAR APPLICATION OF SOP

Tessenderlo Kerley is probably the only manufacturer worldwide that today offers a special grade of SOP, K-Leaf, which has been specifically developed and formulated for use in modern spraying equipment. The quality index developed for water soluble SOP (see earlier) can also be used to quantitatively measure the quality of a foliar grade SOP such as K-Leaf based on the parameters discussed previously. Compared to Tessenderlo Kerley's high grade, market leading fertigation grade SOP, the new foliar grade K-Leaf is even higher quality:

- It contains a higher level of K_2O and a lower level of chloride.
- It dissolves three times as fast, with 90 % dissolved after just one minute (in pure water at ambient temperature).
- It has an even lower level of insolubles.

Whereas the fertigation grade SoluPotasse consistently scores around 150 (out of 200) in the QI system described earlier, K-Leaf is in an even higher league with an average score of around 170. No other product on the market will perform better when it comes to foliar application of potassium.

ASSESSING THE QUALITY OF GRANULAR SOP PRODUCTS

When it comes to applying granular fertilizer products, the ultimate performance in the field is influenced by both the granular applicator and its operator as well as of course the quality of the granular fertilizer being applied.

An accurate application of the fertilizer at the correct dose will help enhance farm profitability whilst minimizing any adverse environmental effects which could result from cases where the fertilizer is not applied in an optimal manner.

In considering the properties of a granular fertilizer it is the chemical properties that will dictate the nutrient content but equally important are the physical properties that help ensure as much of the nutrients as possible are available for the crop.

When it comes to assessing the quality of a granular fertilizer product based on its physical properties most would agree that the following parameters are the most important:

1. Granulometry (particle size and distribution)
2. Granule density
3. Bulk density
4. Hardness
5. Granule shape
6. Flowability
7. Coefficient of friction

PHYSICAL PROPERTIES THAT IMPACT THE QUALITY OF GRANULAR SOP PRODUCTS

1. Granulometry

Granulometry is concerned with both the size of the SOP granules and the distribution of granule sizes to be found in a commercial product. For fertilizer samples including SOP one may find reference to the average granule size although it is, in actual fact, more important to have visibility on the particle size distribution (PSD).

The most commonly used method to determine PSD is sieve analysis whereby the amount of granules that pass through a sieve with a particular mesh size are measured. The test is then repeated for a range of sieves with differing mesh sizes so that the PSD can be determined. This is often then quoted in terms of discrete size ranges "percentage of granules between one size and another". PSD can also be presented in a "cumulative" form, in which the total of all granules retained or passed by a particular sieve is given for a range of sizes. Other ways of referring to granulometry include the d50 number and the SGN number.

- The d50 is the median granule size (value at the peak of the PSD distribution curve) corresponding to the value measured the most times in the sample.
- The SGN (Size Guide Number) is the average (not median) particle size multiplied by 100. For example, SOP with an SGN of 280 has an average granule size of 2.8 mm. Which is to say that 50 % of granules in the sample were retained on a sieve with a 2.8 mm mesh.

Range analysis, d50 or SGN are more often used in cases where a particular ideal mid-range granule size is desired, while cumulative analysis may be preferred in cases where the amount of "under-size" or "over-size" is under investigation.

Another measure of particle size distribution is the uniformity index (UI) which is define as d10/d95 x 100, where d10 is the sieve size over which 10 % of the sample passes through and d95 is the sieve size over which 95 % of the sample passes through.

Granule size and size distribution both impact on the spread width and uniformity. In general, larger granules are dispersed further by a spreader than smaller granules. Therefore, a wider band width can be used for larger particles.

The more variability there is in the granule size in a fertilizer product, the greater the risk of uneven application and/or segregation (a separating out of the individual components in the case of granular blended NPK's). NPK fertilizers with a wide range of particle sizes, including very small particles, will be more difficult to evenly spread. If a blended NPK fertilizer is used, the particle diameters of different components should be within 10 % of each other in order to avoid segregation. Ideally the particle size distribution of the N, P and K components should match (or match as closely as possible), with as narrow a PSD as possible.

The SGN can help given an indication as the to the relative compatibly of components used to make and NPK blend. If there is a difference of less than 10 in the SGN of the component materials then compatibility is likely to be good. If however there is a difference of more than 20 then there may be serious concerns about possibly segregation and uneven application in the resulting NPK blend. This uneven fertilizer application can potentially result in strips of nutrient-deficient crops which means a subsequent loss of income for the grower.

The particle size of granular SOP can be altered (degraded) by many factors including transportation, storage and loading and unloading. These manipulations can lead to breakage of granules, which not only reduces the size of some particles but also increases the PSD.

2. Granule density

The granule density reflects the mass to volume ratio of the granules and is reported in kg/m^3. Beyond particle size, the granule particle density of a fertilizer must be taken into account during the set-up of the applicator and will also impact on the risk of segregation for blended products.

The density also influences the spread width of the fertilizer. More dense granules can be spread across a wider band width and higher spinner disc speeds can be used. Less dense granules cannot be spread as widely and have a higher risk of breaking up when higher spinner disc speeds are used, leading to the formation of dust and fines. An increase in the variation of the densities across a fertilizer sample or across the N, P, K components of a blend will result in a higher risk of segregation. Therefore products for granular fertilizer blends should be selected so as to have similar and consistent densities so as to minimize the risk of segregation during transport, storage and spreading.

3. Bulk density

The bulk density of a material is the mass to volume ratio of a bulk sample, including the space between individual granules, which is in contrast to the granule density (see above) that does not include the space between individual particles and is hence a measurement of the particle density itself. Bulk density is also measured in kg/m^3. Bulk density can be measured by weighing a known volume of fertilizer. The two most commonly reported bulk density measurements are “loose” or “struck” (packed, tapped)

- The "Loose" bulk density is the mass per unit volume of fertilizer granules after they have been poured freely into a container.
- The "Struck" bulk density is the mass per unit volume of fertilizer granules poured into a container followed by mechanically striking or tapping the container until there is no further change in volume.

The struck bulk density of a granular fertilizer will of course be higher that the loose bulk density.

If there is a lack of uniformity in the bulk density this too can resulting in uneven spreading. Since the bulk density is also directly related to the fertilizer dose (kg/ha) it is important that the correct bulk density is used in the setting up of the applicator so that the correct rate is applied to the crop. Variations in the bulk density again can lead to fluctuations in the product metering giving an uneven application rate across the crop, which may once again impact on yield and hence profitability.

4. Hardness

Hardness (or crushing strength) is a measure of a granular fertilizer's ability to withstand blending, storage and transport and to resist breakdown or degradation during the mechanical application onto the field. The strength of granules is determined by their resistance to deformation or fracturing when pressure is applied. Hardness is generally measured in Newtons per granule whereas crushing strength is measured in kg/granule.

Hardness also has a direct influence on the spread width and operating disc speed. Harder products can be spread more widely and are compatible with high spinner disc speeds. Less hard fertilizers must be applied at slower disc speeds resulting in narrow band widths.

Whilst the hardness of granules is very important in determining the resistance to storage, transport, blending and application, it also important, of course, that once applied to or incorporated into the soil, the granule breaks down at the desired speed allowing the nutrients to enter the soil solution, thus becoming available to the plant.

Consequently granules that are too soft may break down too easily prior to application whereas granules that are too hard may not break down in a timely manner once applied. This may result in not all the nutrient content being fully available for the crop.

5. Granule shape

The shape of fertilizer granules varies from one product to another. Granules can be classified as round (spherical), cubic, rectangular and irregular. Round granules generally roll through the spinners, and also tend to bounce more. In contrast irregularly shaped granules would normally slide through the spinners. Because of this the importance of the coefficient of friction is more important for irregular shaped granules than for spherical particles. Granules with a very irregular shape may also be more prone to segregation. That said particle size and distribution differences have a greater impact on the risk of segregation than shape.

6. Flowability

Flowability concerns a material's ability to flow under humid conditions, and so is an important consideration when it comes to the application of fertilizers. Flowability can also affect the accuracy of placement. More flowable granules can be applied at faster rates and have a lower risk of sticking together. Less flowable granules run a higher risk of sticking together, particularly as humidity increases. This can make it more difficult for the operator to apply the product evenly. Flowability in NPK fertilizer blends can in some cases influence whether or not there is risk of product segregation and will have an impact on the spread width that can be achieved.

7. Coefficent of friction

The coefficient of friction is defined as the degree of friction experienced between two materials coming into contact with each other. In this case the fertilizer granules with the spinner discs in the applicator. A higher coefficient of friction means a longer contact between the granules and the spinners discs which leads to a more uneven spread application. The shape of the granule coupled with the coefficient of friction dictate how and when a granule will be expelled from the spreader.

GranuPotasse®: high grade granular SOP from Tessenderlo Kerley

Tessenderlo Kerley is one of the world's leading suppliers of granular SOP and to ensure consistent product quality, controls are made regularly at all stages of the production process. For GranuPotasse, Tessenderlo Kerley's granular form of SOP, a minimum potassium content of 50 % K_2O is guaranteed, along with a maximum chloride content of 2.5 % (compared to the 2003 EC Fertilizer regulation which stipulates minimum 47 % K_2O and maximum 3 % chloride for SOP).

Tessenderlo Kerley uses a compaction process to produce its granular SOP in which powder SOP is first compacted and is subsequently broken to give SOP granules. These are then carefully sieved to produce a product containing granules of the correct size and distribution. When it comes to particle size distribution the target is to have at least 85 % of the granules between 1 mm and 4 mm size. For GranuPotasse the SGN is typically around 320 and the uniformity index around 45.

Prior to shipment the product is de-dusted to remove dust and treated with a protective coating to increase the resistance of the granules to transport, handling and storage and to improve the flowability during application. The typical hardness of GranuPotasse is around 4.9 kg/granule. This is the optimal range thus ensuring the granules are robust enough to withstand the manipulations before and during application, a yet will break down once applied to the soil, in a timely manner thus ensuring optimal nutrient availability to the crop.

Tessenderlo Kerley strives to offer GranuPotasse of a consistently high quality. Whilst there are other producers and suppliers, buyers should be wary of products that:

- Contain higher levels of chloride - many cash crops are sensitive to chloride, which can be detrimental to yield and quality. Also excessive use of chloride based fertilizers in arid and semi-arid regions can to lead to soil salinity issues.
- Contain significant amounts of dust- making the product difficult and unpleasant to handle, blend and apply.
- Have soft granules – which will have a tendency to break down during transport, storage an handling leading to dust formation. In addition breakdown of the granules in the spreader will lead to an irregular application of fertilizer to the field.

It is only by a using consistently high grade product, such as GranuPotasse, that blenders will get the best results in their NKP products and growers will get the best performance in the field.

THANK YOU

It has been my privilege and pleasure to have worked alongside Michel since joining Tessenderlo Group in 2002. During this time I have benefited greatly from his knowledge and expertise, as have many of our colleagues. Michel, with his many years' experience, has been the foundation of Tessenderlo Group's knowledge base for potash and SOP fertilization. With his extensive international experience in agricultural industries, Michel has built up a broad and comprehensive knowledge of agricultural science with specific expertise in fertilizers and especially plant nutrition.

Michel graduated as an agronomist from the 'Ecole Nationale Supérieure Agronomique' in Rennes with the General Diploma in Agronomy (Diplôme d'Agronomie Générale) and completed his studies at the CEMAGREF in Paris, where he obtained the Advanced Diploma in Agronomy (Diplôme d'Agronomie Approfondie).

His career in agriculture began in 1977 when Michel took up the post of Central Service Manager in a palm tree research plantation (CIRAD) in Ivory Coast. In 1978, upon his return to France, he joined Fiat Agri Co. as their Training and New Product Engineer. He later moved to Rhône-Poulenc Agro in 1980 to take up the position of Application Techniques Manager, in their International Division. This was followed by a move to Evrard-Hardi Group in 1989 to become Product Manager for Agricultural Sprayers in France. His entry into the world of potash came in 1995 when Michel joined the Société Commerciale des Potasses et de L'Azote (SCPA) in Mulhouse France, formerly an important center for potash mining. During his 7 seven years as SCPA's Chief Agronomist, Michel travelled widely to promote the benefits of balanced fertilization and to educate growers regarding the importance of potassium, building up a reputation as a specialist of agriculture in Mediterranean and temperate climates.

In 2002, when Tessenderlo Group began marketing directly the SOP produced at their factory in Belgium (which was previously commercialized by the SCPA), Michel transferred to Tessenderlo Group to become their Senior Technical Manager for Fertilizers.

Since joining the group he has worked tirelessly to promote and develop SOP as a valuable chloride free potash fertilizer not only within Tessenderlo Group but also as their representative in a number of important organisations:

For many years Michel was the Coordinator for West Asia and North Africa at the International Potash Institute (IPI), Switzerland, and later on also took up responsibility for the coordination of their activities in Central Europe. He has also served as Chairman of the Agronomic Committee of the Sulfate Of Potash Information Board (SOPIB), since its creation in 1998.

As Michel approaches retirement in 2019 we look back with pride at his career working closely with farmers, dealers, extension workers, researchers and state officials. As Senior Technical Manager for Fertilizers at Tessenderlo Group he has been focused on conducting field trials to promote the benefits of SOP and providing advice and technical support on a global basis. During this time he has also presented his research on SOP fertilization at numerous conference across the globe.

Today Michel is, without a doubt, one the world's leading experts on potassium sulfate. He has expressed that his legacy be a lasting knowledge and expertise with respect to SOP, and it is therefore a fitting tribute to be able to publish this book, written by Michel, which represents the culmination of more than 40 years working in agriculture, of which more than 20 have been focused on potash and more specifically sulfate of potash (SOP). Its publication in 2019 also comes as Tessenderlo Group celebrates 100 years of SOP production in Belgium, confirming without a doubt that both Michel and Tessenderlo Group are 'Global experts in SOP'.

Dr Nicolas White
Portfolio and Knowledge Director
Tessenderlo Kerley International, part of Tessenderlo Group

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This book reflects on more than 100 years of expertise regarding the use of sulfate of potassium (SOP) in agriculture. It features the input of many agronomists and field technicians who worked for the Société Commerciale des Potasses et de L'Azote (SCPA) and latterly for Tessenderlo Group. The knowledge relating to SOP contained herein has been generated as a result of many years of fundamental research involving field experiments across the globe.

The book covers the importance of potassium in balanced nutrition and clearly explains why SOP is such an important fertilizer for many horticultural crops and for areas that are at risk from salinity. It contains comprehensive information on trials in which SOP was applied on a wide range of crops, as well as recommendations for the optimal use of SOP on these crops.

The information provided certainly contributes to an enhanced knowledge of potassium-based plant nutrition and it will help to deliver higher yields and a better quality of agricultural produce.

There is arguably no other book that covers SOP plant nutrition in such depth and it is therefore an essential point of reference for every agronomist who provides advice and makes recommendations on potassium fertilization using SOP.

ABOUT THE AUTHOR

Michel Marchand, who has recently retired, was formerly the Senior Agronomist at Tessenderlo Kerley International as well as the former Chairman of the Sulphate of Potash Information Board (SOPIB) agronomy committee. For a number of years Michel represented the very foundation of Tessenderlo Kerley International's knowledge base for potash and SOP fertilization.

Thanks to his extensive international experience, many people have benefited from Michel's expertise in SOP throughout his more than 40 years working in agriculture. During this time, he has conducted numerous field trials in order to demonstrate the benefits of SOP in collaboration with many research organizations across the world. Michel has also presented the results of his trials at a large number of international congresses. Without question, Michel is one of the world's leading experts on potassium sulfate fertilization.

SULFATE OF POTASH MORE THAN 100 YEARS OF EXPERIENCE

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