OIL PALM

Potassium, magnesium, sulphur and boron four important nutrients

Nutrient requirement of oil palm

There are 14 mineral nutrient elements that are essential for plant growth. These are termed essential because without them any plant will fail to grow. In addition the so-called non-mineral elements carbon, hydrogen and oxygen are also required. Six mineral nutrients, namely potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N), phosphorus (P) and sulphur (S), are required by all crops in large amounts and therefore belong to the group of macronutrients. The target of high palm oil yields cannot be realized without adequate supply of these macronutrients. Besides N and P, adequate supply of K, Mg and S is particularly important in palm oil production.

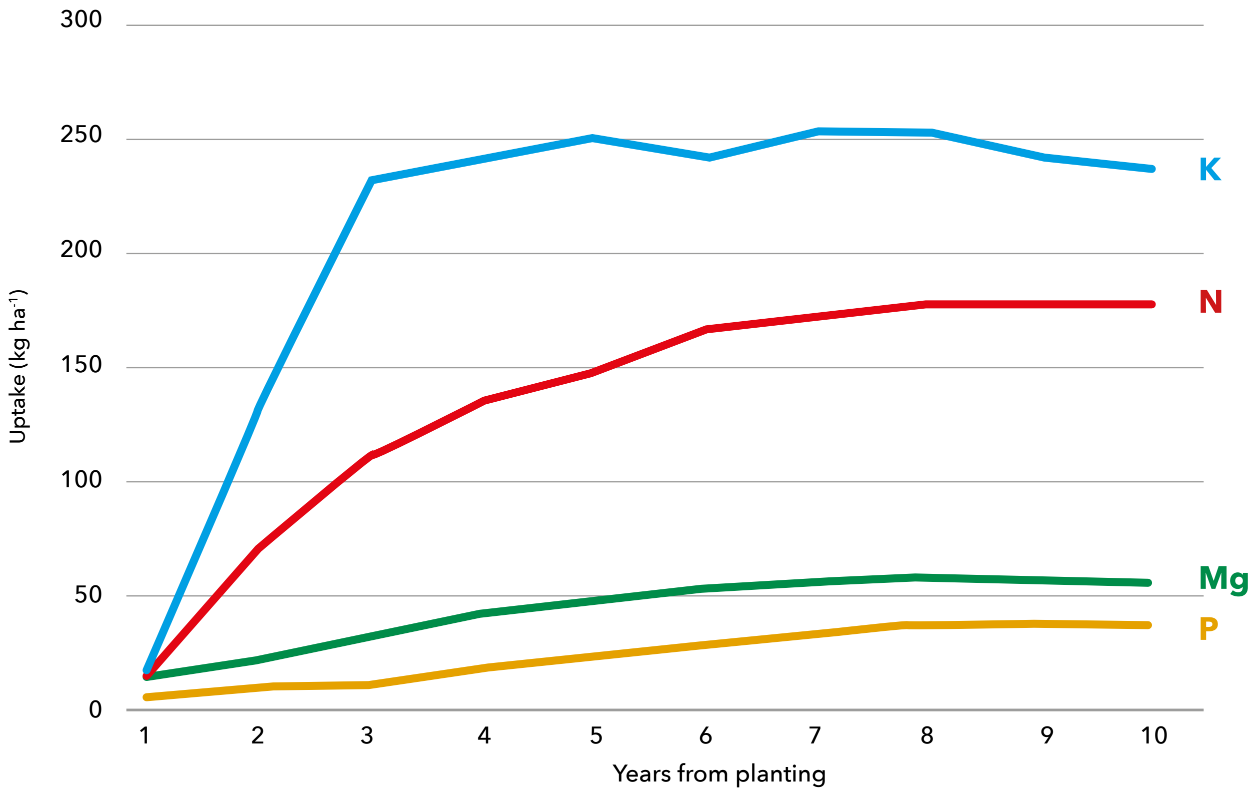
In addition, plants require nine micronutrients, namely iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni), chlorine (Cl), boron (B) and molybdenum (Mo). They are required in small amounts only, as most of them act as catalysts in enzyme reactions. Nonetheless, any deficiency will cause substantial reductions in growth and yield, as all mineral nutrients have essential and specific functions in plants' metabolism. Among all micronutrients, boron appears to be the most prominent, as soils where oil palm is grown are low in this nutrient. Therefore, boron deficiency symptoms are widespread in oil palm plantations.

The production cycle of oil palm, which lasts for about 25 years, is characterised by different stages, each having its specific requirement regarding nutrient demand. During the initial three years after planting, the immature stage, there is a gradual increase in K and Mg uptake by the oil palm. After 3–5 years onwards, the mature stage, the nutrient uptake stabilises at a high level.

This brochure will highlight and discuss the role of Mg, K, S and B for oil palm with respect to soil/plant interactions, focussing on responses to Mg application and its interaction with other cations on yield of fresh fruit bunches (FFB) and oil formation.

Potassium, magnesium and sulphur are important for oil palm nutrition

Nutrient requirement of the oil palm



Source: g, S.K., 1977. Review of oil palm nutrition and manuring – scope for greater economy in fertiliser usage. Oleagineux 32, 107 – 209

Typical oil palm nutrient balance assuming return of EFB and POME, but no change in soil potassium, and calculation of fertiliser needed to support yields of 30 t FFB/ha.
(Ng et al., 1999, with data from several authors).

Nutrients (kg ha-1 yr-1)	N	P	K	Mg
Demand (stored or lost)				
Stored in trunk	42.4	4.1	121.6	10.2
Shell	4.5	0.1	2.1	0.3
Fibre	7.8	1.9	32.3	2.9
FFB (no shell no fibre)	86.8	13.5	95.2	30.1
Runoff (loss)	15.2	1.0	21.6	2.1
Leaching (loss)	3.4	0.9	6.3	3.4
Erosion (loss)	2.4	0.0	0.0	0.2
Total Demand	162.5	21.5	279.1	49.2
Non-fertiliser supply				
EFB (empty fruit bunches)	17.2	2.1	62.6	2.8
POME (palm oil mill effluent)	6.6	1.4	31.3	5.8
Rainfall deposition	17.0	2.4	31.6	4.8
Total non-fertilizser supply	40.8	5.9	125.5	13.4
Balance (supplied by fertiliser)	121.7	15.6	153.6	35.8

Fertilisers
used for oil palm

In order to sustain good growth and high yields of oil palm the fertiliser industry provides a range of mineral fertilisers. Mineral nutrients are inorganic elements that have essential and specific functions in plants' metabolism.

Nitrogen is provided either as urea, Ammonium sulfate, Ammonium Chloride or N. P is applied either as the natural rock phosphate, or as partially or fully acidulated phosphates. It should be noted that ground rock phosphates are recommended for use in acidic soils only, and that the quality of this fertiliser is indicated not primarily by the total P_2O_5 content, but by the P_2O_5 content that is soluble in weak acids. One of the world's major producers and suppliers of potash and magnesium products is K+S. This company extracts potash and magnesium crude salts five mines in Germany and one in Canada, transforming them into a wide variety of high-grade mineral fertilisers and intermediate products for further processing for technical, commercial and pharmaceutical purposes.

K+S is the fifth largest potash producer worldwide and the leader in Europe. In the field of potassium sulphate and magnesium sulphate speciality fertilisers (mainly ESTA Kieserit and Epsom Salt), K+S occupies the leading position worldwide.

Name	Formula	Content	Comment
Nitrogen			
Ammonium chloride	NH_4Cl	28% N	High acidification potential
Ammonium sulfate	$(NH_4)_2SO_4$	21% N, 24% N	High acidification potential
Urea	$CO(NH_2)_2$	46% N	High volatilization losses
Phosphorus			
Triple superphosphate (TSP)	$Ca(H_2PO_4)_2 \cdot H_2O$	41 – 50 % P_2O_5, 12 – 20 % CaO, 1.4 % S	Soluble in water
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	48 – 61% P_2O_5, 10 – 12 % N	Soluble in water
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	46% P_2O_5, 18 % N	Soluble in water
Rock phosphate	$Ca_{10}(PO_4)_6(OH,F,Cl)_2$	25 – 39 % P_2O_5, 46 – 50 % CaO	Partially soluble in weak acids
Potassium			
Muriate of Potash (MOP)*	**KCl**	**60 % K_2O**	60er Kali®
Magnesium			
Magnesium sulphate monohydrate*	**$MgSO_4 \cdot H_2O$**	**26 % MgO, 21 % S**	ESTA® Kieserit
Dolomite	$MgCO_3 + CaCO_3$	30 – 47 % CaO, 2 – 18 % MgO	Partially soluble in weak acids
Boron			
Sodium tetraborate decahydrate	$Na_2B_4O_7 \cdot 10H_2O$	11 % B	Fully water soluble (Borax)
Sodium tetraborate pentahydrate	$Na_2B_4O_7 \cdot 5H_2O$	15 % B	Fully water soluble (Borax)
Ulexite	$Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$	11%	Soluble in weak acids
Colemanite	$2CaO \cdot 3B_2O_3 \cdot 5H_2O$	12 % B	Soluble in weak acids
Multinutrient			
Korn-Kali* (K, Mg, S)	**KCl, $MgSO_4$**	**40 % K_2O, 6 % MgO, 4 % S**	Korn-Kali®
Korn-Kali+B*	**KCl, $MgSO_4$, $Na_2B_4O_7 \cdot 5H_2O$**	**40 % K_2O, 6 % MgO, 4 % S, 0.8 % B_2O_3**	Korn-Kali® +B

** K+S Minerals and Agriculture products*

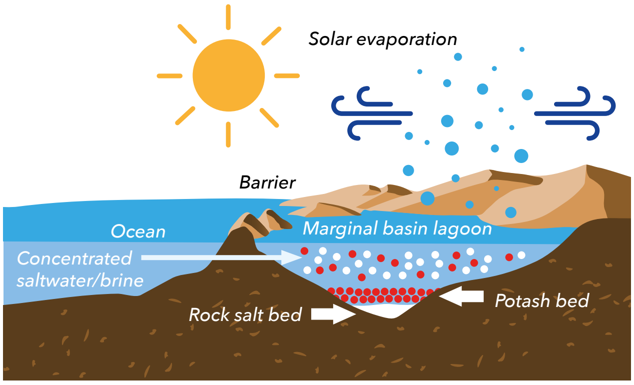
Natural Resources –
the Potash Deposits in Germany

The potash deposits in Germany were formed more than 250 million years ago by the evaporation of the Zechstein Sea. According to the barrier theory as it is known, salty seawater flowed over shallow sea barriers into marginal shallow basins, where it evaporated due to extreme arid conditions. The salt concentration increased, and at last potassium, magnesium and sodium salts were crystallised and deposited in the order of their solubility. This process was repeated for hundred thousands of years, so that two or more potash deposits were formed at a depth of several hundred metres. In the course of the following geological history, the thick salt deposits were covered by vast series of sh ales, sandstones and limestones of the Bunter Sandstone, Coquina and Keuper Ages and thus prevented from dissolution. In most regions of the world, the crystallisation process resulted mainly in rock salt (NaCl) and potassium chloride (KCl). In Germany, the formation of the deposits had a special character. The mines of K+S Minerals and Agriculture are a unique source of kieserite ($MgSO_4 \cdot H_2O$), a mineral based on magnesium and sulphur.

Composition of dissoluted salt in sea water

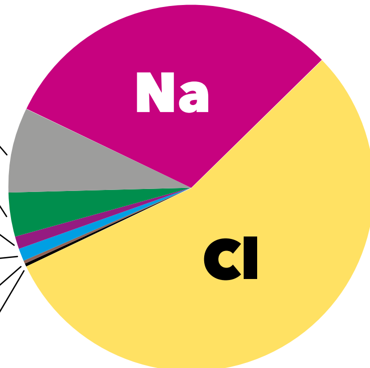
Sea water has average salt contents of 33–37 g/l. Amongst the dissolved salts, which consist of more than 30 elements, rock salt (or common salt) quantitatively accounts for the highest share. It is used as table salt and for various industrial purposes. Other main components are sulphur, magnesium, calcium, potassium and bromine. In hot and dry regions like Spain or Australia, the high salt contents of the sea is still utilised for table salt production via solar evaporation in open ponds.

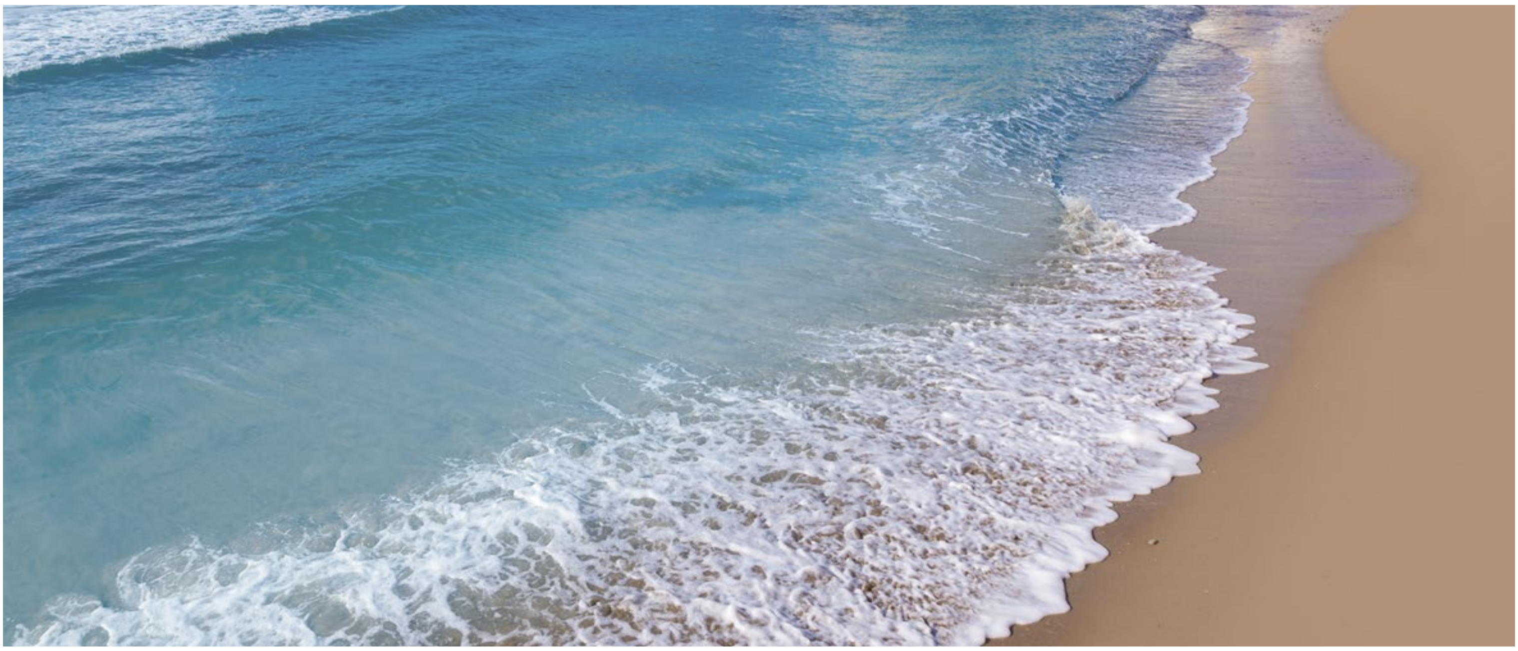
Formation of Potash Deposits



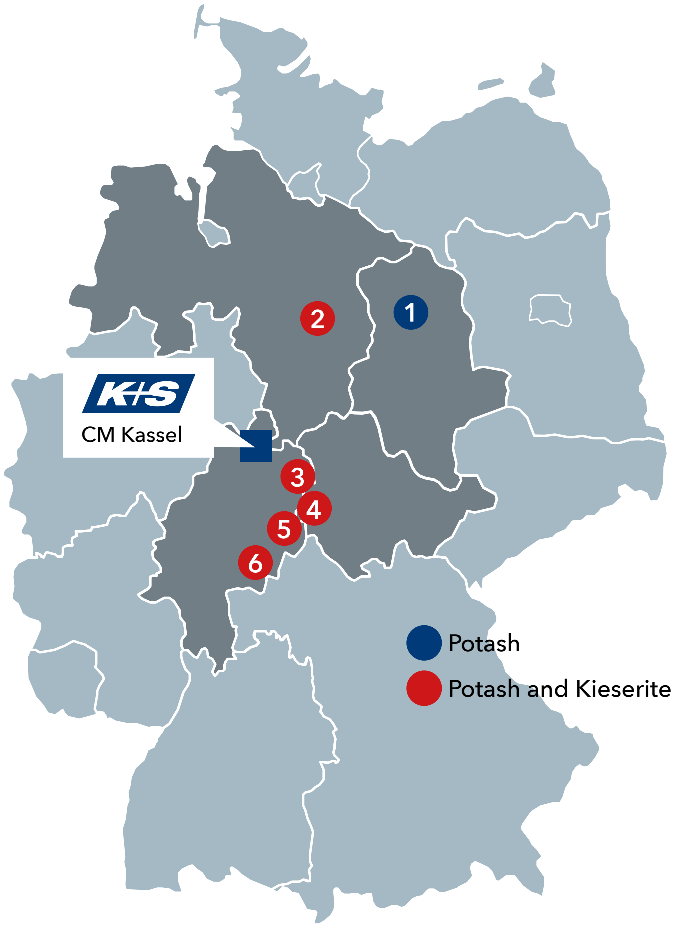
Composition of dissoluted salt in sea water in %

Cl	55.292
Na	30.593
SO_4	7.692
Mg	3.725
Ca	1.197
K	1.106
CO_3	0.207
Br	0.188





Regionally rooted – the Mines of K+S Minerals and Agriculture



K+S Minerals and Agriculture Potash Plants

K+S Minerals and Agriculture is headquartered in Kassel, Germany, and currently operates five mines in several potash districts. Extraction of potash rock takes place in deep mines at depths of between 400 to over 1,400 metres. The potash rock is blasted and huge shovel loaders with a capacity of up to 20 tonnes transport the crude salt to the crusher. From there the ground salt is transported to the mine shaft by conveyor belts. The crude salt is transported to surface from underground in skips with speeds ranging from 15 to 24 metres per second. The next step aboveground is the fine grinding followed by the processing to fertilisers, depending on the potash salt type, via thermal dissolution, flotation or electrostatic separation. The selection of the separation process depends on the composition of the crude salt as well as the desired end product. These processes can also be combined. Potassium chloride and magnesium sulphate (Kieserite) obtained are then used to produce the several products offered by K+S.

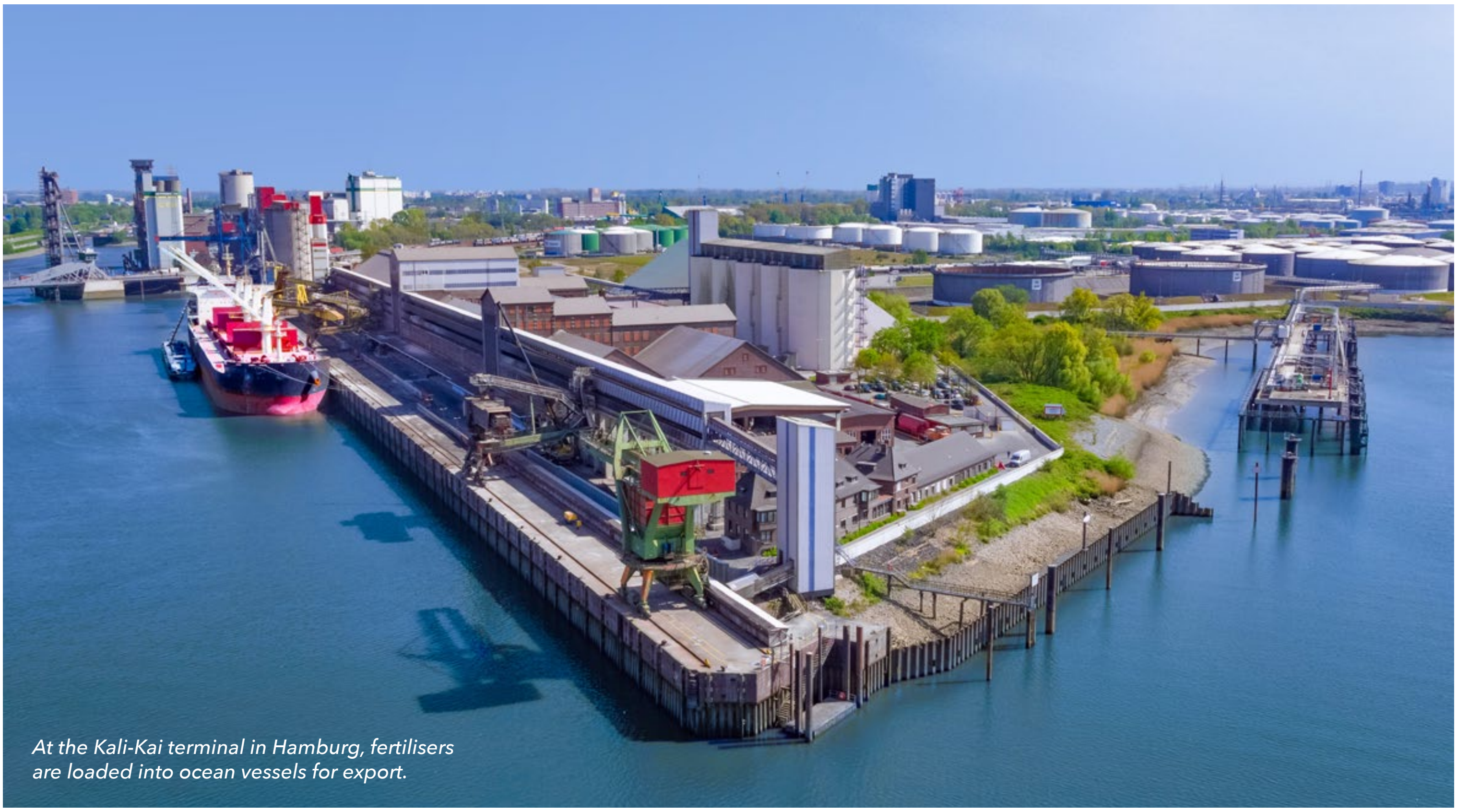
■ Corporate management Kassel

1. Zielitz plant
2. Bergmannssegen-Hugo (Lehrte) (production only, no mining)
3. Werra works – Wintershall (Heringen)
4. Werra works – Unterbreizbach
5. Werra works – Hattorf (Philippsthal)
6. Neuhof-Ellers plant (Neuhof)

Competence Creates Security – Quality Control and Logistics

Automated control systems and constant control analyses ensure the adherence to the specified nutrient contents in the various potash and magnesium fertilisers.

All product delivered is automatically sampled and analysed in laboratories on site, so that the declared nutrient content can be guaranteed on a lasting basis.



At the Kali-Kai terminal in Hamburg, fertilisers are loaded into ocean vessels for export.

Rail is one of the most important means of transport for the high-quality K+S products.

Control analyses are constantly carried out in the state-of-the art laboratory on site.

Potassium in the soil

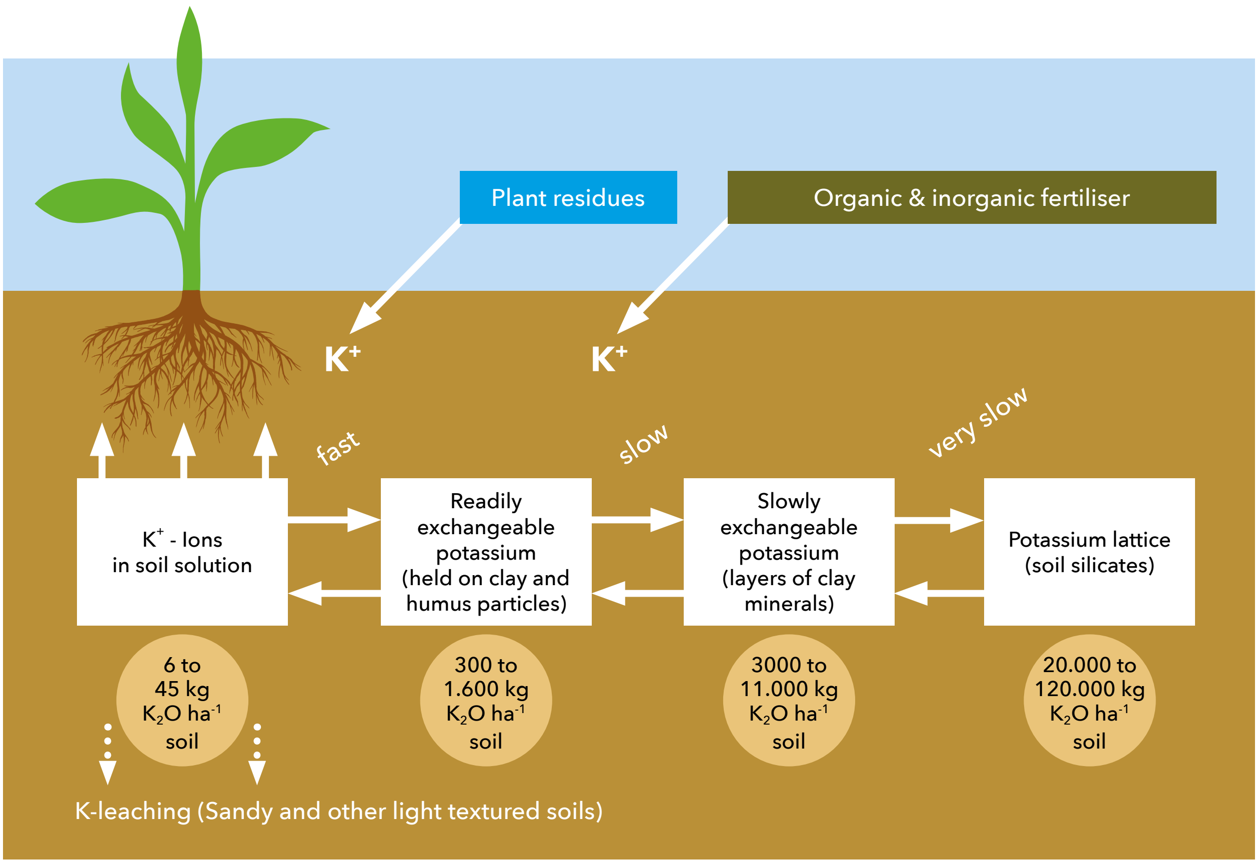
In the soil, four pools of K are usually distinguished (see diagram below):

- K as a component of soil minerals (interlattice position)
- non-exchangeable potassium (fixed K)
- exchangeable K (bound on the surface of soil clays and organic matter)
- potassium in the soil solution

Exchangeable and non-exchangeable K are in equilibrium with each other and with the K in the soil solution. Potassium transfers easily between these pools.

Potassium is taken up actively by palm roots as K^+ ion from the soil solution. Most of the K taken up is transported to the root surface by diffusion (after establishing a concentration gradient to the root surface) and by mass flow (with the water moving to the plant root). In loamy soils K transport is dominated by diffusion, with mass flow increasing in importance in sandy soils.

Potassium dynamics in soils



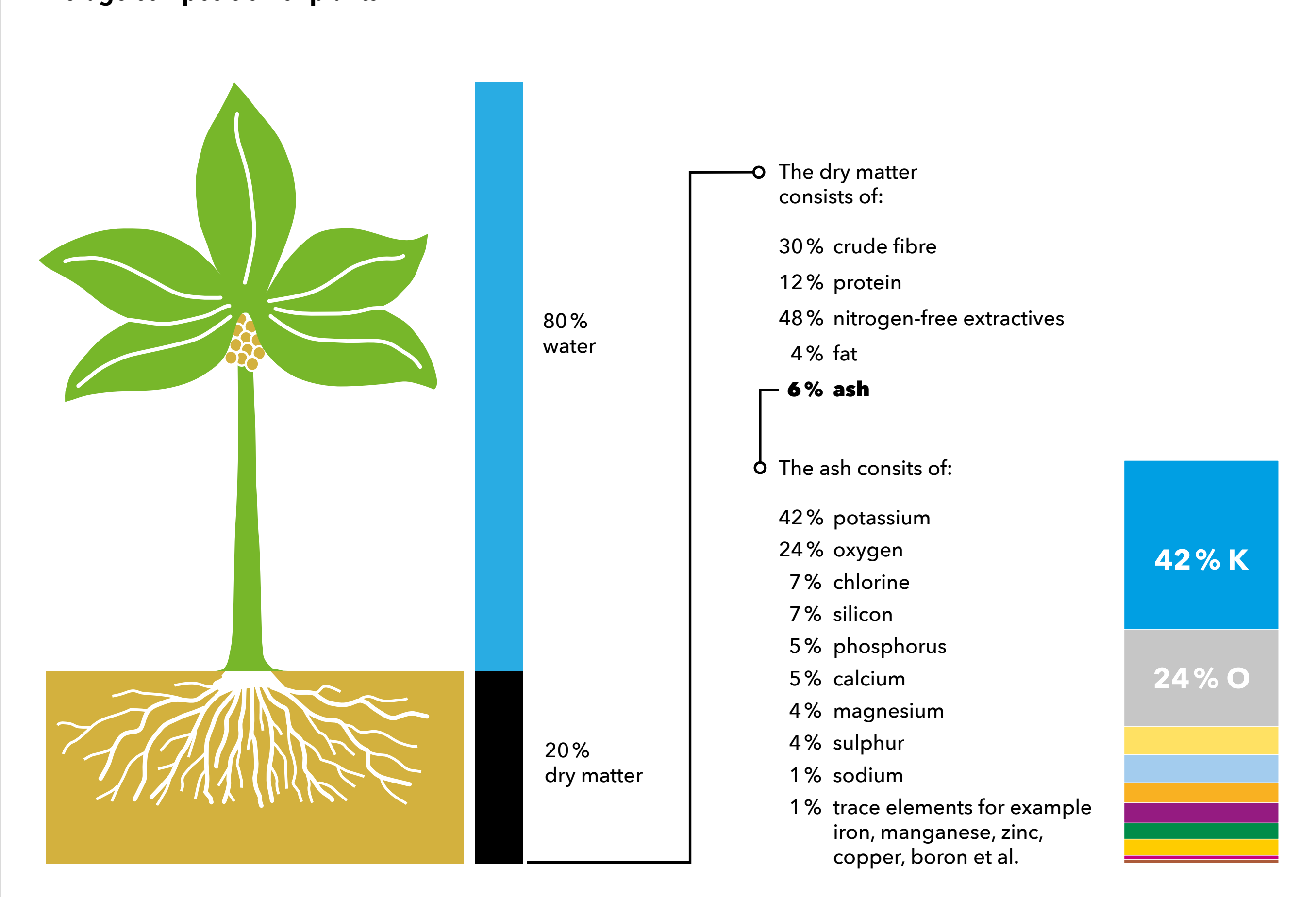
Potassium in the plant

Potassium is needed by the plant in large quantities for the production of high yield (bunch weight and bunch number) and improved crop quality. In contrast to many other essential elements, K is not a structural component of organic compounds. Potassium is present in all plant organs and cells and has many functions in the plant that ultimately are related to three basic functions of K:

1. most important inorganic osmoticum
2. most important counter ion
3. activates many enzymes

- Potassium plays an important role in the conversion of light into biochemical energy during photosynthesis.
- Potassium is essentially required for loading assimilates (photosynthates) into the phloem, the structures responsible for their translocation.
- Potassium enhances the flow of assimilates from leaves (physiological source) to roots, flowers, fruits and buds (physiological sinks).
- Potassium enhances the storage capacity for assimilates (sink size) by increasing the number and size of their cells.
- Potassium promotes the storage of assimilates as a result of increased production and improved translocation of carbohydrates.
- Potassium increases the nitrogen use efficiency through incorporation of Nitrogen into amono acids and Proteins.
- Plants abundantly supplied with K can utilize water more efficiently than K-deficient plants.

Average composition of plants



The importance of potassium in oil palm

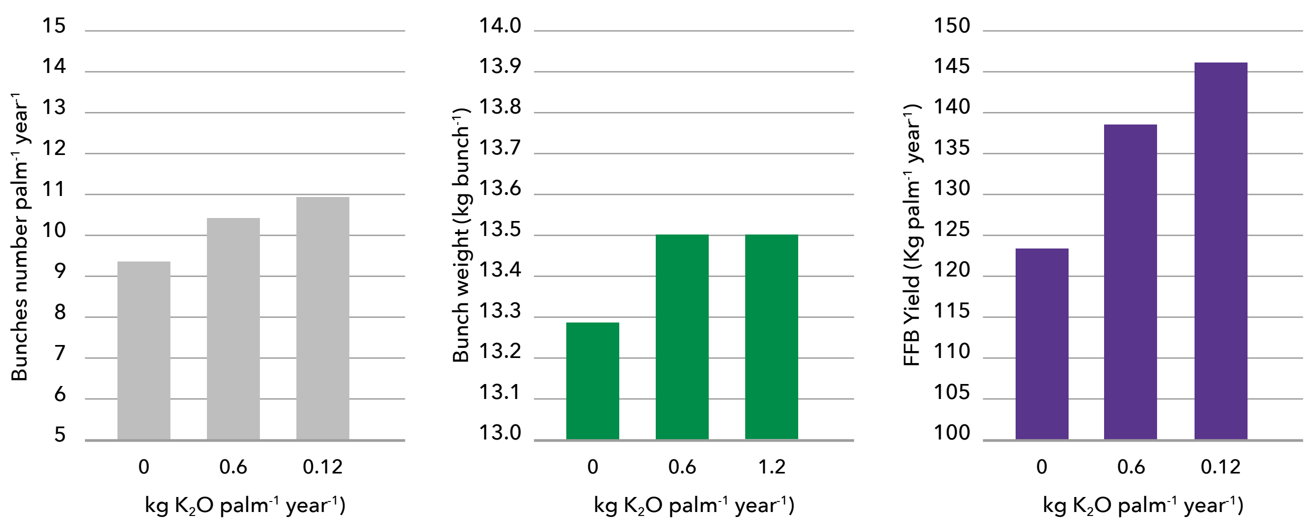
In accordance with the extremely high growth rate of the oil palm, its requirement in nutrients is enormous. Of all major plant nutrients, potassium is taken up in the largest amount. Therefore, potassium plays an important role in plant nutrition and is known as the most important cation in plant physiology.

Annual nutrient demand (kg ha^{-1}) of oil palm of various ages (Tiemann et al., 2018 and Corley et al., 2015)

Palm age	Plant part	N	P	K	Mg	Ca	Reference
9-12	Trunk, roots and FFB	116	12	167	22	NA	Tarmizi and Tayed, (2006)
15-19	FFB and trunk	215	26	199	29	NA	Prabowo et al. (2006)
15-19	FFB , trunk, frond and male inflorescence	386	45	368	55	NA	Prabowo et al. (2006)
10		114	14	149	32	33	Henson (1999c)
15		162	21	279	49		Ng et al. (1999)
15		192	26	251	61	89	Pushparajah and Chew (1998)
9-10		137	18	231			Henson and Chang (2007)

Potassium is involved in numerous biochemical functions and affects yield positively on many soils (bunch weight and bunch number). In addition with nitrogen, potassium causes synergistic effects improving growth, bunch yield and oil/bunch ratio. Under normal circumstances the adequate K content in frond No. 17 is between 0.9% and 1.3% depending on palm age, soil moisture or total leaf cations.

Potassium promotes bunch development and bunch yield (Kusnu et al., 1996)



Potassium deficiency in oil palm

In tropical regions, more soils are poor in plant available potassium than in temperate regions. In oil palm, potassium is the nutrient required in largest quantity. At a yield level of 30 t FFB per hectare about 160 kg of K (Corley et al., 2015) are removed with the bunches every year. K deficiency occurs where soils contain very small amounts of exchangeable K (< 0.15 cmol kg^{-1} of K). Especially in sandy soils and in peat soils, potassium deficiency is widespread because of high leaching losses caused by high rainfall combined with low K reserves. Furthermore, K deficiency occurs where roots are not able to penetrate the soil to deeper soil layers because of an impermeable soil horizon and/or chemical soil conditions, i.e. very low soil pH and aluminium toxicity as a consequence.

A variety of symptoms have been found to be associated with potassium deficiency in mature oil palms. Confluent orange spotting is the most common K deficiency symptom characterised by small, initially pale green spots which gradually turn yellow to yellowish orange and enlarge both between and across the leaflet veins.

A second symptom is called "white stripes" that is associated with N : K ratios above 2.5 (excessive N supply combined with insufficient application of K fertiliser) and probably a lack of boron. These white, pencil-like stripes occur on both sides of the mid-rips and have a transparent look.

Confluent orange spotting

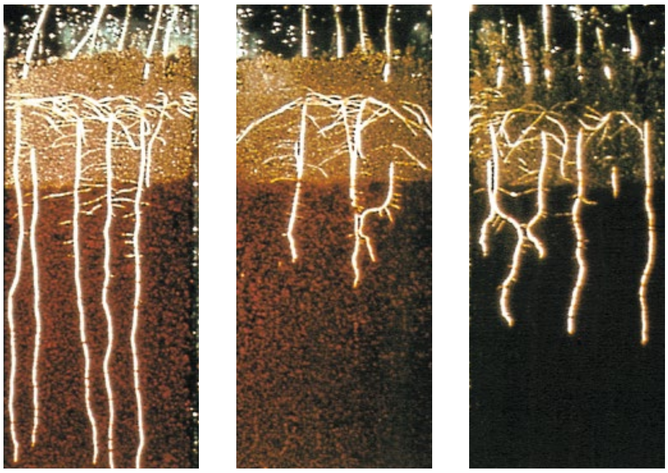
White stripes

Magnesium in the soil

Mg is absorbed by plants as Mg^{2+} from the soil solution. The absorption depends on the Mg^{2+} concentration in the soil solution, soil pH, the % Mg saturation on the cation exchange capacity (CEC) and the concentration of other exchangeable cations (Ca^{2+}, K^+, Na^+ and NH_4^+). The Mg^{2+} in the soil solution is in equilibrium with the exchangeable Mg which is absorbed at the negative charged sites of clay minerals and organic matter. The absorption of Mg^{2+} is very sensitive to competition with other cations. Excessive K supply may inhibit Mg uptake and therefore induce Mg deficiency. Continued use of liming materials with high Ca may increase the Ca/Mg ratio at the exchange complex and induce Mg deficiency.

In acid mineral soils, Al^{3+} becomes the dominant cation of the exchange complex, forming soluble toxic species which impair root growth. This Al-induced root growth depression can be alleviated by adequate magnesium supply.

Impairment of root growth as affected by soil pH



pH 6.5 | pH 5.2 | pH 5.5

Mg alleviates Al-induced root growth depression

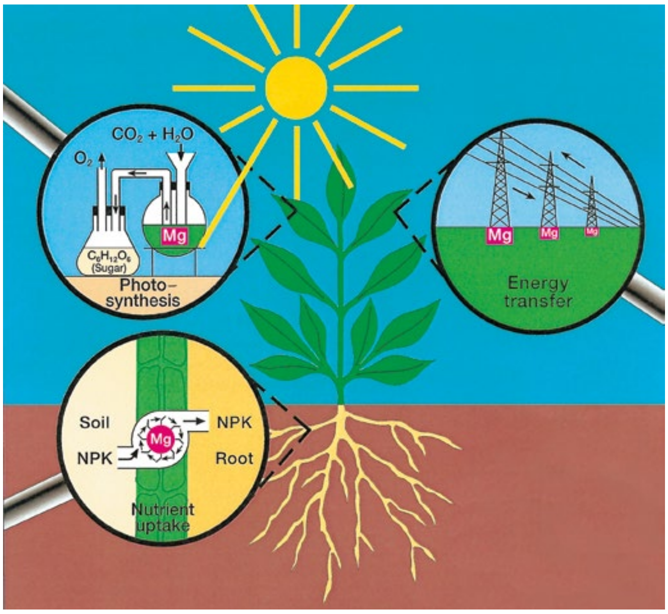
-Al | +Al

0.1 Mg | 0.5 Mg | 0.1 Mg | 0.5 Mg

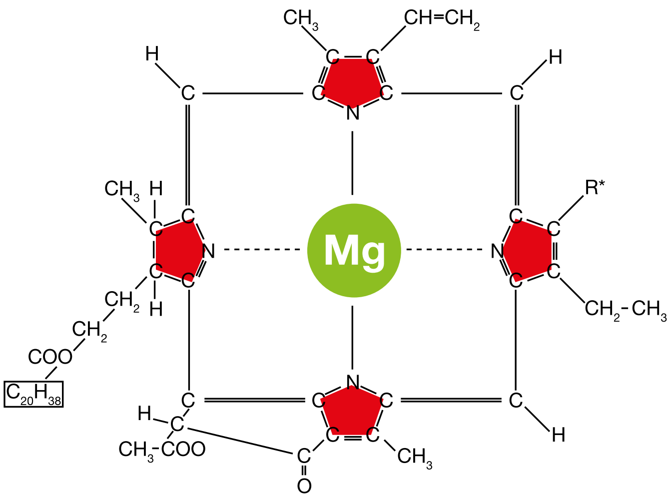
Magnesium in the plant

Magnesium is sometimes referred to as a secondary nutrient, suggesting that it is of secondary importance. However, Mg is an important macronutrient and has many functions in the metabolism of oil palm. The most prominent function of Mg in plants is its role as the central atom of the chlorophyll molecule, the green pigment in leaves that captures the light energy required for photosynthesis.

Functions of magnesium in the plant



Magnesium and its most important function in plants

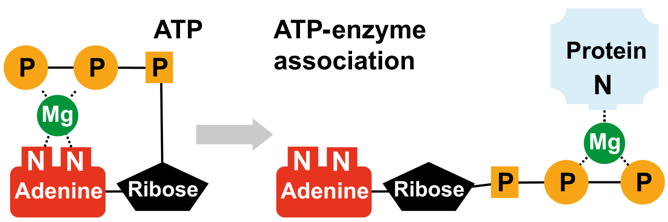


*R=CH_3 Chlorophyll a
*R=CHO Chlorophyll b

Besides being part of the chlorophyll, Mg^{2+} (together with K^+) is a very important counter ion for charge balance across the thylakoid membrane in the chloroplasts. Magnesium is also essential for activation of RuBP carboxylase, the key enzyme responsible for photosynthetic CO_2 assimilation.

Magnesium is also involved in the functioning and activity of phosphatases and ATPases. This is because their cosubstrate ATP is always present as – and only active in the form of – its Mg complex. When ATP associates with enzyme proteins, this also requires bridging by Mg. Phloem loading and hence transport of photosynthates (assimilates) from leaves to sink tissues (fruits, roots, new growth) is mediated by ATPases. Consequently, under Mg deficiency, starch accumulates in leaves, limiting photosynthesis further by feedback inhibition. Under limited photosynthesis, the energy (light) absorbed by chlorophyll is transferred, as electrons, to oxygen (O_2) resulting in the formation of oxygen radicals or reactive oxygen species (ROS). These processes are the physiological background for the higher sensitivity of Mg deficient plants to high light intensities, what explains the associated symptoms discussed in the section 'Magnesium deficiency in oil palm'.

Magnesium is also essential for protein biosynthesis, because the subunits of the ribosomes, which are responsible for the



elongation of the polypeptide chain, are fixed in position by Mg^{2+}. Hence, Mg is needed in all processes that require energy, e.g. starch, protein and vitamin synthesis, assimilate transport to roots and fruit bunches and it is required by many enzymes concerned with fatty acid and oil biosynthesis.

Magnesium deficiency in oil palm

Magnesium was neglected in oil palm plantations in the past which led to widespread Mg deficiency. Mg deficiency occurs in oil palm where soils contain very small concentration of exchangeable Mg (<0.2 cmol kg^{-1} for Malaysian soils, Goh and Chew, 1997). This condition is typical in sandy soils and sites where the topsoil has been eroded. Soils in advanced stage of weathering are inherently poor in magnesium. Leaching losses from those soils led to further depletion of nutrients. Leaching of Mg is further accelerated by low soil pH, which reduces Mg retention in the exchange sites. Application of high rates of K^+, Ca^+ and NH^{4+} induce Mg deficiency because of the antagonistic effect between those cations.

It is commonly but wrongly assumed that, because of the antagonistic effects of cations, Mg should not be applied together with K. On the contrary, because of this effect, the application of K alone at any one time will suppress the uptake of especially Magnesium. It is therefore desirable that these two cations are applied together to keep the balance and minimise such effects.

The free Mg is highly mobile within the plant and is easily translocated from older to younger leaves and tissues, like fruits, etc. Mg deficiency symptoms in oil palm are characterised by uniform discolouration of leaflets and of the older fronds, ranging from yellow to bright orange-yellow. Strongest expression of Mg deficiency occurs during the dry season at high solar radiation and exposure to the sunlight. Therefore, among planters the symptoms are often called "heat-induced sunburn" and are rarely associated with Mg deficiency. The causal effects, however, are that under dry conditions Mg mobility in the soil and hence uptake is reduced. Low Mg supply leads to impaired sugar translocation and accumulation of starch in leaves and the activation of O_2 resulting in toxic radicals, being responsible for the chlorosis and necrosis of pinnae. "Sunburn" is hence an expression of latent Mg deficiency under high light intensities while shaded pinnae may remain green (see photograph below).

Mg deficient oil palm

Mg deficiency on pinnae

Magnesium sources affect oil palm productivity

Since the sustained plant availability of Mg is crucial for high FFB yield and oil extraction rates, it is absolutely necessary to pay attention to the nutrient release characteristics from the magnesium sources to provide the oil palm continuously with this essential nutrient. Very slow releasing sources may lead to a temporal under-supply. In contrast, very fast releasing sources may be prone to dramatic Mg losses by leaching.

In principle, there are three different forms in which magnesium is typically applied to the soil:

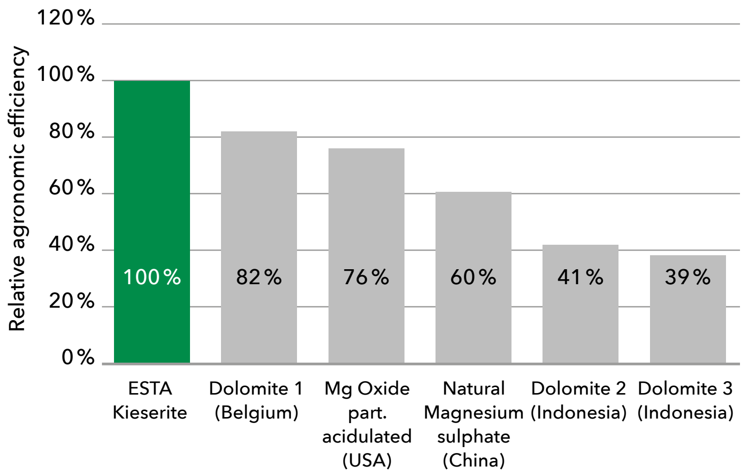
- the oxide form (magnesium oxide and calcined lime stone)
- the carbonate form (in magnesite and dolomite)
- the sulphate form (ESTA Kieserit and other magnesium sulphates).

The physicochemical properties of Mg fertilisers are crucial for their use in oil palm plantations. Mg oxides and carbonates (dolomite) have a very low solubility in water. They must be solubilized by the soil acidity, what is a very slow process, often releasing the Mg at a speed insufficient to meet crop demand.

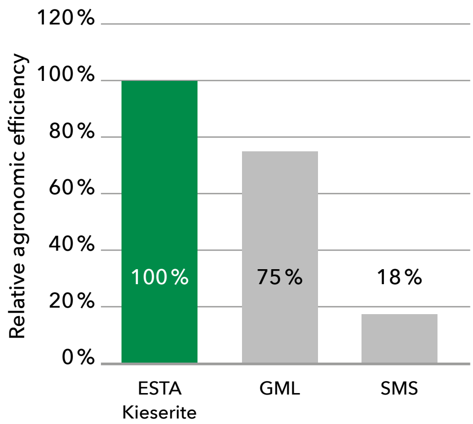
Dolomite can be used partly to maintain Mg levels on acid soils but because of its low solubility it is not as effective as ESTA Kieserit to correct Mg deficiency and to supply plants adequately with Mg.

ESTA Kieserit, as a natural Mg source dissolves gradually, independently of the soil pH and provides oil palms more efficiently with both essential nutrients (Mg and S). Attention should be paid to other magnesium sulphate fertilisers available in the market. Many of them are chemically produced (synthetic magnesium sulphates – SMS), and depending on the origin of the sulfuric acid for production may contain heavy metals. They usually have a variable Mg content and poor particle structure (dusty powders). The synthetic magnesium sulphates and even other kinds of natural magnesium sulphates usually present lower agronomic efficiency than ESTA Kieserit. Some of them will have too much of its Mg content in the oxide form, not being readily available to crops. Others, will have a dissolution rate too fast, what results in higher leaching losses. Hardter et al. (2004) compared ESTA Kieserit and SMS leaching losses in a lysimeter trial and found that Mg leaching losses of ESTA Kieserit were 33% lower than the losses of an SMS fertiliser.

Relative agronomic efficiency based on frond dry weight and petiole cross section 30 months after application of Mg sources (data from Sidhu et al. 2014)



Relative agronomic efficiency of magnesium sources based on FFB yield on a 8 years trial in Harimau soil series in Malaysia (data from Tang et al. 2001)



Several independent studies have shown the superior agronomic efficiency of ESTA Kieserit compared with other magnesium sources in oil palm. In one of the most recent trials, Sidhu et al. (2014) compared ESTA Kieserit with several other magnesium sources in the correction of acute magnesium deficiency in an oil palm plantation in Indonesia. Although all the sources tested were able to increase the foliar Mg content to normal levels and eliminate the deficiency symptoms, ESTA Kieserit was much superior in terms of improving palm growth parameters that are highly correlated to FFB yield. Based on that, ESTA Kieserit had a relative agronomic efficiency 18% superior than the second most efficient source.

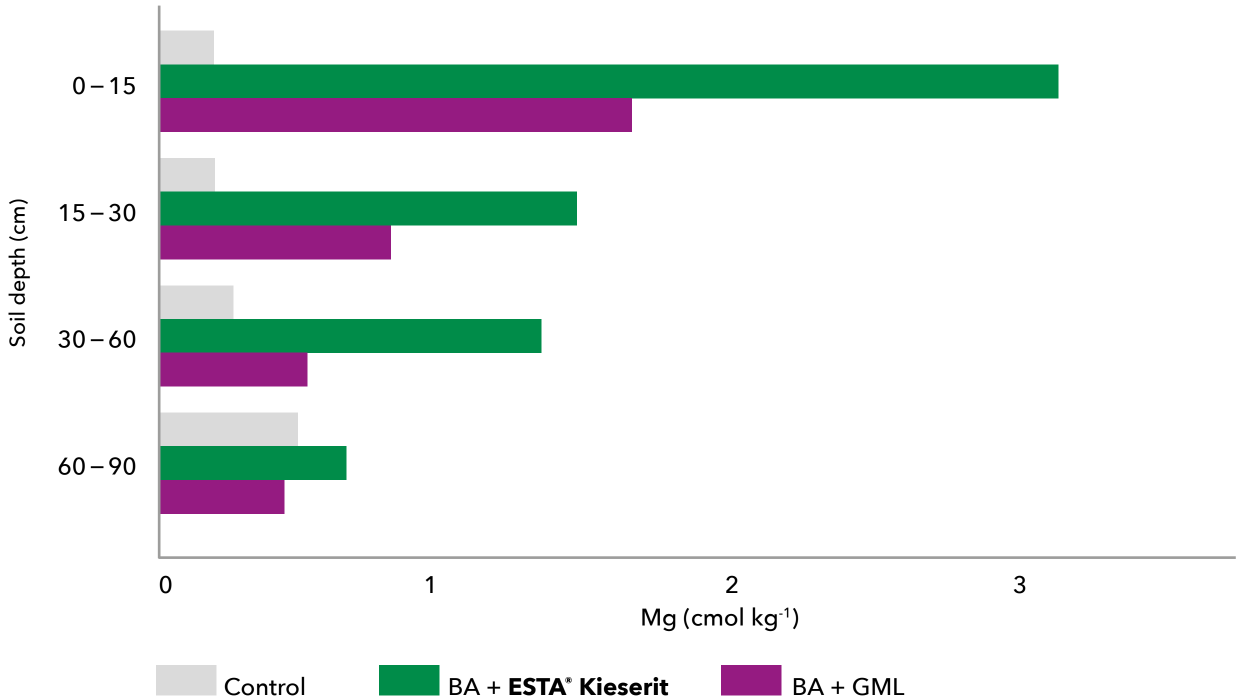
Long term trials have also confirmed the superior agronomic efficiency of ESTA Kieserit. Tang et al. 2001 compared ESTA Kieserit to GML (ground magnesium limestone) and a synthetic magnesium sulphate in a 8 years trial in Malaysia. ESTA Kieserit was the most agronomically efficient Mg source in promoting oil palm yield, increasing FFB yield by 8 to 11%, followed by GML at between 5 to 8% and SMS at 0 to 4%.

Magnesium and surface application

Oil palm roots active in nutrient uptake are mostly located in the top 50 cm of the soil profile whereas the highest quantities are located in the top 30 cm. The incorporation and mixing of fertilisers with the soil to improve its dissolution is usually not feasible because the upper root network will be destroyed and nutrient uptake will be inhibited.

The effect of a typical surface application of two Mg carriers (ESTA Kieserit and dolomite) on soil exchangeable Mg was studied in oil palm. The results show that dolomite, owing to its poor solubility, only increased exchangeable Mg contents in the upper soil layers, whereas substantial Mg from ESTA Kieserit penetrated to deeper soil horizons.

The effect of bunch ash (BA) and magnesium sources (ESTA® Kieserit and dolomite (GML)) on soil exch. Mg (cmol kg^{-1})*

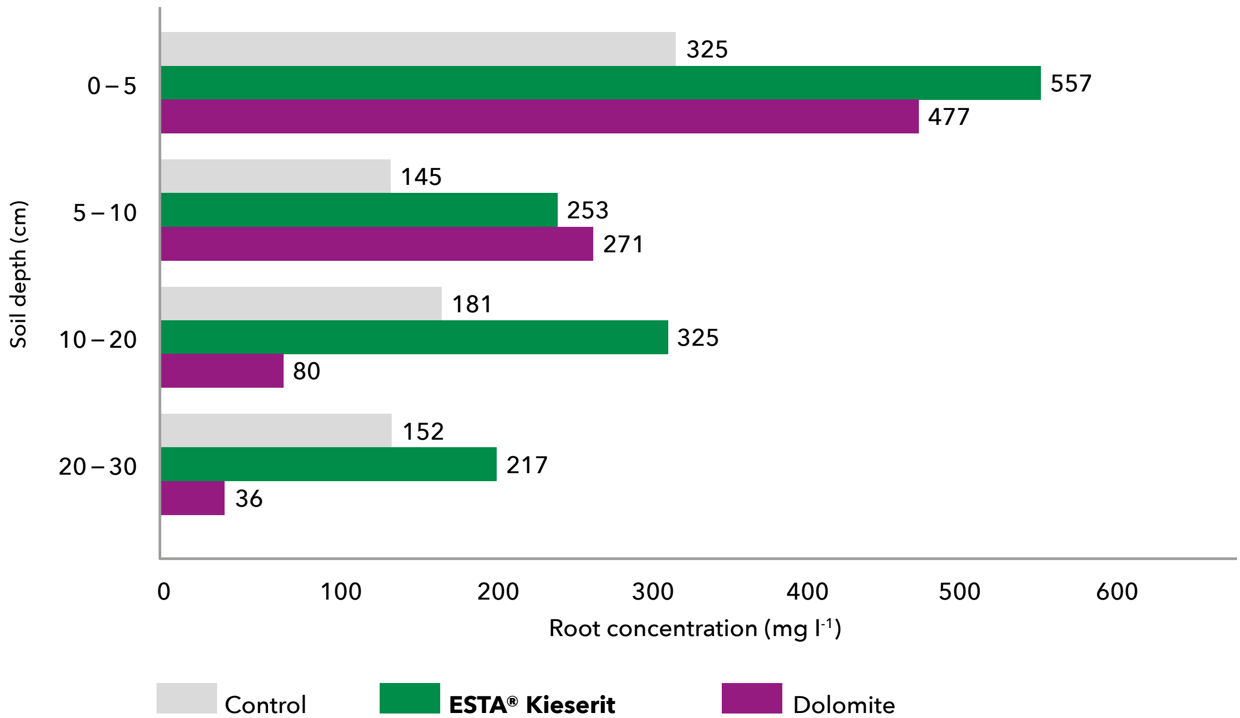


Soil: Sedu Soils, typic Sulfaquept	BA	= 8.0 kg palm^{-1} bunch ash
	ESTA® Kieserit	= 3.0 kg palm^{-1} **ESTA® Kieserit**
	GML	= 5.0 kg palm^{-1} dolomite

Source: Singh (1989) PORIM International Palm Oil Development Conference, Proceedings 383-394

The effect that Mg from ESTA Kieserit penetrated deeper into the soil than Mg from dolomite (after a surface application) has a significant effect on root growth. The effect of an improved root growth was studied with forest trees on an acid soil in Germany. The observation of this experiment was that dolomite owing to its slow release of magnesium only benefited the roots in the top 10 cm whereas in the lower soil horizon root growth was even reduced after dolomite application compared to the control. The explanation of this effect may be related to the promotion of root growth in the more favourable environment with higher Mg and Ca availability, whereas penetration into the acid subsoil did not occur. On the other hand, Kieserite, due to its pH-independent solubility pH and deeper penetration into the soil profile, benefited also the roots at the larger soil depth. This is an important feature of soluble magnesium in form of ESTA Kieserit, improving root growth to enhance uptake of N, P, K and Mg also from the subsoil.

Distribution of feeder roots (<2 mm) of Norway spruce on an acid forest soil (pH 3.7) as affected by Mg supply



Source: Schaaf and Zech (1991) Allgemeine Forstzeitschrift 46, 766-768

Magnesium and oil yield

The importance of Mg for oil production is evident from the fact that it promotes oil formation. According, Corley et al. (2015), there is a strong quadratic relationship between the oil/bunch (O/B) ratio and leaf exchangeable Mg expressed as a percentage of total leaf cations (TLC). Trials in Malaysia indicated an optimal O/B ratio when leaf Mg is 30 – 35% of total leaf cations (Foster et al., 1987).

Magnesium in form of ESTA Kieserit positively influenced oil production. Tayeb Dolmat (2005) reported results of a field trial carried out on a Serdang Series soil. Application of ESTA Kieserit substantially increased the oil-to-bunch ratio (oil content) as illustrated in the table below. An extra 0.57 t oil ha^{-1} yr^{-1} was obtained through consistent application of 1.5 kg ESTA Kieserit $palm^{-1}$ yr^{-1}. It is suggested that this beneficial effect of Mg is attributed to its function in assimilate translocation from source leaves to fruit bunches, as described earlier. As K was supplied as SOP throughout a sulphur effect can be excluded and the positive effect of ESTA Kieserit is attributed to Mg only.

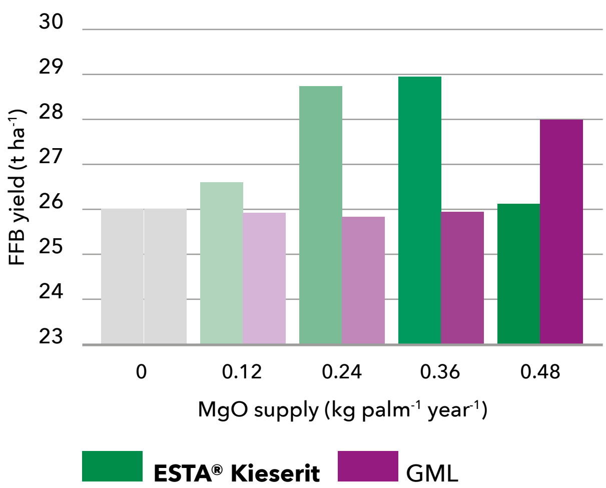
Effect of ESTA® Kieserit on palm oil yield and oil/bunch ratio in a five years trial on Serdang Series soil in Malaysia

Treatment	Oil/bunch**	Oil yield (t ha^{-1})**
NPK*	27.90	6.00
NPK* +1.5 kg ESTA® Kieserit	28.49	6.54
NPK* +3.0 kg ESTA® Kieserit	29.27	6.18

* K applied as potassium sulphate
**Average of 5 years
Source: Tayeb Dolmat, 2005

Although different sources may supply Mg, differences in solubility and nutrient release pattern, e.g. between ESTA Kieserit ($MgSO_4 \cdot H_2O$) and dolomitic limestone (Ca-Mg carbonates) are important with respect to oil formation and yield. Experiments on a Rengan series soil clearly show that due to the low solubility of Mg-carbonates a much lower rate of ESTA Kieserit already satisfies the Mg requirement. A much higher rate of GML (ground magnesium limestone) is required because of its lower efficacy. Such high rates may eventually lead to impaired K nutrition because of antagonism by high Ca supply (Fairhurst, 1998). As Mg constitutes typically a very low percentage of the total fertiliser cost, the cost savings in using a less effective Mg source is similarly insignificant, but may affect yield significantly.

Mean FFB yield on a Rengam series soil as affected by rate and form of Mg



GML: ground magnesium limestone
(average of 7 years)

Source: Mohd Hussin et al. (1998)
Kemajuan Penyelidikan Bil. 31, 29-34

The importance of sulphur in oil palm

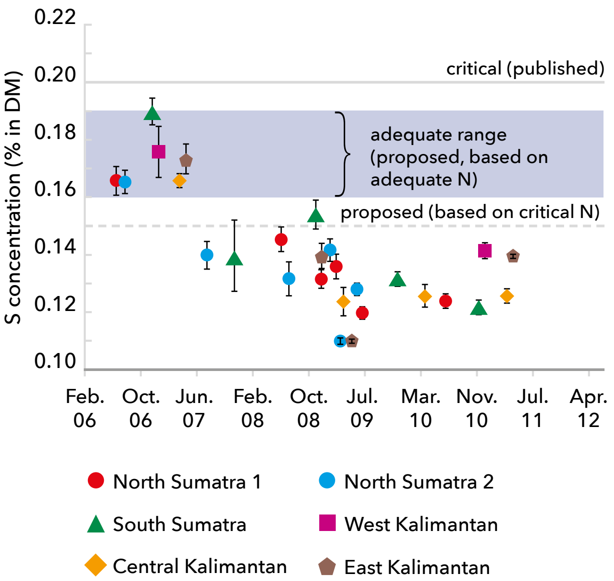
Just as magnesium, sulphur belongs to the six macronutrients and is usually taken up by plants in the same order of magnitude as phosphorus and magnesium. The total sulphur concentration of most crops varies between 0.2% and 0.5% of the dry matter. Sulphur is involved in numerous metabolic processes of the plant, e.g. the photosynthesis, sugar and starch, amino acid and protein formation as well as oil and fat synthesis.

In all productive soils, about 95 – 90 % of the sulphur is stored in the organic matter. In the soil solution, SO_4^{2-}, is highly mobile and weakly adsorbed onto the surface of soil particles. It is vulnerable to displacement by strongly adsorbed ions such as phosphate and leaching from the soil layer explored by plant roots. The interactions between the environment, microorganisms and plant uptake can cause very large seasonal fluctuations in the plant available SO_4^{2-} levels. Consequently, the rates of the biological mineralization and fixation processes are major determinants in the supply of SO_4^{2-} to plants.

Sulphur is taken up by palm roots as SO_4^{2-} ion from the soil solution which is merely transported by mass flow to the root surface. Another source of sulphur are stemming from atmospheric depositions of SO_2 and other S compounds that, particularly in industrial countries, served for many years as an important S source, but also represented a strong environmental burden. Therefore, air pollution control technology has been employed so that this source of sulphur has been drastically reduced and S deficiency in agriculture has become widespread.

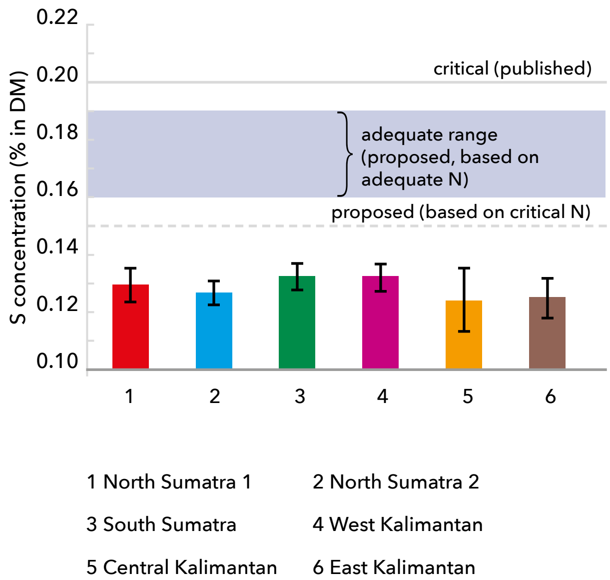
Sulphur deficiency symptoms are similar with those of nitrogen although the former tend to be more prominent in the youngest part of a plant, while the latter is most strongly seen on older leaves. In the beginning the pinnae are pale and small and under acute deficiency they show small brown necrotic spots. Sulphur deficiency symptoms are as yet rarely observed in oil palm, but recent measurements of leaf nutrient status by the International Plant Nutrition Institute (IPNI) strongly suggest that large areas of oil palm are grown with inadequate S supply. Not only did the results indicate a declining S status, but also suggest that the phenomenon is widespread. This conclusion is valid irrespective of whether data are referenced to the published critical S concentration of 0.2%, or to a lower, refined critical S concentration (see diagrams below).

Time course of the S concentration of frond #17 at selected sites (means ± SE, n = 5)



Source: Gerendás et al. (2011), Tropentag 2011, Proceedings (http://www.tropentag.de)

Leaf S concentration of frond #17 in 2009 (means ± SE, n = 5)



Source: Gerendás et al. (2011), Tropentag 2011, Proceedings (http://www.tropentag.de)

The importance of boron in oil palm

Boron is the most important micronutrient in oil palm nutrition. Mature palms contain up to 658 g B ha^{-1}, and deficiency symptoms are frequently observed in above ground biomass. The annual B requirement of oil palm increases quickly from the second year of planting, reaching a maximum of 343 g B ha^{-1} yr^{-1} in the sixth year. The annual B requirement then declines to about 220 g B ha^{-1} yr^{-1} in the eight year before stabilizing at 198 g B ha^{-1} yr^{-1} from the twelve year (Goh et al., 2007).

Boron exists in four forms in the soil:

- bound in rocks and minerals
- adsorbed on surfaces of clays
- combined with organic matter
- as free non-ionized boric acid (H_3BO_3) in the soil solution, forming $B(OH)_4$ at pH>7

Sorption of free boric acid to clay minerals is generally low, resulting in substantial losses by leaching in sandy, acidic soils. Soils developed from marine sediments and those located in coastal areas are usually rich in B due to the B richness of the ocean water.

The general understanding of the boron uptake by plants appears to be still incomplete. The undissociated boric acid may be the most effective form, which is transported in the soil solution merely by mass flow. Plant uptake of boron is a passive process where H_3BO_3 moves in response to its concentration gradient in the xylem to sites of greatest water loss.

Boron is phloem-immobile in oil palm. It follows that the principle of sustained B availability in the soil applies, and therefore more frequent applications at shorter intervals should be adopted when using water-soluble B sources. This is practical only when boron is incorporated into macro nutrient fertilisers like Korn-Kali+B. Otherwise, the use of B sources with prolonged availability ('slow release') is desirable.

The primary role of B is in cell wall biosynthesis and structure, and numerous physiological effects observed under B deficiency have been interpreted as secondary effects (cascade effects). Boron is also essential for pollen tube growth and pollen function and if inadequately supplied leads to abortion of fruitlets. It is also required for legume-rhizobium symbiosis and therefore for the successful establishment of legume cover crops.

Boron deficiency is the most widespread micronutrient disorder in oil palm and often occurs on sites where B could be leached out easily (high rainfall, in sandy soils and in peat soils). Boron deficiency symptoms are quite specific, and well known as „crinkle leaf", „fishbone leaf", „hook leaf" and „little leaf".

A typical B-deficiency symptom: crinkle leaf on oil palm pinneae

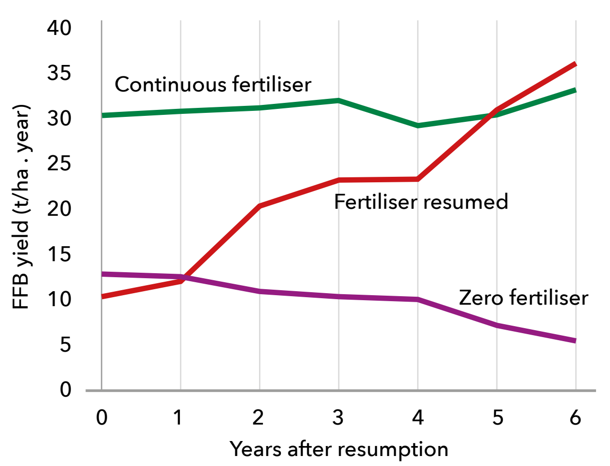
B deficiency, from left to right: blind leaf, hook leaf, hook leaf.

Fertiliser management in oil palm

Oil palm belongs to the ten most heavily fertilised crops worldwide and therefore, the fertiliser costs are considerable. At times of a high oil price, the fertiliser management seems to be easier because of a higher profit whereas at times of a low oil price the quantity of fertiliser used is reduced.

Drastic fertiliser reductions during low CPO price periods may have dramatic consequences in yield performance for the next 4 years (see chart below). This is because each bunch harvested has a history of formation of about 3 years! A constant fertiliser application is essential to supply the oil palm continuously with nutrients to guarantee good yield performance over years.

Yields following resumption of fertiliser application in unfertilised control plots, compared to zero an continuous fertiliser (Corley, R. H. V. The Oil Palm, 2015; from data of Sidhu et al., 2009)



Several studies have shown that after fertiliser application has been suspended for several years it takes about 5 years to restore the full yield potential, when CPO prices may long have recovered. In other words, the short-term savings by suspending fertiliser application should be assessed in relation to the long term yield gap this approach induces. The K+S fertilisers (ESTA Kieserit, Korn-Kali, Korn-Kali+B) support the oil palm industry with high-quality fertiliser to ensure high yield performance. K+S fertilisers are established in the oil palm industry worldwide and are part of the straight fertiliser programme on oil palm plantations.

Innovative products like Korn-Kali+B (a combination of MOP, ESTA Kieserit and Borax) allow optimizing the fertiliser management with the following options:

Option 1 – reducing the number of fertiliser application rounds:

The combined application of K, Mg, S, and B allows reducing the number of fertiliser application rounds, as can be seen in the example shown in the table below. This not only reduces labour costs compared to the traditional manuring programmes based on straight fertilisers. It also requires less supervision in the field, and ensures a more uniform distribution of all nutrients, particularly boron, that is required in small amounts (e.g. 50 g B per palm and year). The application of 5 to 6 kg Korn-Kali+B per palm split in two or three applications will satisfy the annual requirements of K, Mg, S, and B in mature oil palms.

Common practice	Korn-Kali+B
2 applications N (ur/ac/as)	2 applications N (ur/ac/as)
1 application P (RP)	1 application P (RP)
2 applications K (MOP)	2 applications K/Mg/S/B as Korn-Kali+B
1 application Mg (Kies.)	
1 application B (Borax)	
Total: 7 applications	Total: 5 rounds

Option 2 – keeping the number of fertiliser application rounds, reducing potential leaching losses:

In sandy soils nutrient losses by leaching are considerable, and this not only includes N (as nitrate), but also ammonium, potassium, magnesium, sulphur and boron. The use of Korn-Kali+B instead of separate applications of MOP, kieserite and borax allows a more continuous, more frequent provision of all its nutrients over time, without increasing the number of rounds. This particularly applies to sandy areas in high-rainfall regions. The table below shows an example of Korn-Kali+B application in that situation.

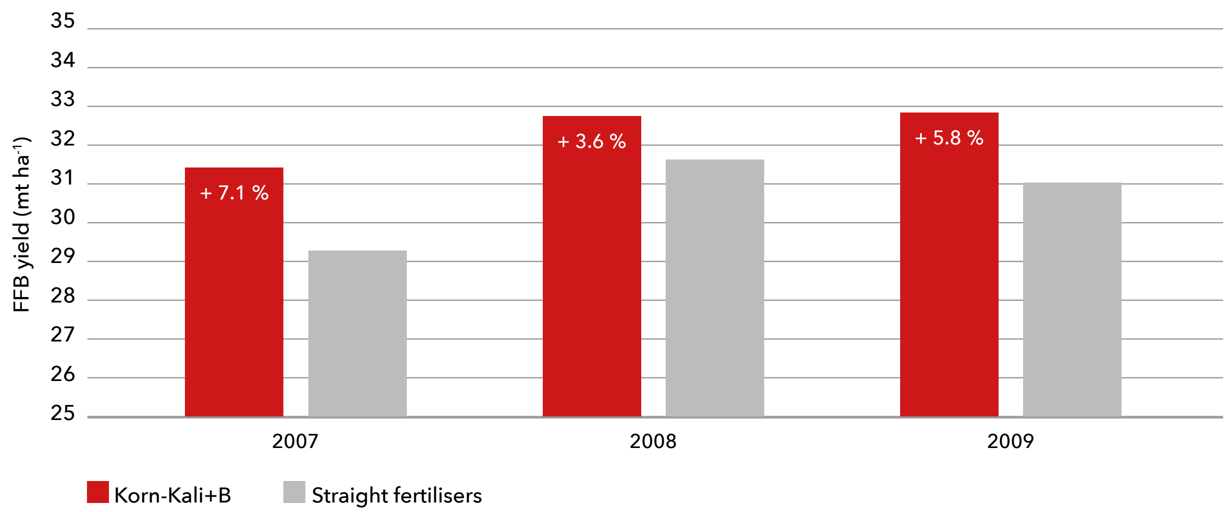
Common practice	Korn-Kali+B
2 applications N (ur/ac/as)	2 applications N (ur/ac/as)
1 application P (RP)	1 application P (RP)
2 applications K (MOP)	4 applications K/Mg/S/B as Korn-Kali+B
1 application Mg (Kies.)	
1 application B (Borax)	
Total: 7 applications	Total: 7 rounds

Option 3 – replacing straight fertilisers by good quality bulk blends with Korn-Kali®+B:

Due to its uniform granulometry, Korn-Kali+B provides an ideal component for bulk blending with granular sources of N and P. High quality N-K-Mg-S-B or even N-P-K-Mg-S-B bulk blended fertilisers can be produced at lower cost than compound fertiliser with greater flexibility in the formulation.

An experiment comparing application of Korn-Kali+B against the straight fertilisers was carried out for three consecutive years and the results are depicted in figure below. A yield increase of 3.6 to 7.1% as compared to the control treatment (straight fertilisers) was observed.

Yield response of oil palm to Korn-Kali®+B vs. straight fertilisers. The experiment involved three pairs of plots within three different blocks. (Gerendas and Heng, 2010)



High FFB yield with K+S products.

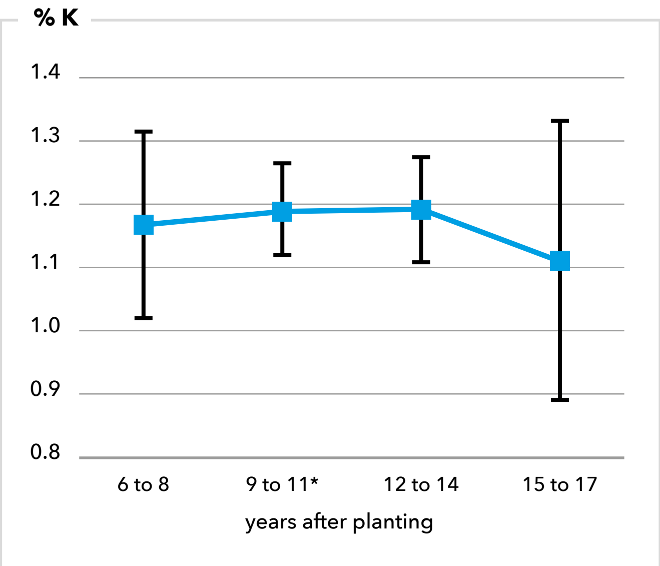
Nutrient interactions

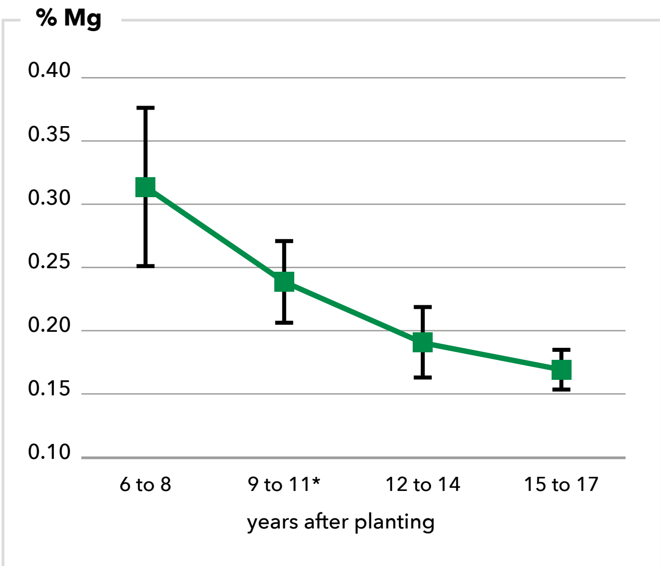
Nutrient interactions are frequently observed in most crops and may be categorised as follows:

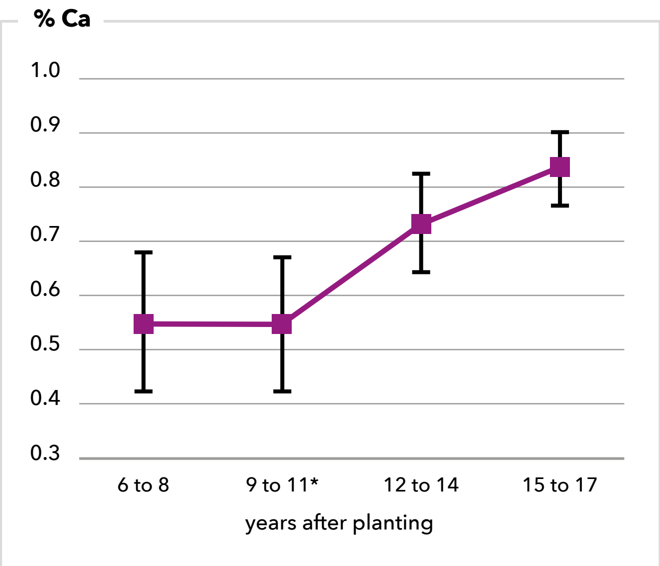
According to the nature of the interaction into
- **Synergisms**
- **Antagonisms**

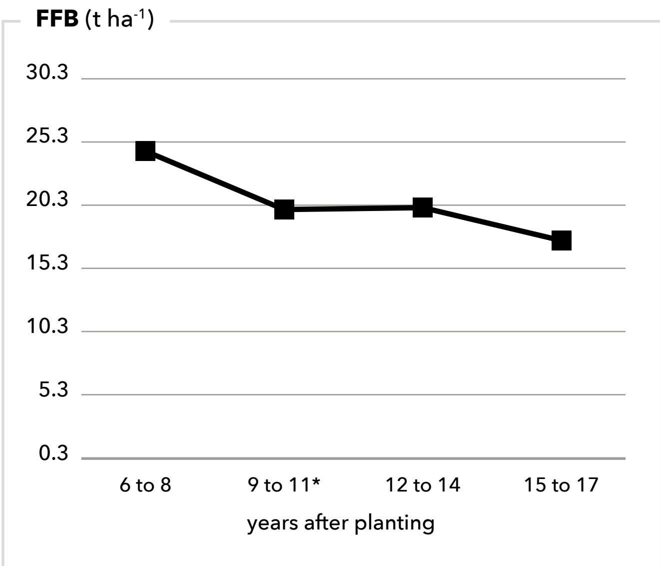
According to the site of the interaction into
- **Uptake interactions**
- **Physiological interactions**

Uptake antagonisms are often observed between nutrient ions of the same charge, e.g. K^+ vs. Mg^{2+}, Ca^{2+} vs. Mg^{2+}, nitrate vs. chloride. This results in the well-known K-induced Mg deficiency discussed before, and the yield depression by excessive Ca supply when replacing dolomite for ESTA Kieserit shown below.









* Onset of GML use after 11th year

Source: Ng et al. (1995) 24th Colloquium of the IPI, Chiangmai, Thailand, 235-244

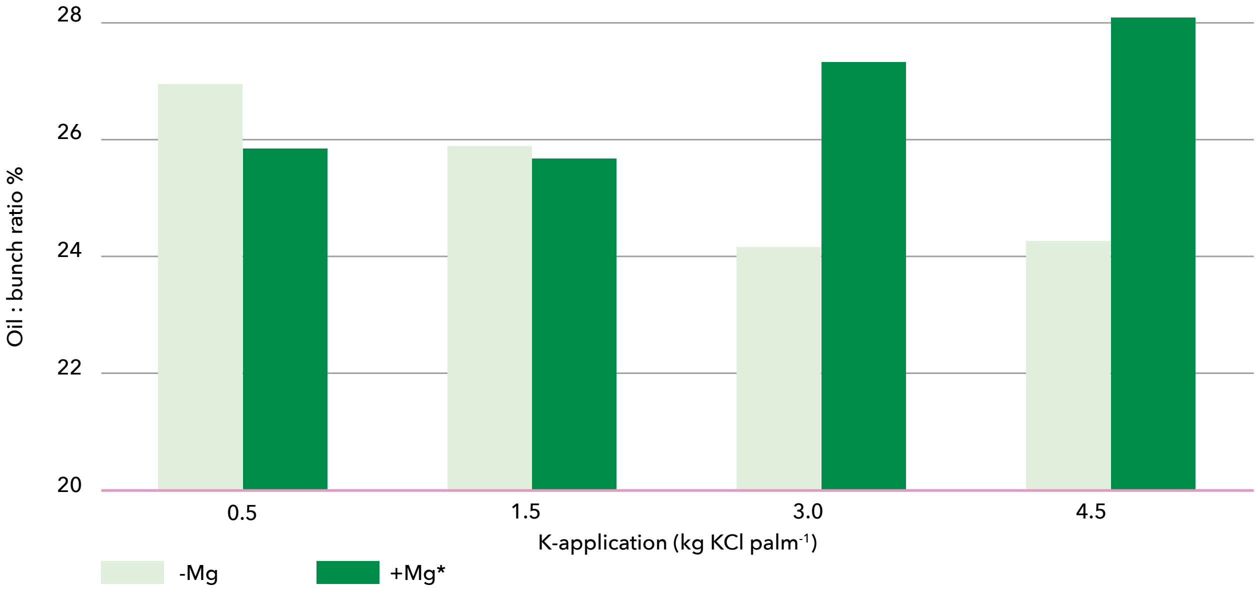
Physiological interactions are caused by synergistic or antagonistic functions of nutrients. A typical example is the positive N × S interaction observed in many crops, as both nutrients are essentially required for protein synthesis.

A very important example regarding the yield formation in oil palm relates to the complementary function of K and Mg in photosynthesis and assimilate partitioning (sugar translocation) illustrated before. This, together with the significant uptake antagonism, results in a strong synergism of K and concomitant Mg supply with respect to yield formation. In other words the full yield response to K supply requires adequate provision of Mg.

Another important nutrient antagonism is the K × N interaction. This results in typical symptoms called 'white strip' when N : K ratios exceed 2.5 and is illustrated on page 17. White stripe is a complex physiological disorder that is common in young, vigorously growing palms. It is caused by a nutrient imbalance due to excess N and insufficient K and B, which leads to the development of long and soft pinnae. White stripe symptoms in combination with confluent orange spotting symptoms may be found when N and K are imbalanced, and the status of B in the leaf is low (Uexküll and Fairhurst, 1999)

Finally, the low boron levels induced by excessive K supply are also well-described in oil palm (e.g. Fairhurst and Härdter, 2003). This supports the recommendation to provide both nutrients simultaneously in a well-balanced fashion as provided by Korn-Kali+B.

Effect of K x Mg interaction on the oil : bunch ratio



* + Mg = 0.5 kg Kieserite per palm
Source: Ochs and Ollganier (1977) Proceedings of the 13th Colloquium of the IPI; York, UK, 269-293

Korn-Kali®

The All-rounder – Extremely Versatile

Korn-Kali®

EC FERTILISER
Potassium chloride with magnesium

40 % K_2O	water-soluble potassium oxide
6 % MgO	water-soluble magnesium oxide
5 % S	water-soluble sulphur

Korn-Kali®

- multinutrient fertiliser based on potassium choride, magnesium sulphate (ESTA Kieserit), produced by compaction.
- contains all nutrients in fully water-soluble forms, immediately available to the plant, irrespective of soil pH.
- has a narrow particle size spectrum ensuring a high spreading quality and enabling a constant distribution at large spreading widths.
- is a valuable partner especially in bulk blending.

Korn-Kali® +B

The Multi-talent -
with the extra boron

Korn-Kali® +B

EC FERTILISER
Potassium chloride with magnesium

40 % K_2O	water-soluble potassium oxide
6 % MgO	water-soluble magnesium oxide
5 % SO_2	water-soluble sulphur
0,25 % B	water-soluble boron

Korn-Kali®+B

- High quality multinutrient fertiliser based on potassium chloride, magnesium sulphate (ESTA Kieserit) and sodium borate, produced by compaction.
- All nutrients present in the water-soluble form, immediately available to the plant, irrespective of soil pH.
- Ensure better distribution of Boron, leading to greater efficiency in the nutrient use when compared with application of straight Boron sources.
- Granular product with excellent spreading characteristics.
- Particle size distribution of Korn-Kali+B is ideal for bulk blending. Is it perfect way to introduce boron to bulk blends avoiding segregation problems.

ESTA® Kieserit

Fine and Granulated – Magnesium-Sulphur-Power

ESTA® Kieserit

EC FERTILISER
Kieserit fine 26+21

26 % MgO water-soluble magnesium oxide
21 % S water-soluble sulphur

Kieserit gran. 25+20

25 % MgO water-soluble magnesium oxide
20 % S water-soluble sulphur

ESTA® Kieserit fine and gran.

- magnesium sulphate fertilisers based on the naturally occurring mineral kieserite ($MgSO_4 \cdot H_2O$), which is extracted through the environment-friendly electrostatic separation process (ESTA) from salt deposits in Germany.
- contains the nutrients magnesium and sulphur in fully water soluble form, immediately available to plants regardless of soil pH.
- used in oil palm production worldwide as the most efficient magnesium fertiliser for this crop
- the natural crystalline structure of ESTA Kieserit makes its dissolution in water slower than other kinds of magnesium-sulphates, that allows lower losses of Mg and S by leaching and higher nutrient use efficiency.
- is allowed for the use in organic agriculture according EC regulations (EU) 2018/848 and (EC) No 889/2008.
- ESTA Kieserit gran. has an excellent particle size distribution, granule hardness and spreading properties and it can be applied precisely and properly with all modern fertiliser spreaders.
- ESTA Kieserit gran. is well-suited for use in fertiliser blends and straight application while ESTA Kieserit fine can be used for compound NPK production or straight application.

60er Kali®

Potassium Chloride – Fine and Granulated

60er Kali® fine and gran.

EC FERTILISER
Potassium chloride

60 % K_2O water-soluble potassium oxide

60er Kali® fine

- highly concentrated single-nutrient fertiliser containing 60 % K_2O as potassium chloride.
- crystalline product ideally suited to the manufacture of compound fertilisers.
- universal potash fertiliser suitable for all chloride tolerant crops and is applicable for all types of soil.

60er Kali® gran.

- highly concentrated single-nutrient fertiliser containing 60 % K_2O as potassium chloride.
- universal potash fertiliser suitable for all chloride tolerant crops and is suitable for use on all soil types.
- 60er Kali gran. has an ideal particle size distribution and is highly suitable both for use as a straight fertiliser or for bulk blending.
- 60er Kali gran. has a high spreading quality and can be applied with all modern fertiliser spreaders.

KALI-TOOLBOX
Detect Deficiencies – Calculate Requirements

Every plant has a specific nutritional requirement to achieve the highest possible yield. Take advantage of important information on mineral fertilisation using the **KALI-TOOLBOX App**.

Identify Deficiencies

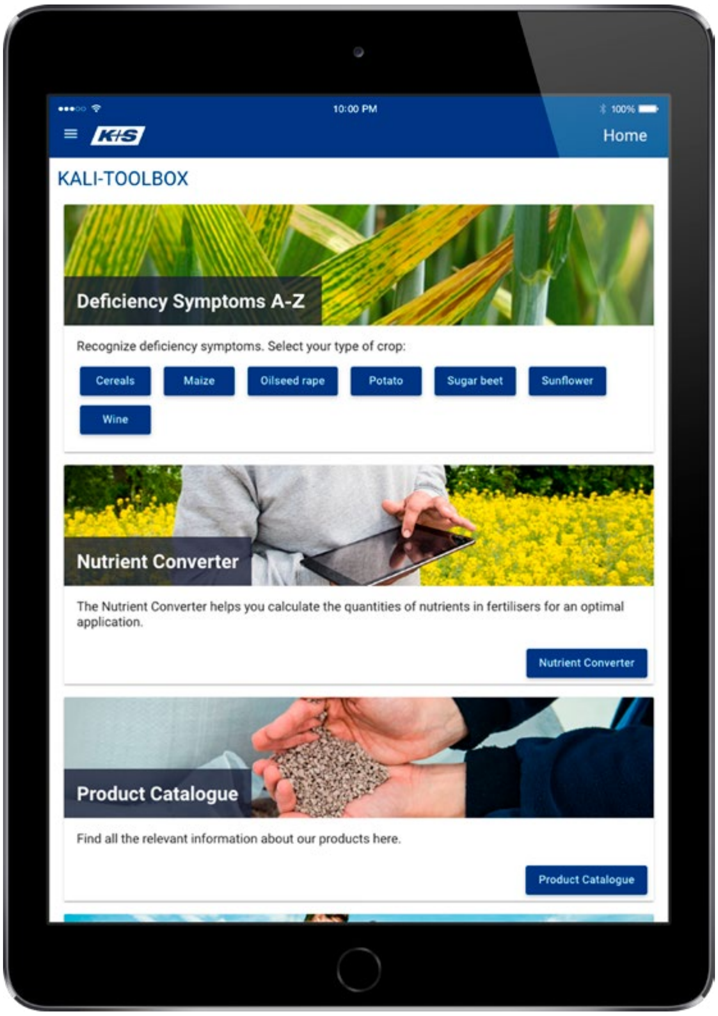
With the help of our **Deficiency Symptoms A – Z**, you can directly distinguish plant nutrient deficiency symptoms in the field. As soon as you have identified the problem, K+S products with their high nutrient availability will fix it immediately.

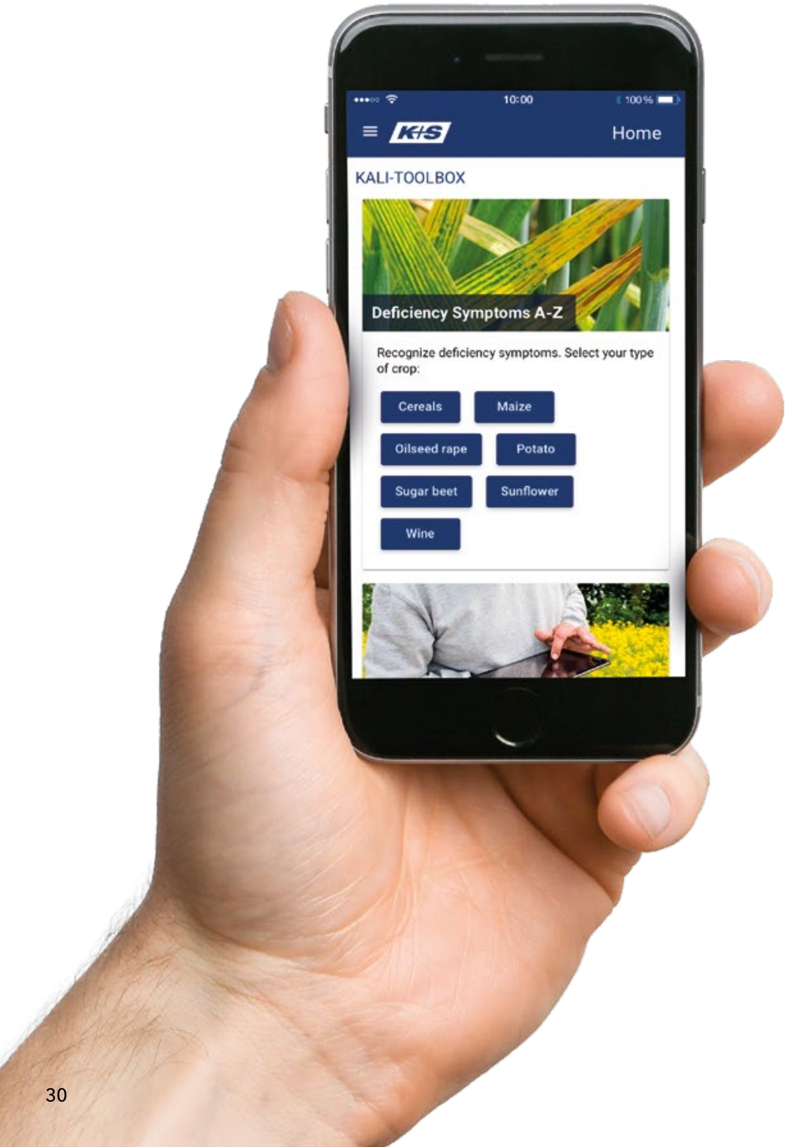
Convert nutrient forms

The **Nutrient Converter** helps you to keep an overview when nutrients are expressed in different chemical forms.

Both applications are available in our KALI-TOOLBOX App. The **deficiency symptoms A – Z** can be used by mobile devices on the field or at home on th e PC: **www.kpluss.com**.

K+S is committed to support its customers with all important and relative information about optimal care of their cultivations.





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www.kpluss.com

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Strong Know-how:
Agronomy & Advisory of K+S

K+S supports growers all over the world by providing expert knowledge on fertilisation, in order to achieve high yields and excellent quality, and to maintain these even under adverse climatic conditions. The foundation of the advice provided is our extensive research activity.

For more than 100 years, K+S has been involved in agricultural research, always looking for solutions to agronomical challenges, such as how to increase productivity, how to improve soil fertility and how to efficiently use resources. To reinforce its activities in this field, K+S has entered a Private Public Partnership with the Georg-August-University of Göttingen and formed the Institute of Applied Plant Nutrition (IAPN). In this partnership relevant subjects on current crop nutrition issues are studied, results and knowledge gained are shared with all stake holders, especially advisors and the growers.

The advisory service of K+S is the link between science and agricultural practice, taking problems from the fields to the scientist and into the laboratories and returning research findings in form of practical advices back to the growers. This generation and sharing of knowledge helps growers around the world to adopt best nutrient management practices and thereby improve yields and quality of their harvests. Our commitment and our expertise represent significant contributions to securing global food supply and to protect the livelihoods of farmers.

Benefit from our expertise in agronomy and plant nutrition and get more information on www.kpluss.com. Here you will find useful technical information, brochures and also our app, KALI-TOOLBOX.

For personal advice, call our Agronomy & Advisory department in Kassel that might as well provide local contacts.

How to contact us

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