CropKit

Specialty Plant Nutrition Management Guide
Tomato

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Foreword

SQM is a major supplier of specialty plant nutrition and related services to distributors and growers around the world.

As part of its commitment to the agricultural community, the company has developed a comprehensive series of **Crop Kits**. Each Crop Kit consists of a Specialty Plant Nutrition Management Guide, a PowerPoint presentation and a CD with relevant pictures.

These guides compile the results of yearlong research and development activities, as well as the practical experiences of the company's specialists from around the world, in order to provide comprehensive **Specialty Plant Nutrition Management Information** to SQM's distributors, agronomists, growers and farmers.

This **Tomato Nutrition Management Guide** summarizes the main market requirements and the nutrient management needed to produce high yields of top quality fresh and processing tomatoes.

More information is available through SQM agronomists or SQM's alliance partner YARA. SQM recognizes that there is no universal blueprint for tomato production – hence no detailed plant nutrition programme is included in this guide. However, by working together with your local agronomist you can be sure to achieve excellent crop performance. For area specific programmes consult your local SQM distributor or agronomist.

This guide, which has been developed with the full support of the world's leading specialty plant nutrition specialists, is part of a range of the most comprehensive **Specialty Plant Nutrition Management Guides** available.

This particular Tomato Nutritional Guide has been produced in close co-operation with our alliance partner YARA.

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Introduction

The target of this Tomato Nutrition Management Guide is to provide comprehensive Tomato Nutrition Management information to SQM's business partners such as the tomato industry, distributors, agronomists and growers.

Chapter 1 describes how nutrition management in tomato can optimize plant performance (yield, quality) thus generating a maximum financial income for the grower.

A general crop description is given in Chapter 2, followed by an overview of the role of nutrients with emphasis on potassium and calcium in Chapter 3.

Chapter 4 features guideline data to facilitate nutrient management. A photo gallery of visual nutrient deficiency and excess imbalances is presented in Chapter 5. Specialty Plant Nutrition (SPN) product characteristics regarding imbalance rectification effectiveness (Chapter 6) form the base for plant nutrition practices and effective programmes (Chapter 7). A scientific back-up with research results demonstrating the need for balance is given in Chapter 8.

Chapter 9 summarizes the economic results of SQM's demonstration fields, whereby a traditional tomato nutrition programme was compared to a balanced nutrition programme. The demos were carried out both in greenhouse grown tomato as in open field grown tomato for the fresh market and for the industry.

Chapter 10 features a literature overview.

Note to the reader.

In this booklet a period (.) has been used as thousand denominator; a comma (,) as decimal point. The number 1.500 should therefore be read as "one thousand five hundred". The number 1,5 should therefore be read as "one and a half".

1 Crop Nutritional Status as it Relates to Performance

This chapter describes how tomato nutrition management can optimize the performance of the plants (yield, quality), thus generating a maximum financial income for the grower.

Balanced plant nutrition means offering all the essential nutrients in well balanced proportions and in the correct amounts, following the growth curve of the plant in order to optimize its potential. Plant performance, in terms of revenue generation, is fundamentally related to plant health, whereby the balance of the nutrient levels in the various tissues in each growth stage is a determinative factor for that health. In case of imbalance, a reduction in performance will occur, both with respect to deficiency (deficiency imbalance) and excess (excess imbalance).

As a result of the general removal of mineral nutrients from the production site, via harvest, leaching and water runoff, nutrient replenishment is generally required. Thus, nutritional status management generally entails the supply of mineral nutrients in correct proportions and at opportune times.

An ideal fertilization programme shall take into account a perfect nutritional-status balance, both contents wise and time wise. Guideline information, procured from focused research, can be used to facilitate nutrient-balance management. This information can take the form of leaf norms, for leaves sampled at a specific stage and adopting a particular method of sampling. Nutrient incorporation, in quantitative and relative terms, in the various plant parts as growth and development occurs (nutrient uptake curves) can also serve as valuable information to maintain balance. Soil attribute and soil nutritional status norms are also useful. The provision of guidance data should be such that its procurement is from superior performing plants.

Fertilizers, whether applied on the aboveground parts or to the soil, should be viewed as nutritional-balance management tools. Fertilization products can be expected to differ vastly in their ability to maintain nutrient status balance, whereby of course some are more effective than others.

Plant revenue generation relates both to yield and quality. Quality is dictated by the target market, relating to the attributes required by the buyer. (Each nutritional balance has a quality/yield (revenue) ratio in quantitative terms). Guideline data should therefore be procured from superior performing plants, in terms of revenue generation, revenue being a function of target market requirement and yield.

2 Tomato Crop Description

This chapter describes the tomato crop with regard to: botanical family and varieties, world production and crop statistics, climate (temperature, light), water and soil, organic matter and manure, salinity, phenology, uniform maturity, physiological disorders, pests and diseases, and quality parameters for the fresh market and the industry. This information should lead to an optimal understanding of the tomato crop in general and will help to make proper nutrition management decisions.

2.1 Botanical Name and Varieties

Tomato *(Lycopersicon esculentum Mill.)* belongs to the family of *Solanaceae*.

Tomato is sold as a single tomato or as a truss tomato. Tomato varies in shape: cherry, cocktail, plum, round and beef tomato are commonly found on the market (Figure 1, 2, 3, 4, 5 and 6).

Figure 1. *Loose beef tomato Geronimo - De Ruiter Seeds.*

Figure 2. *Loose medium sized tomato Toronto - De Ruiter Seeds.*

Figure 3. *Cherry loose tomato Favorita - De Ruiter Seeds.*

Figure 4. *Cocktail plum tomato Flavorino - De Ruiter Seeds.*

Figure 5. *Cocktail cluster tomato Picolino - De Ruiter Seeds.*

Figure 6. *Yellow truss tomato Locarno - De Ruiter Seeds.*

Tomatoes vary in size from cherry and plum types with two divisions of the ovary (locules), to large beef types that have six or more locules (Figure 7).

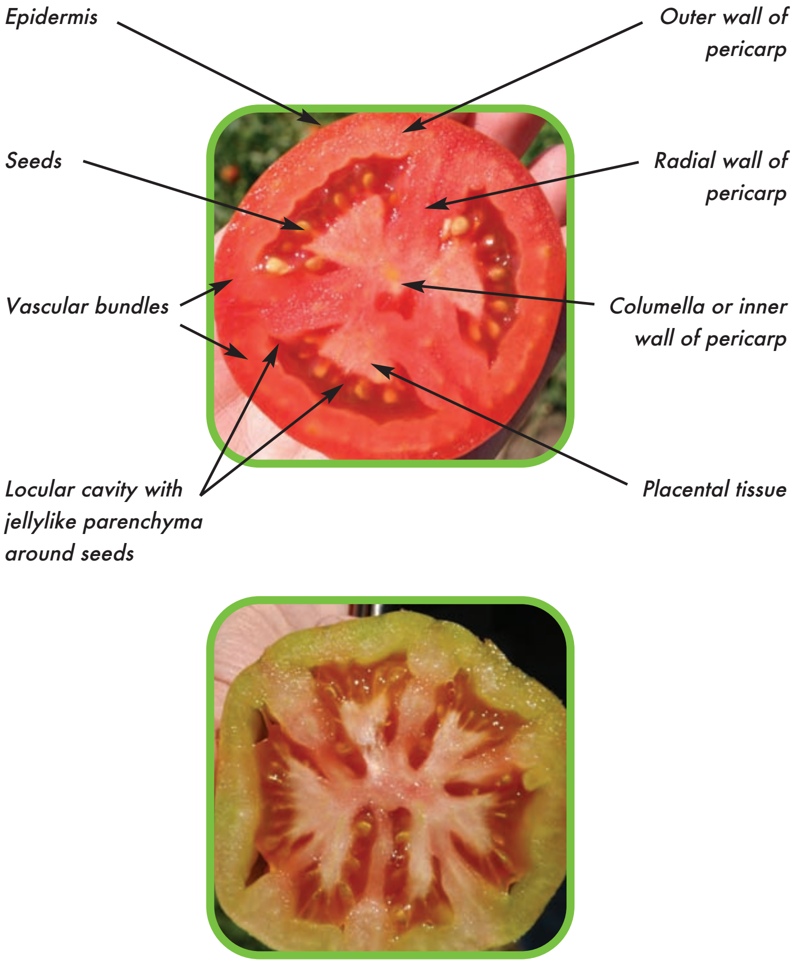


Figure 7. *Tomato cross-sections.*
Top: tomato with 3 cross-sections.
Bottom: tomato with 6 cross-sections.

2.2 Global Production

About 75% of the global tomato production is used for fresh consumption, while 25% is used for industrial purposes (concentrated paste, ketchup, sauces, peeled and diced tomato, etc.).

Five countries account for 56% of the world production (Table 1) and 55% of the harvested area (Table 2): China, India, Turkey, Egypt and the USA. China produces 26% of the world's volume of tomato for fresh consumption, the USA (mainly California) produce 35% of the world's volume of tomato for the industry (Table 3).

Table 1. *Overview of the major tomato producing countries/areas, their production (x million tonne) and their relative market share in the global tomato production (%).*

Ranking	Country/Area	Production (x million t)	MS (%)
1	China	30,1	26
2	United States of America	12,4	11
3	Turkey	8,0	7
4	India	7,6	7
5	Egypt	6,8	6
	Subtotal 1-5	**64,9**	**56**
	Rest of the world	50,0	44
	Total World	**114,9**	**100**

Source: FAOSTAT data, 2004

Table 2. *Overview of the major tomato producing countries, their harvested area (x 1.000 ha) and their relative market share in world harvested area (%).*

Ranking	Country/Area	Area Harvested (x 1.000 ha)	MS (%)
1	China	1.255	29
2	India	540	13
3	Turkey	220	5
4	Egypt	191	4
5	United States of America	176	4
	Subtotal 1-5	**2.382**	**55**
	Rest of the world	1.925	45
	Total World	**4.307**	**100**

Source: FAOSTAT data, 2004

Table 3. *Overview of the major producing countries of tomato for industrial purposes, their volumes (x million tonne) and their relative market share in world production of tomato for industrial purposes (%).*

Ranking	Country/Area	Production for the Industry (x million t)	MS (%)
1	USA	10,0	35
	California	9,4	33
	Other USA	0,6	2
2	Italy	4,8	17
	North Italy 50% paste	2,4	8
	South Italy 50% peeled	2,4	8
3	Spain	1,4	5
4	Turkey	1,3	5
5	China	1,2	4
	Subtotal 1-5	**18,7**	**65**
	Rest of the world	10,1	35
	Total World	**28,8**	**100**

Source: Based on 2001/2002 AMITON figures (averages of 1999-2001) + 2003 update report AMITON.

In Table 4 the production of tomato per growing system and typical range of yield are summarized.

Table 4. *Type of growing system and typical range of yield (tonne/ha) that is obtained under such a specific growing system.*

Growing system	Yield (t/ha)
Average world (FAOSTAT data, 2004)	27
Open field rain fed	50-70
Open field drip/fertigation	80-150
Greenhouse non heated (9 month cycle)	180-220
Modern greenhouse Netherlands year round	550-700

2.3 Climate

2.3.1 Temperature

Tomato is a warm-season crop. The ideal temperature ranges between 18°C and 27°C. For this reason most outdoor crops are grown in temperate climates, between the 30th and 40th parallels in both the northern and the southern hemisphere.

At temperatures below 10°C flower formation is negatively affected, while night frost will result in serious crop damage (Figure 8).

Figure 8. *Night frost damage.*

Temperatures above 35°C in combination with low humidity will lead to flower abortion, while pollen viability is strongly reduced by drying out. A balanced plant nutrition programme instead of an unbalanced one has proven to reduce the loss of flower clusters under these high temperature conditions.

2.3.2 Light

The amount of global radiation determines the amount of sugars produced in the leaves during the photosynthesis. The higher the amount of sugars produced, the more fruits a plant can support, thus the higher the tomato yield can be.

Tomato is sensitive to low light conditions, as the crop requires a minimum of 6 hours per day of direct sunlight in order to flower. However, as day length is not a critical factor in producing tomatoes, greenhouses occur across a very wide range of latitudes.

If the intensity of solar radiation is too high, cracking, sunscald and uneven colouration at maturity can result. Sufficient foliage will help to prevent sunburn. Adequate potassium and calcium levels will maintain cell turgor and cell strength, thus making the plant cell more resistant to water loss and consequently also more sunburn-resistant (Figure 9).

Figure 9. *Sunburn damage.*

2.4 Water and Soil

2.4.1 Water

Proper irrigation management (Figure 10) is essential to assure high yield and quality. In open field, tomato may need up to 6.000 m^3/ha of water, in greenhouses up to 10.000 m^3/ha.

Daily fertigation with small amounts of nutrients will avoid salt stress in the rooting zone (salinity) or early nutrient depletion (lack of nutrition), as could be the case with weekly fertilizer applications.

Water shortage (Figure 11) will lead to reduced growth in general and reduced uptake of calcium in particular, leading to calcium deficiency imbalance, shown by the fruit as Blossom End Rot (BER) (Figure 12). Flowering is negatively affected and clusters might get lost. On the other hand, too much water will cause root death in anaerobic soil conditions, delayed flowering and fruit disorders (Figure 13).

Figure 10. *Irrigation system.*

Figure 11. *Drought stress.*

Figure 12. *Blossom End Rot.*

Figure 13. *Cracking.*

Irrigation water with a high pH generally contains high levels of calcium and magnesium bicarbonates and carbonates. Acidification of such water is recommended to reduce the pH to 5-6 as it will go to the plant. This will improve the availability of certain nutrients, like P, Fe, Zn, Cu, Mn and B and will avoid the precipitation of insoluble salts that might block the drip irrigation system.

The addition of acid (H^+) to bicarbonate (HCO_3^-) or carbonate (CO_3^{2-}) will result in carbonic acid, an unstable compound that will be transformed immediately into water and carbon dioxide.

1 HCO_3^-	+	1 H^+	→	1 H_2CO_3	→	1 H_2O	+	1 CO_2
1 CO_3^{2-}	+	2 H^+	→	1 H_2CO_3	→	1 H_2O	+	1 CO_2
(Bi)carbonate	+	acid	→	carbonic acid	→	water	+	carbon dioxide

It is recommended to neutralize with an acid about 90 to 95% of the (bi)carbonates in the water. By this, the water will keep a small pH buffering capacity that helps to avoid a further drop in pH. A very acidic pH of the irrigation water is undesired and might lead to the dissolution of toxic elements present in the soil, like for example aluminium (Al^{3+}).

2.4.2 Soil

The ideal soil has good drainage capacities and a good physical soil structure.

Roots are present in the upper 60 cm, with 70% of the total root volume in the upper 20 cm.

The ideal pH of the soil is 6.0-6.5 (Figure 14). At a pH > 6.5 the metal micronutrients (Fe, Zn, Mn, Cu), boron (B) and phosphorus (P) become less available for plant uptake. At pH < 5.5 phosphorus (P) and molybdenum (Mo) become less available for plant uptake.

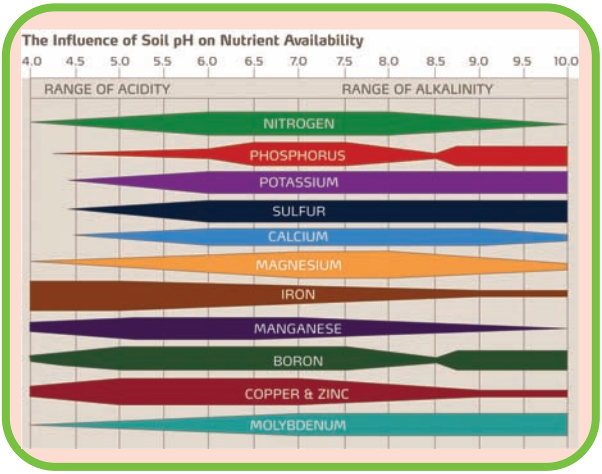


Figure 14. *The influence of soil pH on nutrient availability.*

Alternative growing media in greenhouses: rockwool (Figure 15), perlite (Figure 16) and bags filled with coco peat (Figure 17).

Figure 15. *Greenhouse tomato grown on rockwool substrate.*

Figure 16. *Greenhouse tomato grown on perlite.*

Figure 17. *Greenhouse grown tomato grown in bags filled with coco peat.*

2.5 Organic Matter and Manure

Organic matter and manure are applied to increase the water holding capacity of the soil, in order to improve soil structure and microbiological activity. Attention should be paid to the fact that manure may contain substantial amounts of nutrients, thus increasing the risk of getting an excess of nutrients in the rooting zone (risk of salinization) and of getting certain nutrient imbalances.

Applications of 10-50 tonne manure/ha will contribute to an essential part of the total nutrient demand. Dry chicken manure (Table 5) is more concentrated than dry cow manure (Table 6). With 10 tonne of chicken manure 134 kg N/ha is applied. If 50 tonne of dry cow manure/ha is applied, approximately 50 tonne/ha x 5,5 kg N-total/tonne = 275 kg N-total/ha will be given.

Table 5. *The average nutrient contribution in dry chicken manure.*

		N total	N-min	N-org	P_2O_5	K_2O	MgO	Na_2O
		in kg per 100 kg manure						
Chicken (dry)		2,4	1,1	1,3	2,8	2,2	0,4	0,3
Application (t/ha)	10	243	109	134	283	222	35	30

Source: Handboek Meststoffen NMI, 1995.

Table 6. *The average nutrient contribution in dry cow manure.*

		N total	N-min	N-org	P_2O_5	K_2O	MgO	Na_2O
		in kg per 100 kg manure						
Cow (dry)		0,55	0,11	0,44	0,38	0,35	0,15	0,10
Application (t/ha)	10	55	11	44	38	35	15	10

Source: Handboek Meststoffen NMI, 1995.

Most of the nitrogen is organically bound and will be released during the growing season as a consequence of microbiological activity. This will lead to a high release of nitrogen later in the growing season, when the tomato is already in its generative phase, possibly causing uneven ripening, poor flavour and short shelf life.

As this is one of the major problems in farmers' practice, it is recommended to limit the dose of manure to maximum 25% of the total N requirement and to add the remainder of the nutrients with specialty plant nutrition.

2.6 Salinity

Salinity is the accumulation of all salts in the rooting zone to such a level, that it limits the potential yield of the crop. For example, salinity can be caused by wrong fertilizer management, lack of water or lack of rainfall to flush the soil, and/or irrigation water with high EC (Figure 18).

It is not recommended to apply organic matter and/or to use fertilizers with chloride and sulphates (KCl, ammonium sulphate and potassium sulphate) under saline conditions to avoid any further increase of the EC in the soil. Other measures to avoid or to reduce salinity problems include the following: improve the soil drainage capacity, do not use granular fertilizers in base- or side dressing, mix water of bad quality with water of good quality, select salt tolerant varieties, do single row planting with double line drip irrigation, apply plastic mulching and design the irrigation system for over irrigation with 35%.

Figure 18. *Fertilizer salt accumulation in the soil surface.*

Tomato is relatively tolerant to salinity (Table 7). In order not to reduce its potential yield, the EC in the saturated soil extract should be: EC_{se} < 2,5 mS/cm and the EC of the irrigation water < 1,7 mS/cm. For example, an EC_{se} = 3,5 mS/cm reduces the potential yield with 10%. However, in some cases a higher EC is desired to improve taste, °Brix (e.g. cherry tomato) and shelf life.

Table 7. *Reduction in potential tomato yield, caused by salinity.*

%	EC sat. soil extract	EC irrigation water	Necessary lixiviation (%)
0	< 2,5	< 1,7	7
10	3,5	2,3	9
25	5,0	3,4	14
50	7,6	5,0	20

Source: Libro Azul, 2002.

2.7 Phenology

In tomato both indeterminate and determinate varieties are grown. Both types of tomato are going through the same phenological stages.

2.7.1 Indeterminate and Determinate Varieties

In case of **indeterminate growth** the main and side stems continue their growth. The number of leaves between inflorescences is more or less permanent starting from a specific flowering set. Indeterminate varieties are grown for the fresh market and are handpicked over a certain period of time (Figure 19).

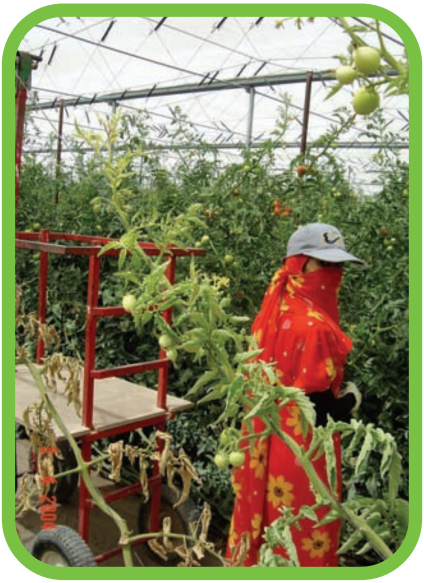


Figure 19. *Handpicked tomato for the fresh market.*

Indeterminate tomatoes go through the same phenological phases as the determinate, with this difference that the growing period (harvesting period) in greenhouses can be much longer than in open field (Figure 20). Open field tomatoes have a life span of 90-150 DAT. Greenhouse tomatoes have a life span of 120-300 DAT.

Figure 20. *Greenhouse grown tomato.*

In case of **determinate growth** the main and side stems stop growing after a specific number of inflorescences which varies in accordance with the cultivar. Determinate varieties, used for industrial purposes, are harvested manually in 2 to 3 pickings (Figure 21) or are harvested mechanically at once (Figure 22). Uniformity of the crop and fruit (size, maturity) is therefore important, especially in case of mechanical harvesting.

Figure 21. *Manual harvesting of tomatoes.*

Figure 22. *Mechanical harvesting of tomato for the industry.*

2.7.2 Phenological Stages

Tomato has various development stages in its growth cycle: young plant establishment, vegetative growth, flowering, fruit development and ripening (Figure 23). Each stage being different with respect to its nutritional needs. Hereunder the phenological stages for tomato, grown in open field, are discussed. The information is purely indicative, as timing will depend on variety, environmental conditions and crop management.

- **Plant establishment:** focus on firm root development and the formation of the initial aerial parts of the plant.

- **Vegetative growth:** takes place in the first 40-45 days, after which the fruits start to develop continuously. This period is followed by another 4 weeks of rapid growth, while the plant is flowering and developing fruits. After 70 days, there is almost no further vegetative development, nor accumulation of dry matter in leaves and stems.

- **Flowering and fruitset:** depending on the variety, environmental conditions and crop management, flowering and fruitset both start around 20-40 days after transplanting and continue during the rest of the growing cycle. Pollination is done by bees, wind and hormone application (auxin) in order to promote fruitset.

- **Fruit development:** after flowering and fruitset, the fruit starts to develop and grow, achieving in this period major accumulation of dry matter in the fruit, at a relatively stable rhythm.

- **Physiological ripeness and harvest:** on average, fruit ripeness is achieved at 80 DAT. Harvesting continues permanently, unless being stopped for climatic reasons (frost) or for economical reasons (price of the tomato).

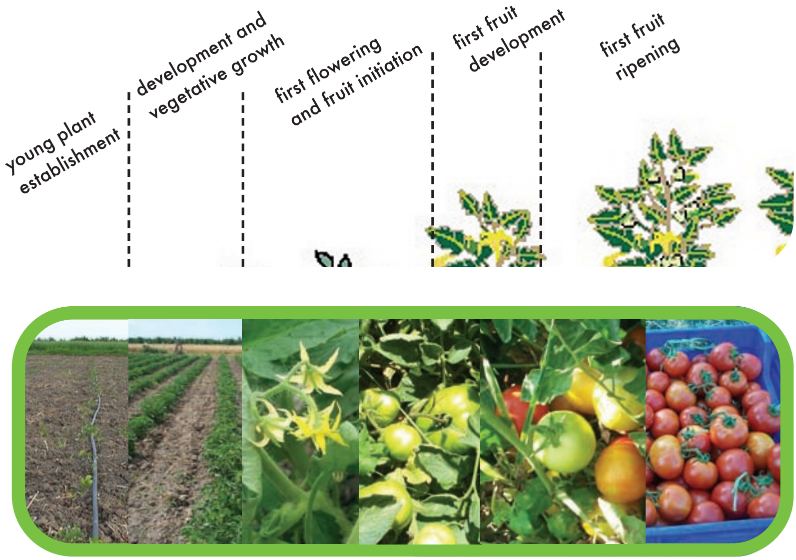


Figure 23. *The phenological stages in tomato, grown in the open field.*

Source: SQM Mexico brochure.

2.8 Uniform Maturity

Balanced plant nutrition will lead to a uniform maturity with well-coloured fruits of equal size. Uniform maturity of the tomato crop means that all tomatoes reach maturity at the same moment. This is especially important for those tomatoes, which are harvested mechanically. Determinate varieties are used for this purpose.

The once-over, destructive harvest is initiated when at least 90% of the fruits are ripe (red coloured). Processors accept fruit showing external colour change. In some fields a fruit-ripening agent is applied several weeks before harvesting in order to maximize the percentage of coloured fruit (Hartz and Miyao).

Figure 24. *Harvested tomatoes for the industry.*

However, the quality attributes looked for in the tomato fruit, reach their optimum value a week before the agronomic harvesting date and they remain constant for at least one week after, when the % of maturity is still low from the agronomic point of view. For this reason, the selection of the best harvesting date is based on the agronomic aspects, more than on the physical-chemical parameters (pH, °Brix, consistency, colour, carotenoid content), due to the fact that the yield expected for harvesting is reached after the analytical quality (De la Torre *et al*, 2001).

Especially for the canning industry of whole and diced tomatoes, fruits have to be equal and well coloured and uniform in size (Sonito, 2003).

From a plant nutritional point of view this means that sufficient K should be applied, because the amounts of K required for production of evenly ripened fruit considerably exceed those required for maximum yield (Roorda van Eysinga, 1966; Winsor and Long, 1967; Adams *et al*, 1978).

Figure 25. *Uniform tomatoes for the fresh market.*

2.9 Physiological Disorders

Various physiological disorders may occur in tomato. They are mainly caused by extreme environmental conditions (high or low temperatures, high humidity) at critical plant stages (flowering, fruitset).

2.9.1 Puffiness, Hollowness or Boxiness

Puffiness is described as slab-sided fruit with hollow gaps between the outer wall and locules and a reduced number of seeds. Puffy fruits lack some or all of the gel that normally surrounds the seed. Externally, fruits are angular rather than round (Figure 26).

Puffiness is caused by a variety of extreme environmental conditions such as high or low temperatures, low light intensity or heavy rainfall. Hormonal imbalances between auxins and cytokinines may cause puffiness in particular under cold climate conditions. It can also be caused by excessive nitrogen use and potassium deficiency imbalance.

Puffiness, hollowness and boxiness (Figure 27) express the various symptoms belonging to the same disorder.

Figure 26. *Hollowness in tomato.*

Figure 27. *Boxiness in tomato.*

2.9.2 Russetting

Russetting is shown as a brown scarring of the skin due to humid (usually glasshouse) growing conditions (Figure 28). Spray damage can also cause similar problems.

Figure 28. *Russetting.*

The incidence of russetting increases with low fruit load (i.e. less than 20 developing fruits). The percentage of russetted fruit is greatest during early production and at the end of the production period. A great amount of assimilates from the source leaves, in relation to the size of the sink (fruit), is available for fruit growth and as a result, the fruit growth rate increases. Cracks occur because expansion of the epidermis cannot keep pace with fruit enlargement.

Russetting is often unseen by the consumer, however, shelf life is significantly reduced in fruit exhibiting the russet symptoms (Grodan, 2005).

2.9.3 Anther Scarring

Anther scarring is a vertical scar along the side of the fruit. The scar looks like a zipper, or the mark left by stitches (Figure 29). Scarring is caused by the anther sticking to the edge of the ovary (immature fruit). As the fruit increases in size, the anther tears away from the fruit, leaving a scar. This is a genetic problem and probably not caused by any environmental conditions.

Figure 29. *Anther scarring.*

2.9.4 Catfacing

Catfacing is described as a misshapen fruit due to abnormal development, normally due to cold conditions at flowering and fruitset (Figure 30).

Figure 30. *Catfacing.*

2.10 Pests and Diseases

Figure 31. *Tomato fruit affected by Botrytis.*

If the plant's nutritional status is unbalanced, it becomes more susceptible to pests and diseases. For example an excess imbalance of nitrogen will make the plant grow very fast, and because the new cells are relatively weak, they are more susceptible to penetrating insects.

Also a calcium deficiency imbalance leads to weaker plant cells, making it more susceptible to Botrytis (Grey mould, Figure 31) and other fungi.

2.11 Quality Parameters for the Fresh and the Industry Tomato Market

The income of the farmer largely depends on both yield and quality of the harvested crop, which may include characteristics that positively affect human health, like a high lycopene content. Balanced plant nutrition plays a key role in meeting the quality standards of the fresh market and the tomato industry (concentrated paste, peeled and diced tomato).

2.11.1 Quality Parameters for the Fresh Tomato Market

The following quality parameters are essential for the fresh tomato market:

- Well coloured and bright (without green shoulders or immature green spots or blotches).
- Uniform in shape (Figure 32).
- Texture or firmness of bite (firmer tomatoes are less prone to damage and have a longer shelf life).
- Flavour: a high sugar (mainly fructose) and high acid (mainly citric acid) content give the best flavour.
- Clean and free of external defects.
- Health related characteristics, like high levels of lycopene (anti-cancer) and vitamin C.

Figure 32. *High quality tomato fruit with uniformity in fruit size and colour.*

2.11.2 Quality Parameters for the Concentrated Tomato Paste Industry

The following quality parameters are essential for the concentrated tomato paste industry:

- High level of dry matter (soluble + insoluble solids; Figure 33), which means less water in the fruit, so it will cost less money to remove the water in the concentration process.
- High °Brix, high level of total soluble solids (TSS > 99% sugars).
- Colour of the juice (before and after the concentration process).
- High lycopene content.
- Viscosity (related to the level of insoluble solids, which is around 50% of total solids).
- Acidity (pH).
- The presence/absence of fungi (Howard index).

Figure 33. *Tomato cross-section with thick fruit walls, indicating high dry matter content.*

2.11.3 Quality Parameters for the Peeled and Sliced Tomato Industry

The following quality parameters are essential for the peeled and sliced tomato industry:

- Well coloured.
- Free of external defects (before and after the industrial process).
- Easy to peel.
- Uniform calibre.
- High organoleptic quality of the final product.

3 Role of Nutrients with Emphasis on Potassium and Calcium

An adequate nutrition management programme can only be made when there is a clear understanding of the main roles of all nutrients. Special attention is paid to potassium and calcium, which have proved to be key elements in all our demonstration fieldwork when aiming to improve yield and quality (also see Chapter 9). However, it still remains important to consider <u>all</u> nutrients for a balanced nutritional programme.

3.1 Potassium

The roles of potassium in tomato are directly related to quality and quantity. Increased K levels will improve plant performance.

3.1.1 Potassium for Quality and Quantity

Potassium is the most important nutrient affecting the quality of fruit (Roorda van Eysinga, 1966; Winsor and Long, 1967; Adams *et al*, 1978).

Essential roles of potassium are to be found in the protein synthesis, the photosynthetic process and the transport of sugars from the leaves to the fruits. A good potassium supply shall therefore sustain the leaf function all along fruit growth and shall contribute to the positive effect of K on yield and on a high soluble solid content (more sugars) in fruits at harvest time. About 60-66% of K absorbed by the plant is found in the fruit (Winsor *et al*, 1958). The action of potassium on protein synthesis enhances the conversion of absorbed nitrate into proteins contributing to a better efficiency of the N fertilizer supplied.

Potassium is a cation that is involved in the maintenance of plant osmotic potential (cell turgescence), one implication of this being the movement of stomata, the openings that allow plants to exchange gas and water with the atmosphere. This enables plants to maintain an adequate hydric status under stress conditions such as salinity or water shortage. Indeed, tomato crops with a high potassium content generally show a better water use efficiency, that is, they consume relatively less water than K deficient crops to produce the same amount of biomass. In addition, potassium is involved in maturation processes of the fruit such as the synthesis of the pigment lycopene, which is responsible for the red colour of the tomato fruit. Potassium also promotes a high acid content, which is essential for a good fruit flavour.

Summary of the role of potassium in the tomato plant:

- Promotes the production of proteins (faster conversion to proteins).
- Promotes the photosynthesis (more CO_2 assimilation, more sugars).
- Intensifies the transport and storage of assimilates (from leaf to fruit) (Figure 34).
- Prolongs and intensifies assimilation period (higher fruit quality).
- Improves the efficiency of N fertilizers.
- Improves the water use efficiency (less water needed/kg plant).
- Regulates the opening and closure of stomata (guard cells).
- Is responsible for the synthesis of lycopene (red colour).

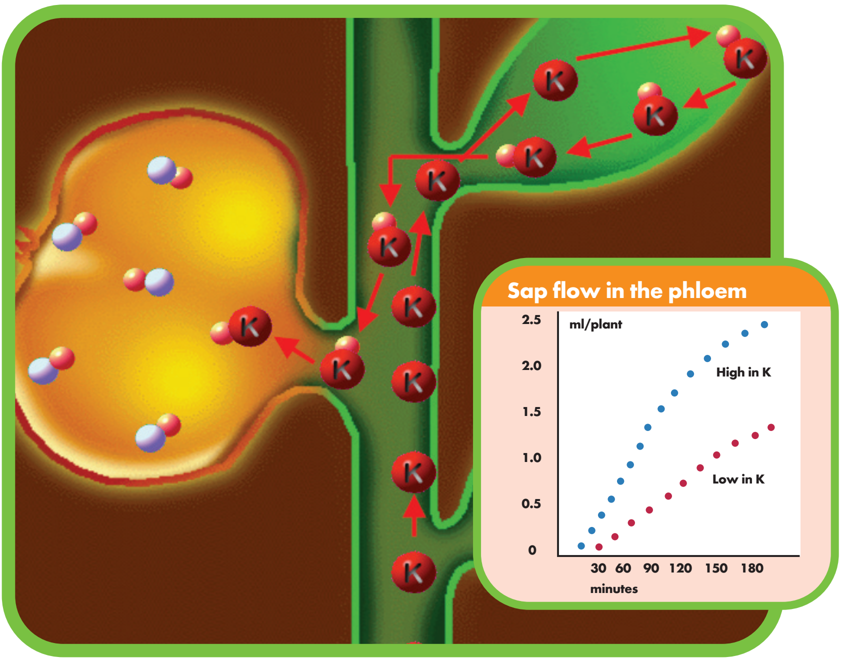


Figure 34. *K intensifies the transport and storage of assimilates from the leaf to the fruit.*

3.1.2 Increased Potassium Levels in Tomato

- Research has shown that increased K levels in tomato will lead to the following effects:
- Improved fruit shape (Winsor and Long, 1968).
- Reduced incidence of ripening disorders (Bewley and White, 1926, Adams *et al*, 1978).
- Reduced proportion hollow fruit (Winsor, 1966).
- Improved fruit firmness (Shafshak and Winsor, 1964).
- Improved taste by increased acidity (Davis and Winsor, 1967).

Ca 3.2 Calcium for Strong Plants

Calcium has three main functions in the plant:

- It is essential for cell walls and plant structure. About 90% of the calcium is found in the cell walls. It acts as a cohesion factor that cements cells together and holds their structure in plant tissues. Without Ca, the new tissue development (cell division and extension) of roots and shoots is stopped. As a consequence the crop yield is badly affected. Calcium is the key element responsible for the firmness of tomato fruits. It delays senescence resulting in long lasting leaves capable to continue the photosynthesis process.

- It maintains the integrity of cell membranes. This is important for the proper functioning of uptake mechanisms as well as for preventing leakage of elements out of the cells.

- It is also at the heart of plant defence mechanisms that help plants to detect and react against external stresses. Both roles in plant defence and on tissue firmness are important for resistance against pathogen attacks and decay during fruit storage.

One particularity of calcium is that it is almost exclusively transported with the transpiration stream along the xylem, i.e. it is mainly distributed from the roots up to the leaves, the main transpiring organs (Figure 35). On the other hand, fruits with a low transpiration rate are poorly supplied with calcium. Only 5% of the calcium goes to the fruit (Table 8). Thus, transient Ca deficiency can occur easily in fruits and especially at periods when growth rate is high, leading to the necrosis of the apical end of the fruits identified as BER.

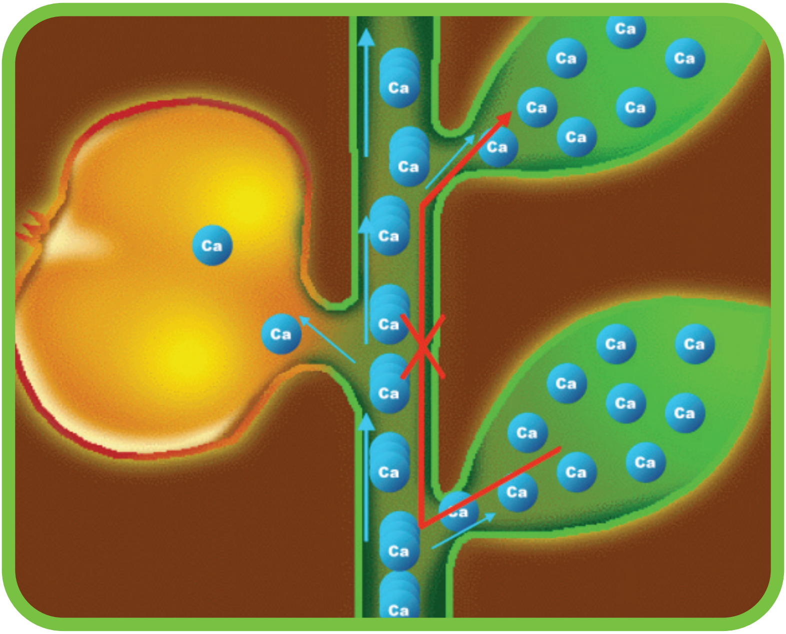


Figure 35. *Calcium transport in the plant.*

Table 8. *Partitioning of nutrients and dry matter among plant parts, expressed in % of the total.*

Nutrient and dry matter	Leaves %	Stem %	Side shoots %	Total vegetative parts %	Fruits %	Total %
N	23	8	8	39	61	100
P	20	15	5	40	60	100
K	19	11	5	34	66	100
Ca	76	15	4	95	5	100
Mg	50	15	5	70	30	100
S	72	8	4	83	17	100
Dry matter	20	14	4	38	62	100

Source: Voogt, 1993.

Factors that either increase the transpiration stream towards the leaves (climatic conditions) or decrease the Ca availability for plant uptake (drought, high EC/salinity, nutrition imbalance) will increase the risk of BER development. Only sufficient and constant calcium supply in a water soluble form with calcium nitrate can prevent calcium deficiencies.

3.3 Main Problems in Tomato Growing in Relation to a Lack of Potassium and Calcium

Table 9 describes the main problems in tomato growing, which are related to a deficiency imbalance of potassium and calcium.

Table 9. *The main problems in tomato growing and their relation to a deficiency imbalance of potassium and calcium.*

	Main problems in tomato growing	Related to	
		K	Ca
Plant Performance	Low yield	x	x
	Heterogeneity in size, uneven ripening	x	
	Limited fruitset	x	
	No bulking / small tomato	x	
External quality	Lack of colour	x	
	Soft fruit / no firmness	x	x
	Limited storability / shelf life	x	x
Internal quality (taste)	Low °Brix (Soluble solids)	x	x
	Lack of acidity	x	
Disorders and defects	BER (blossom end rot)		x
	Cracking	x	x
	Sunburn	x	x
Tolerance / Resistance	Water status (drought / transpiration)	x	x
	Diseases (fungal)	x	x
	Salinity	x	x

3.4 Summary Main Roles of Nutrients

Table 10 summarizes the main roles of all nutrients.

Table 10. *The main roles of all nutrients.*

Nutrient	Symbol	Main Roles
Nitrogen	N	Chlorophyll and protein synthesis (growth and yield).
Phosphorus	P	Cell division, energy transfer.
Potassium	K	Sugar transport. Water regime regulation.
Calcium	Ca	Storage quality, reduced disease susceptibility.
Sulphur	S	Synthesis of essential amino acids: cysteine, methionine.
Magnesium	Mg	Central part of the chlorophyll molecule.
Iron	Fe	Chlorophyll synthesis.
Manganese	Mn	Required for photosynthesis.
Boron	B	For cell wall formation (pectin and lignin), B is a structural component of the cell wall. For sugar metabolism and transport. For flowering, fruitset and seed development (pollen germination + pollen tube growth).
Zinc	Zn	Early growth and development (auxins).
Copper	Cu	Influences carbohydrate and N metabolism. Enzyme activator for lignin and melanin production.
Molybdenum	Mo	Component of the enzymes nitrate reductase ($NO_3 \rightarrow NO_2 \rightarrow NH_3$) and nitrogenase ($N_2 \rightarrow NH_3$ conversion in N fixing Rhizobium bacteria).

4 Guideline Data Facilitating Nutrition Management

Guideline data are essential for the agronomist in order to make objective recommendations in relation to the target market and buyer request. Nutrient uptake curves for tomato grown in soil in the open field and on rockwool in a greenhouse are given.

Nutrient absorption curves describe the nutrient uptake per nutrient per phenological phase. A split can be made between the aerial parts (flowers, leaves, stems and fruits) and soil parts (roots, storage organs). The nutrient uptake curve is the base for a fertilizer recommendation.

Guidelines are given for nitrogen management in open field tomato, for tomato for the industry and for greenhouse grown tomato on rockwool.

4.1 Nutrition of Open Field Tomato

4.1.1 Nutrient Uptake Curves of Open Field Grown Tomato

Figures 36, 37, 38 and 39 describe the uptake of N, P and K during the growing cycle of open field grown tomato in the South East of France for an estimated yield of 90 tonne/ha (Dumas, 2005).

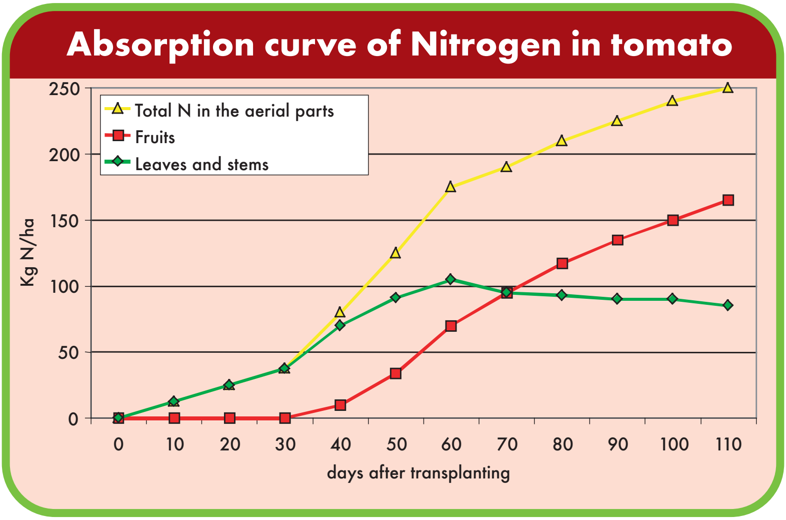


Figure 36. *The N absorption in the fruits, leaves and stems, and the total N absorption in the aerial parts of a 90 tonne/ha yielding open field tomato crop.*

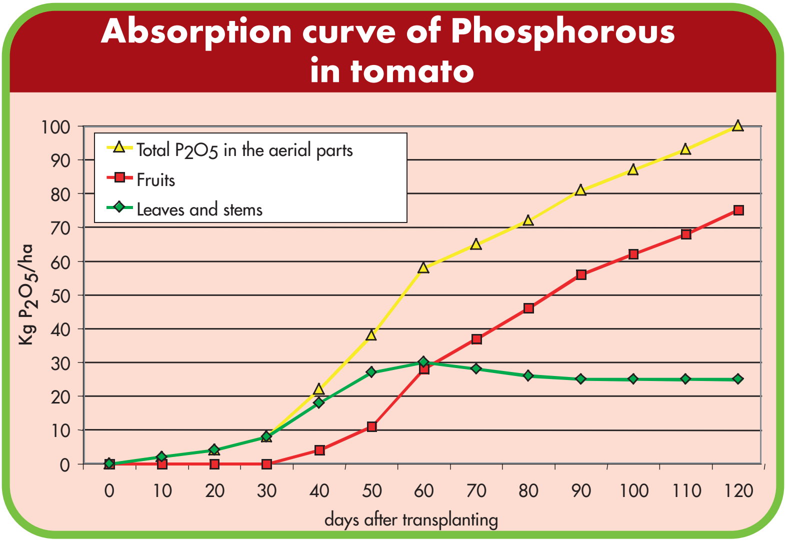


Figure 37. *The P_2O_5 absorption in the fruits, leaves and stems, and the total P_2O_5 absorption in the aerial parts of a 90 tonne/ha yielding open field tomato crop.*

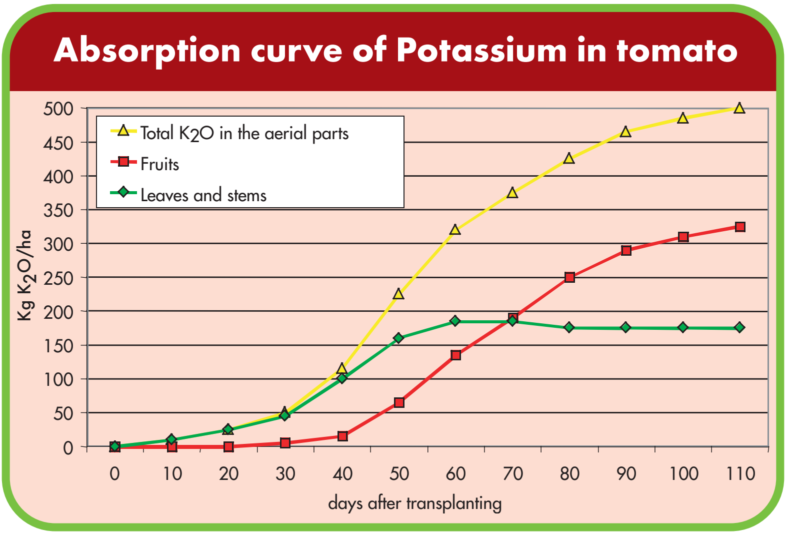


Figure 38. *The K_2O absorption in the fruits, leaves and stems, and the total K_2O absorption in the aerial parts of a 90 tonne/ha yielding open field tomato crop.*

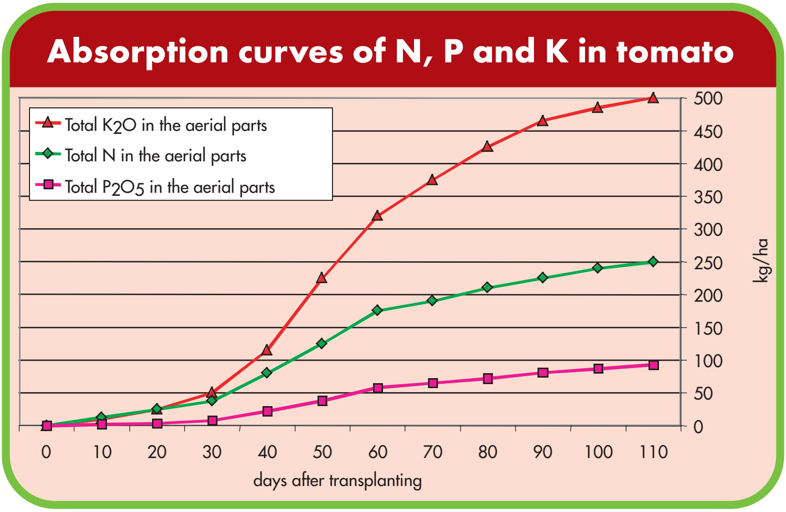


Figure 39. *The total N, P_2O_5 and K_2O absorption in the aerial parts of a 90 tonne/ha yielding open field tomato crop.*

4.1.2 Nitrogen Management in Open Field Tomato

Nitrogen is the main nutrient responsible for the development of leaf area and should therefore be present from the first stages of plant development onwards. Given the short period in which N absorption can take place, the nitrogen applied as fertilizer should be immediately available for the plant and ideally in the nitrate form ($N\text{-}NO_3^-$), because nitrate is the nitrogen form which the plant prefers to absorb. It is recommended to apply no more than 20% of the total N as ammonium and at least 80% as nitrate (Table 12).

4.1.3 Nitrogen Management for Tomato for the Industry

The following nitrogen management guidelines can be used for tomato for the industry:

- Apply only N-NH_4^+ in the base dressing and in the initial phase of the crop in order to avoid an explosion of nitrogen during the generative phase.
- Create "Hunger for Nitrogen".
- From flowering onwards the farmer should cut back the applied amounts of nitrogen. He shall thus avoid excessive vegetation (leaves), which will complicate the mechanical harvesting. A limited N supply will also stimulate a uniform ripening and increase the amount of soluble solids (°Brix).

4.2 Nutrition of Greenhouse Tomato

Figure 40 shows a nutrient absorption curve for a year round tomato crop, grown in a greenhouse on a rockwool substrate. There is a sharp increase in K uptake concentration (mmole/l) during flowering of the first 10 trusses (= period of increased fruit load), with a peak in between the flowering of the 7th and 10th cluster. This increase coincides with a decline in Ca and Mg uptake concentration.

In this phase of heavy fruit load, there is a reduction in root growth, which results in a decreased capacity for Ca and Mg uptake. The uptake ratio between N, P, S is more or less stable over time. Fertilization guidelines and adjustments are based on these absorption curves. They are related to the crop stage, for which the trussnumber at anthesis was chosen (Voogt and Sonneveld, 1998).

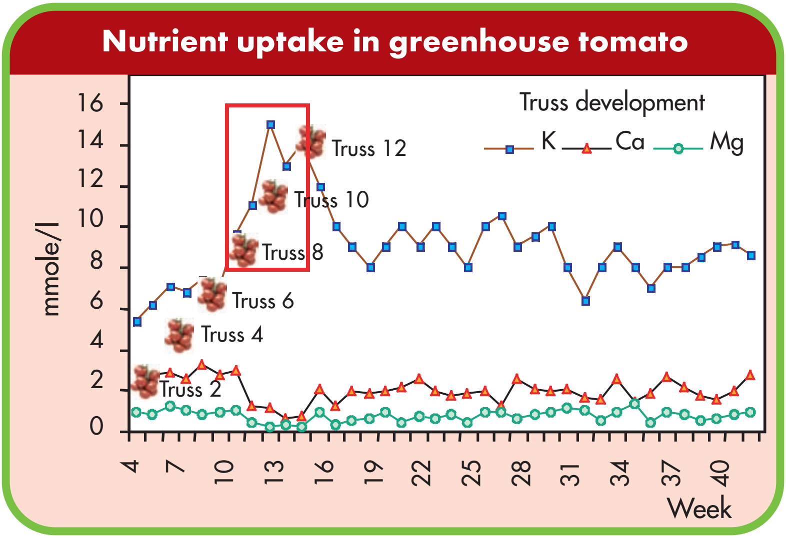


Figure 40. *The K, Ca and Mg uptake by the plant in relation to the truss development and time.*

The standard nutrient solution for greenhouse tomato on rockwool with open drain and changes per phenological stage is presented in Table 11. The EC = 2.6 mS/cm. The changes are expressed in mmole/l and ppm (as the diluted nutrient solution goes to the plant).

Table 11. *The standard nutrient solution for greenhouse tomato on rockwool with open drain and changes per phenological stage.*

Tomato open drain rockwool, 1 cycle/year	NO_3	K	Ca	Mg	SO_4	H_2PO_4	NH_4	Fe	Mn	Zn	B	Cu	Mo
	mmole/l							mole/l					
Standard nutrient solution	**16**	**9,5**	**5,4**	**2,4**	**4,4**	**1,5**	**1,2**	**15**	**10**	**5**	**30**	**0,75**	**0,5**
Changes per phenological phase													
1 saturation rockwool slabs	16	5,7	6,90	3,40	4,7	1,0	0,0	15	10	5	40	0,75	0,5
2 from planting to flowering 1st cluster	17	8,5	5,90	2,90	4,4	1,5	1,2	15	10	5	30	0,75	0,5
3 from flowering first flower 1st cluster	16	9,5	5,40	2,40	4,4	1,5	1,2	15	10	5	30	0,75	0,5
4 from flowering first flower 3rd cluster	16	10,0	5,28	2,28	4,4	1,5	1,2	15	10	5	30	0,75	0,5
5 from flowering first flower 5th cluster	16	11,3	4,78	2,15	4,4	1,5	1,2	15	10	5	30	0,75	0,5
6 from flowering first flower 10th cluster	16	10,0	5,28	2,28	4,4	1,5	1,2	15	10	5	30	0,75	0,5
7 from flowering first flower 12th cluster	16	9,5	5,40	2,40	4,4	1,5	1,2	15	10	5	30	0,75	0,5

Tomato open drain rockwool, 1 cycle/year	$N\text{-}NO_3$	K	Ca	Mg	S	P	$N\text{-}NH_4$	Fe	Mn	Zn	B	Cu	Mo
	ppm							ppm					
Standard nutrient solution	**224**	**371**	**216**	**58**	**141**	**47**	**17**	**0,84**	**0,55**	**0,33**	**0,32**	**0,048**	**0,048**
Changes per phenological phase													
1 saturation rockwool slabs	224	222	276	83	149	31	0	0,84	0,55	0,33	0,43	0,048	0,048
2 from planting to flowering 1st cluster	238	332	236	70	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048
3 from flowering first flower 1st cluster	224	371	216	58	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048
4 from flowering first flower 3rd cluster	224	390	211	55	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048
5 from flowering first flower 5th cluster	224	439	191	52	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048
6 from flowering first flower 10th cluster	224	390	211	55	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048
7 from flowering first flower 12th cluster	224	371	216	58	141	47	17	0,84	0,55	0,33	0,32	0,048	0,048

Adapted from: Bemestingsadviesbasis substraten, 1999.

Table 12 shows the average nutrient uptake of a long cycle tomato crop grown in 5 different greenhouses in The Netherlands. The uptake of the whole plant (leaves + stems + fruits) is expressed as tonne fruit yield. The average yield was 40 kg/m^2 or 400 tonne/ha.

Table 12. *The average nutrient uptake of a long cycle tomato crop grown in 5 different greenhouses in The Netherlands.*

	kg nutrient / t fruit
N	2,2
P	0,5
K	3,9
Ca	1,6
Mg	0,4
S	0,6

	kg nutrient / t fruit
N	2,2
P_2O_5	1,2
K_2O	4,7
CaO	2,2
MgO	0,6
SO_3	1,5

Adapted from: Voogt, 1993.

Table 13 summarizes the maximum recommended levels of ammonium in hydroponics and in soil to avoid BER.

Table 13. *The maximum recommended levels of ammonium in hydroponics and soil to avoid BER.*

Tomato Growing System	Max. NH_4^+ level in % of N total	Reason
Hydroponics	5-7	to avoid BER
Soil	20	to avoid BER

Source: Voogt, 2002.

5 Visual Nutrient Deficiency and Excess Imbalances

A visual description of nutrient deficiency and excess imbalances is a useful tool to determine the cause of such an imbalance. It is recommended to get a confirmation and better understanding of the nature of the symptoms via plant, soil and/or water analysis, performed by a qualified laboratory. For example a visual deficiency imbalance of a certain nutrient might be provoked by an excess imbalance of another nutrient.

Hereunder, the nutrient deficiency imbalance symptoms are described and illustrated by pictures. In some cases nutrient excess imbalance descriptions and pictures are presented.

N

- Slow plant growth.
- Yellow-green leaves with premature dying of the oldest leaves.
- New developing leaves are small.
- Thick and hard stems.
- Poor fruitset as flower buds fall off.
- Small fruits and green fruit before maturing.
- Reduced yield.

Figure 41. *N deficiency imbalance.*

P

- Very dark blue-green or purplish in colour, purpling on the undersides of the leaf include both the veins and interveinal areas, mature leaves were small with down-curled leaflets, stems are thin and stunted and roots are brown and develop few lateral branches.

Figure 42. *P deficiency imbalance.*

K

- Young plants have dark green leaves, small stems and short internodes.
- Necrosis of the leaf border in the oldest leaves, the leaf curls upwards.
- Interveinal necrotic spots in the oldest leaf.
- Fruits drop easily during ripening.
- Blotchy ripening (Hewitt, 1944).
- Fruits are insipid (tasteless), lacking acidity (Hewitt, 1944).
- Green and yellow areas merging into the red colour of the surface (Wallace, 1951).
- Uneven ripening (Hewitt, 1944).
- 'Glassy' blotches (Seaton and Gray, 1936).
- Reduced plant height and leaf area (White, 1938).
- Reduced number of fruits per truss (Clarke, 1944).
- Reduced proportion of fruitset (Clarke, 1944).
- Reduced average weight per fruit (Clarke, 1944).

Figure 43. *K deficiency imbalance.*

Figure 44. *Lack of colouring.*

Figure 45. *Peel cracking.*

Figure 46. *K deficiency in leaf.*

Ca

Calcium deficiency imbalance results in:

- Scorching of new growth and death of the growing points in both the roots and shoots.
- The leaves of seedlings become distorted and develop yellow, brown or purple necrotic areas starting at the leaf margin and moving into the interveinal areas.
- In mature plants, the edges of the youngest leaves become brown and some interveinal areas turn yellow.
- The growing point dies and the flower buds fail to develop.
- The fruit is affected by blossom end rot.

Figure 47. *Ca deficiency imbalance.*

Figure 48. *Ca excess imbalance (goldspeck) caused by calcium oxalate accumulation under the skin, shown as small spots on the shoulder of the fruit.*

Mg

- Yellowing and white chlorotic and necrotic interveinal tissue of the older tomato leaf.

Figure 49. *Mg deficiency imbalance.*

S

Sulphur deficiency is similar in appearance to nitrogen deficiency, however it begins in the younger leaves, because sulphur is not as mobile as nitrogen within the plant.

- Pale green colour in the younger leaves.

Figure 50. *S deficiency imbalance.*

Fe

Tip tissue chlorosis, especially in tomato grown on high pH soil. Free $CaCO_3$ can induce Fe deficiency.

Figure 51. *Fe deficiency imbalance.*

Figure 52. *Fe deficiency imbalance.*

Zinc deficiency imbalance results in a:

Stunted tomato plant, with white and necrotic interveinal spotting of older leaves.

Figure 53. *Zn deficiency imbalance.*

Figure 54. *Zn excess imbalance with interveinal yellowing on the leaflets.*

Mn Manganese deficiency imbalance leads to:

- Interveinal chlorosis, with green veins, of the expanded young leaf.

Figure 55. *Mn deficiency imbalance.*

Figure 56. *Mn excess imbalance, normally shown as black deposits (not shown here) around the veins, with yellowing in the surrounding tissue, which gradually spreads across the leaf.*

B

Boron deficiency imbalance leads to severely stunted tomato seedling. Can be induced by excess of lime.

Figure 57. *B deficiency imbalance.*

Figure 58. *B deficiency imbalance.*

Figure 59. *B excess imbalance with small brown spots along the margins of the leaflets.*

Cu

The margins of the mature leaves tend to curl upwards and inwards. May occur in organic substrates such as peat.

Figure 60. *Cu deficiency imbalance.*

Mo

First shown as mottled chlorosis between the veins in the older leaves. The smallest veins also become chlorotic. The margins of the leaf curl upward.

Figure 61. *Mo deficiency imbalance.*

6 SPN Product Characteristics regarding Imbalance Rectification Effectiveness

This chapter describes which fertilizer products are available and why certain fertilizer products are better than others in correcting nutritional imbalances by meeting the needs of the plant during its growth and development.

6.1 Fertilizer Selection

There are various possibilities to select fertilizers for tomato fertilization. This can be done with granular specialty plant nutrition for field applications (Qrop™), with water soluble specialty plant nutrition for fertigation (Ultrasol™) or combinations of both, possibly complemented with specialty plant nutrition for foliar applications (Speedfol™).

The selection will mainly depend on:

- Type of tomato growing (e.g. rainfed, flood irrigation, drip irrigation).
- Economy (cost/benefit).
- Access to the fertilizer.
- Knowledge about the product and its uses (farmer, consultant, distributor).
- Convenience.

6.2 Specialty Plant Nutrition per Nutrient

6.2.1 Nitrogen

Urea, ammonium and nitrate, being the 3 main forms of nitrogen in N fertilizers will undergo different processes in soils (Figure 62).

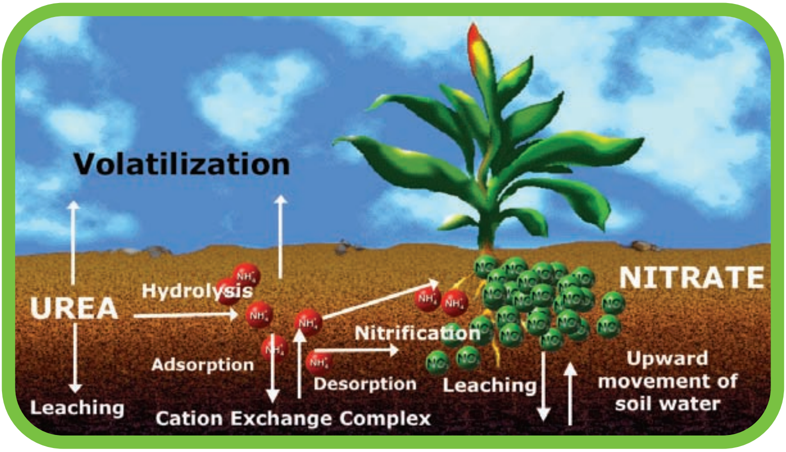


Figure 62. *The chemical transformation process in the soil when using urea, ammonium and nitrate containing fertilizers.*

6.2.1.1 Urea

Urea cannot be used directly by the plants. However once applied on soil, it will be quickly hydrolyzed into ammonium. Before or during this hydrolysis, N losses can occur as urea leaching or as ammonia emission. Urea is electrically neutral and thus won't be adsorbed to the charged layers in the soil. Consequently it will easily move to the borders of the wet bulb in drip irrigation systems, becoming out of reach of the roots.

6.2.1.2 Ammonium

Ammonium is easily fixed at soil particles, making it less susceptible to leaching. At the same time it is therefore almost immobile in soil, which restricts its availability for plants. Most of the ammonium is transformed into nitrate prior to plant uptake. Before this nitrification process, significant amounts of ammonium can be lost as ammonia (NH_3) on high pH soil.

The conversion from urea and ammonium into nitrate can last from one to several weeks depending on pH, humidity, temperature and the presence of certain bacteria (Nitrosomas, Nitrobacteria). This implies a delay in N availability and results in a greater imprecision in N management.

A high amount of ammonium in the rooting zone can lead to root starvation under high temperature in the rooting zone as a consequence of oxygen depletion due to the nitrification process.

Ammonium competes for the uptake by the roots with other cations (antagonism) like potassium, magnesium and calcium and this may induce nutritional disorders. In particular, an excess of ammonium may lead to blossom end rot (BER) problems (Figure 12), resulting from a shortage of calcium in fruits, even if ample Ca is present in the nutrition solution.

Ammonium applied on a calcareous soil with pH > 7.5 will lead to ammonia (NH_3) formation and volatilization.

6.2.1.3 Nitrate

On the other hand, plants can directly take up nitrate applied to the soil. It does not require any transformation, and, because nitrate is soluble in the soil solution, it easily comes into contact with roots. Split application of nitrate fertilizers allows a very precise management of the N supply to the crop. Nitrate is not volatile, which means there is no N-loss as ammonia emission. A synergy in nutrient uptake exists between anions and cations. Nitrate, being an anion, promotes the uptake of cations (K^+, Ca^{2+}, Mg^{2+}, and NH_4^+) (Figure 63). The conversion of nitrate into amino acids takes place in the leaf. This makes it an energy efficient process, because solar energy is used for the conversion. The conversion of ammonium mainly takes place in the roots. The plant has to burn sugars to fuel the conversion. This means that fewer sugars are available for growth and fruit development. Nitrate is not fixed to the soil particles and is therefore susceptible to leaching. However, proper irrigation management can reduce to a minimum the risk of losing nitrogen via leaching.

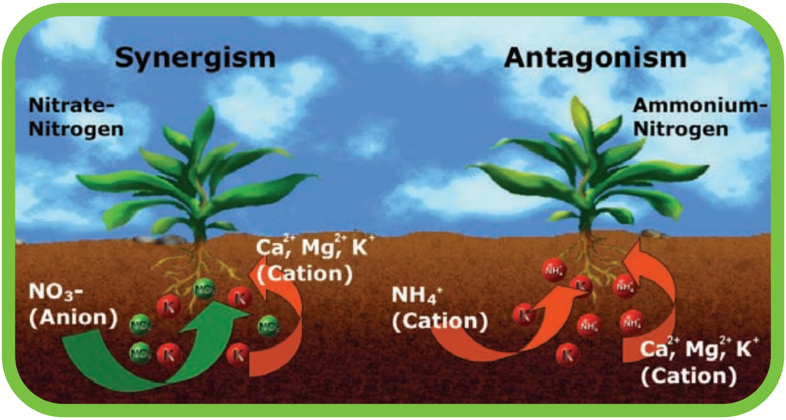


Figure 63. *Synergism and antagonism in the nutrient uptake in the rooting zone of the plant between cations and nitrate or ammonium as nitrogen source.*

6.2.1.4 Nitrate versus Sulphate and Chloride in Tomato

Calcium uptake is positively influenced by the chloride concentrations in the root environment. With increasing SO_4^{2-} and specifically Cl^-, less BER appeared. On the other hand, a high Cl^- content in the rooting zone increased the symptoms of goldspeck (Figure 64 and 65).

Figure 64. *Goldspeck.*

Figure 65. *Goldspeck: small spots on the fruit shoulder.*

Goldspeck reveals itself as small spots on the shoulder of the fruit, giving it an undesirable appearance. Goldspeck is caused by calcium oxalate accumulation under the skin. It often develops in certain varieties or under high humidity conditions. Increased chloride levels promote calcium uptake and increase gold-speck incidence (but reduce BER).

The shelf life of fruits tended to decrease when increasing Cl^- and SO_4^{2-}, for fruits severely affected by goldspeck have a shorter shelf life. (Nukaya *et al*, 1991). Although the use of Cl^- in tomato (to replace part of the N-NO_3^-) is common practice these days, the applied amounts must be carefully monitored in order to avoid goldspeck. For more information go to 6.2.5 Chloride.

6.2.1.5 Nitrogen Containing Specialty Plant Nutrition

Nitrate containing fertilizers are potassium nitrate, magnesium nitrate, calcium nitrate and ammonium nitrate. Calcium nitrate (15,5% N = 14,3% N-NO_3^- + 1,2% N-NH_4^+) also provides partly ammonium nitrogen which can be enough for pH control in hydroponics. Ammonium nitrate is used in small quantities in green-houses for pH control in the rooting zone and in open field fertigation as part of the total nitrogen fertilization (Table 14). Urea is the less preferred N-source because of its inefficiency.

Table 14. *The main nitrogen fertilizers split per type of nitrogen.*

Main N-form in the fertilizer	Common name	Formula
Nitrate	Potassium nitrate	KNO_3
	Sodium potassium nitrate	$KNO_3.NaNO_3$
	Calcium nitrate solid	$(5(Ca(NO_3)_2).NH_4NO_3).10H_2O$
	Calcium nitrate liquid	$Ca(NO_3)_2$ in solution
	Magnesium nitrate	$Mg(NO_3)_2.6H_2O$
	Ammonium nitrate	NH_4NO_3
	Nitric acid	HNO_3
Ammonium	Ammonium sulphate	$(NH_4)_2SO_4$
	Mono ammonium phosphate (MAP)	$NH_4H_2PO_4$
	Di ammonium phosphate (DAP)	$(NH_4)_2HPO_4$
Urea	Urea	$CO(NH_2)_2$
	Ureaphosphate	$CO(NH_2)_2.H_3PO_4$

6.2.2 Phosphorus

All phosphate fertilizers are pH buffers. However, some of them are stronger acidifiers than others. Another difference is found in its chemical purity and solubility (i.e. the amount of insolubles). For example MAP is available as a field and fertigation grade. Therefore the choice of which phosphorus fertilizer should be used is mainly decided in function of its desired effect on pH of water and soil, and its solubility.

Table 15. *Characteristics of phosphorus fertilizers.*

Common name	Formula	Characteristics
Mono ammonium phosphate (MAP)	$NH_4H_2PO_4$	for soils with pH > 7.5
Di ammonium phosphate (DAP)	$(NH_4)_2HPO_4$	for soils with pH 6-7.5
Mono potassium phosphate (MKP)	KH_2PO_4	
Triple super phosphate (TSP)	mainly $Ca(H_2PO_4)_2$	for soils with pH < 6
Ureaphosphate	$CO(NH_2)_2.H_3PO_4$	strong acidifier in solid form
Phosphoric acid	H_3PO_4	strong acidifier in liquid form

In fertigation systems phosphate can't be mixed with calcium in the highly concentrated mother solution. This would result in the precipitation of calciumphosphates.

6.2.3 Potassium

Table 16. *Characteristics of potassium fertilizers.*

Common name	Formula	Characteristics
Potassium nitrate	KNO_3	Is the ideal K fertilizer during all growth stages and also supplies part of the nitrate demand of the plant. High solubility of 320 g/l at 20 °C.
Sodium potassium nitrate	$KNO_3.NaNO_3$	Ideal product with a 15% N-nitrate, 14% K_2O. Contains 19% Na to increase the osmotic pressure in the soil solution to improve °Brix and dry matter content of the fruits, both being important characteristics for the tomato industry.
Potassium sulphate	K_2SO_4	Ideal fertilizer for the final growth phase when no N is required. SOP has a limited solubility in farmer's practice of about 6% (when mixed with other fertilizers).
Potassium bicarbonate	$KHCO_3$	Mainly used as a pH corrector to increase the pH.
Potassium chloride	KCl	See 6.2.5 Chloride

6.2.4 Calcium

Table 17. *Characteristics of calcium fertilizers.*

Common name	Formula	Characteristics
Calcium nitrate solid	$(5(Ca(NO_3)_2).NH_4NO_3).10\ H_2O$	By far the most used water soluble calcium source. Solid calcium nitrate contains some ammonium for pH control in hydroponics.
Calcium nitrate liquid	$Ca(NO_3)_2$ in solution	Is free of ammonium and can be used when no ammonium is required.
Calcium chloride	$CaCl_2$	See 6.2.5 Chloride

6.2.5 Chloride

The major chloride sources are $CaCl_2$, $MgCl_2$, KCl and NaCl. Cl is sometimes used to increase the taste of tomato. However, excess of Cl will easily lead to:

Salinization of the rooting zone.

Competition for the uptake sites of the root with other anions (NO_3^-, $H_2PO_4^-$, SO_4^{2-}), resulting in nutrient imbalances.

Incidence of goldspeck (Ca excess imbalance provoked by excess Cl).

Shorter shelf life. Shelf life of fruit tended to decrease with increasing Cl, for fruits severely affected by goldspeck have a shorter shelf life. (Nukaya *et al*, 1991).

6.2.6 Magnesium

Table 18. *Characteristics of magnesium fertilizers.*

Common name	Formula	Characteristics
Magnesium sulphate	$MgSO_4.7H_2O$	Is the most used Mg source. It can't be mixed with calcium in the mother tank (formation of gypsum ($CaSO_4$)).
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	Has a quick dissolution and high solubility, also at low temperature. It is compatible with all other fertilizer sources at the normally recommended doses.

6.2.7 Sulphur

Table 19. *Characteristics of sulphur fertilizers.*

Common name	Formula	Characteristics
Magnesium sulphate	$MgSO_4.7H_2O$	Used to complete the magnesium demand and to supply part of the S.
Potassium sulphate (SOP)	K_2SO_4	Used to supply to remainder of the S demand and part of the K demand in tomato nutrition.
Ammonium sulphate	$(NH_4)_2SO_4$	Its use should be limited to the recommended amounts of S and ammonium to avoid salinity and nutritional imbalances in the root zone.
Sulphuric acid	H_2SO_4	Strong acid. Its use should be limited to the recommended amounts of S and acid.

Sulphate can't be mixed with calcium in the highly concentrated mother solution. This would result in the precipitation of calciumsulphate (gypsum).

6.2.8 Water Soluble and Granular NPK's

Besides the mentioned straight fertilizers, there are also numerous formulae of water soluble and granular NPK mixes available in the market. NPK's are a good alternative for the straight fertilizers as long as they meet the nutritional requirements of the plant during the different growth stages. They can be grouped by phenological stage (Ultrasol™ initial, development, growth, production, multi-purpose, colour, quality, fruit post-harvest, special) or by crop based formulae (Ultrasol™ tomato, sweet pepper, cucumber, flower, strawberry, lettuce). A similar segmentation exists for Qrop™ specialty plant nutrition for field applications.

6.2.9 Summary of Most Used Water Soluble and Granular Fertilizers with Macro and Mesonutrients

Table 20 summarizes the most used water soluble and granular fertilizers and their possible restrictions for use in tomato growing. The table should be read as follows: Each crosspoint of a row and a column represents a fertilizer. For example: where nitrate and potassium cross, the fertilizer is potassium nitrate; where P and K cross, the fertilizer is mono potassium phosphate, etc.

Table 20. *Summary of most used water soluble and granular fertilizers and their possible restrictions for use in tomato growing.*

		H acid	$N\text{-}NO_3$ nitrate	$N\text{-}NH_4$ ammonium	$N\text{-}NH_2$ urea	P phosphor	K potassium	Ca calcium	Mg magnesium	S sulphur	Cl chloride
H	acid		X			X				(X)	
$N\text{-}NO_3$	nitrate	X		(X)			X	X	X		
$N\text{-}NH_4$	ammonium		(X)			X				(X)	
$N\text{-}NH_2$	urea				■	(X)					
P	phosphor	X		X	(X)		X	(X)			
K	potassium		X			X				X	■
Ca	calcium		X			(X)			X		■
Mg	magnesium		X					X		X	■
S	sulphur	(X)		(X)			X		X		
Cl	chloride						■	■	■		
NPK			X	(X)	■	X	X		X		

X prefered source
(X) source with restricted use
■ not recommended

6.2.10 Micro-elements

Table 21 summarizes the main sources of micro-nutrients used in fertigation, foliar and field applications. For fertigation and foliar applications, iron (Fe) should be applied as a chelate. The type of chelate depends on the pH of the irrigation water and soil: Fe-EDTA (pH < 6), Fe-DTPA (pH < 7) and Fe-EDDHA (pH > 7). In case of EDDHA at least 50% of the Fe should be chelated by the ortho-ortho isomer, whereas 80% ortho-ortho will provide the highest stability of the Fe in the chelate. On top of the products listed in Table 21, numerous trace element mixes and other specialty products are available. Contact your local SQM agronomist or distributor to learn more about these products.

Table 21. *Summary of the main sources of micro-nutrients used in fertigation, foliar and field applications.*

Symbol	Nutrient	Main sources	Remarks
Fe	Iron	EDTA	For fertigation when pH<6 and as foliar.
		DTPA	For fertigation when pH<7.
		EDDHA	For fertigation when pH>7.
Zn	Zinc	EDTA	EDTA dissolves easier than sulphate.
		Sulphate	
Mn	Manganese	EDTA	EDTA dissolves easier than sulphate.
		Sulphate	
Cu	Copper	EDTA	EDTA dissolves easier than sulphate.
		Sulphate	
B	Boron	Boric acid	Acidifying effect. Plants absorb boron only as boric acid, thus making it the most efficient boron source.
		Sodium borate	Alkaline reaction.
		Ulexite	A sodium calcium borate with 32% B_2O_3 for progressive release of boron. This reduces the risk of boron toxicity and secures a long period of boron supply to the plant.
Mo	Molybdenum	Sodium molybdate	Sodium molybdate is the cheaper source.
		Ammonium molybdate	

7 Plant Nutrition Practices and Effective Programmes

An effective plant nutritional programme for open field tomato and for greenhouse tomato can now be designed, based on the information which has been presented priory in this Specialty Plant Nutrition Management Guide.

Crop specific programmes will depend on a variety of variables. Consult your local SQM distributor or agronomist to find out which nutrition management programme is suitable for your area.

Hereunder we provide you with an example of how to calculate the fertilizer recommendation for soil grown tomato.

To make a fertilizer recommendation for soil grown tomato one should follow the following steps:

- Analyze soil or soil solution and water before planting.
- Balance the soil according to the analysis and add strategic reserves in the base dressing.
- When organic matter or manure is used, take into consideration that this can release substantial amounts of nutrients during the growing phase. These amounts have to be used in the calculation of the final fertilizer programme.
- The fertilizer scheme should be based on the nutrient absorption per phenological phase, in relation to the expected yield, nutrient reserves in the soil and the nutrient absorption efficiency per irrigation system.
- After calculating the total nutrient application needed for the expected yield, fertilizers can be selected for each phenological phase.
- It is recommended to analyze the soil again at 4-6 weeks and 8-10 weeks after planting (flower initiation, fruitset), or to analyze the soil solution via alternative methods on a regular base and correct the fertilizer dose if necessary.

Table 22 shows the nutrient demand of tomato in relation to an expected yield of 100 tonne of tomato/ha under drip irrigation.

After having calculated the total nutrient need, one should deduct the amount of nutrients present in the soil and irrigation water, available for plant nutrition. This should be measured as water soluble nutrients. Acidification of the irrigation water by using e.g. urea phosphate, nitric or phosphoric acid might neutralize calcium and magnesium carbonates and bicarbonates, thus increasing the availability of these nutrients for plant nutrition. The remainder has to be divided by the efficiency of each nutrient applied via drip irrigation. An example is given in Table 23.

In the next step the nutrients have to be divided per phenological phase. Table 24 is showing a split per nutrient per phenological phase. Multiplying the total nutrient application (kg/ha) and the nutrient application per phenological phase (%) results in the nutrient need per phenological phase expressed in kg nutrient/ha. From Table 24 the amount of water soluble fertilizer/ha can be calculated per phenological phase. Check with your local SQM agronomist to see which products are most suitable to match this calculation.

Table 22. *Nutrient demand of 100 tonne tomato/ha under drip irrigation.*

Step 1	Characteristics soil and tomato plant	Unit	N	P_2O_5	K_2O	CaO	MgO	S
	Nutrient required for canopy formation	kg/ha	95	27	130	260	95	76
	Nutrient required for fruit production	kg/t	1,8	0,39	3,77	0,17	0,24	0,12
	Nutrient required for fruit production (t)	100	180	39	377	17	24	12
	Total (canopy + fruit production)	kg/ha	275	66	507	277	119	88

Adapted from: Fertirrigacão, 1999; Cristou et al, 1999; Voogt, 1993

Table 23. *Example deducting nutrient reserves from nutrient demand for 100 tonne tomato/ha under drip irrigation and correction for the efficiency of each nutrient applied via drip irrigation.*

Step 2	Characteristics soil and tomato plant	Unit	N	P_2O_5	K_2O	CaO	MgO	S
	Assumption: reserves in soil and water/base dressing	kg/ha	55	36	82	187	59	43
	To be applied via fertigation	kg/ha	220	30	425	90	60	45

Step 3	Nutrient uptake efficiency drip irrigation	Unit	N	P_2O_5	K_2O	CaO	MgO	S
		%	80	30	85	60	60	60
	Total fertilizer application	kg/ha	275	100	500	150	100	75

Table 24. *Split of nutrients per phenological phase expressed in percentages and in kg/ha.*

Step 4	Fertilizer application phases	DAT (*)	N %	P_2O_5 %	K_2O %	CaO %	MgO %	S %
	Transplant establishment	0-14	5	17	5	5	5	5
	Plant development	15-28	12	17	7	15	20	20
	From flower initiation to begin fruitset	29-42	20	17	17	20	20	20
	From begin fruitset to fruit formation	43-63	20	16	20	20	20	20
	From fruit formation to first harvest	64-84	17	17	18	20	20	20
	From first harvest to full harvest	85-112	17	16	18	15	15	15
	From full harvest to end of harvest	113-140	9	0	15	5	0	0
		TOTAL	100	100	100	100	100	100

Step 5	Fertilizer application phases (grouped)	DAT (*)	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	CaO kg/ha	MgO kg/ha	S kg/ha
I	Transplant establishment to plant development	0-28	47	34	60	30	25	19
II	From flower initiation to fruit formation	29-63	110	33	185	60	40	30
III	From fruit formation to full harvest	64-112	94	33	180	53	35	26
IV	From full harvest to end of harvest	113-140	25	0	75	8	0	0
		TOTAL	275	100	500	150	100	75

(*) DAT = Days After Transplanting.

A similar calculation can be made for dry applied granular fertilizers in rainfed or flood irrigated tomato. In that case the following nutrient efficiency percentages can be used in Table 23 under point 3:

Table 25. *Nutrient efficiency percentages for dry applied fertilizers under rain fed or flood irrigation tomato.*

Nutrient	%
N	40-50
P	10-20
K	50-60
Ca	35-45
Mg	30-40
S	30-40

Nitrogen should be split into 3 to 5 applications. The first application (base dressing) may contain more ammonium than nitrate, but the next applications should contain more nitrate than ammonium. About 55-60% of all nitrogen should be applied until the start of flowering, the remainder to be applied afterwards in split applications.

All phosphorus may be applied during base dressing. A foliar application of phosphorus during flowering is recommended in combination with boron and zinc.

Potassium may follow the same split applications as nitrogen. In the first application a mix of 55% potassium nitrate and 45% potassium sulphate may be used, but in the next applications prilled or granular potassium nitrate is the preferred potassium source. About 40% of the total K should be applied until the start of flowering, the remainder to be applied afterwards in split applications.

Calcium should be applied as calcium nitrate during all growth stages of the plant. A small quantity may be included in the base dressing followed by higher amounts during vegetative growth and fruit development.

Some magnesium could be included in the basedressing, followed by higher doses during the vegetative growth and fruit formation phase.

Sulphur may be fully applied in the basedressing.

Trace elements should be applied according the need. The soil pH will decide for the preferred source of trace element (chelate, salt) to be used.

Ask your local SQM agronomist for an adapted programme
in accordance with the local needs and requirements.

8 Research Results Demonstrating the Need for Balance

This chapter shows a selection of scientific research to demonstrate the effect of nutrients and nutrient (im)balances on yield and quality and the importance of selecting the proper plant nutritional products.

The highest levels of K, Ca and Mg in several plant organs of sweet pepper were found with nitrate being the N source (Table 26) (Xu *et al*, 2001).

Table 26. *The effect on K, Ca and Mg uptake in various plant parts of sweet pepper when fertilized with nitrate or ammonium fertilizers.*

Organ	N-Source	Nutrient content in the dry matter (meq/100g)		
		K	Ca	Mg
Leaf	NO_3	58	161	30
	NH_4	29	62	25
Petiole	NO_3	176	126	38
	NH_4	90	61	17
Stem	NO_3	162	86	35
	NH_4	54	50	18
Root	NO_3	93	44	40
	NH_4	43	38	11

The use of ammonium may induce an imbalance in plant nutrition. Ammonium competes with the uptake of other main cations (antagonism) like potassium, magnesium and calcium that may induce nutritional disorders. In particular, an excess of ammonium may lead to BER problems, resulting from a shortage of calcium in fruits, even if ample Ca is present in the nutrition solution.

Table 27 shows the negative effect of ammonium-nitrogen on the proportion of fruit affected by BER and on the calcium content of the leaves of tomato plants grown in nutrient film culture (after Massey and Winsor, 1980).

Table 27. *The effect of ammonium-nitrogen on the proportion of fruit affected by BER and on the calcium content of the leaves of tomato plants grown in nutrient film.*

Effect	% N supplied as ammonium-N		
	0	20	40
Fruits affected by BER in the first 4 harvests (% by number)	0,0	24,0	46,0
Calcium content of leaves (% Ca)	1,8	1,5	0,9

Table 28 shows the results of the tomato response to N fertilization in hydroponics (Sonneveld and Voogt, 1983; Sonneveld and Voogt, 1985). The overall best result was obtained with 100 % N-NO_3^-. When 25% or 50% of the nitrogen was applied as ammonium or urea, the incidence of BER increased. However, an N fertilization with 100% N-NO_3^- also led to the highest chlorosis index. Therefore in hydroponics about 7% of the N-total should be N-NH_4^+ and 93% N-NO_3^-. The ammonium will reduce the pH in the rooting zone, keeping the micro-nutrients in an available form for easy plant uptake, whereby reducing the incidence of chlorosis (Fe, Mn deficiency).

Table 28. *Tomato yield and quality response to N fertilization in hydroponics.*

Treatment in %			Yield	Fruit weight	BER %	Chlorosis
NO_3	NH_4	Urea	relative	relative		index
100			100	100	0,2	5,2
75	25		101	100	3,0	3,5
50	50		96	90	2,8	2,7
75		25	94	94	2,2	4,4
50		50	104	97	4,2	1,0
75	25)*		96	94	2,7	3,6
50	50)*		101	93	2,1	2,0

) with nitrification inhibitor*

Table 29 shows that there was more uniformity in shape and ripeness at higher K levels (Winsor, 1979).

Table 29. *Some effects of K on the shape of tomato fruit and on the incidence of ripening disorders.*

Effect	Potassium applied (kg/ha)			LSD
	359	706	1.428	(P = 0.05)
% irregularly shaped (amongst the uniformly coloured fruit)	56,3	32,6	28,0	2,9
% unevenly ripened	40,4	12,4	5,8	3,3
% unevenly ripened (severe forms only)	24,1	5,3	1,3	2,6

% By weight

There is a positive relation between the K level in the leaf and acidity (Figure 66). Acidity is one of the main taste components of tomato (Adams *et al*, 1978).

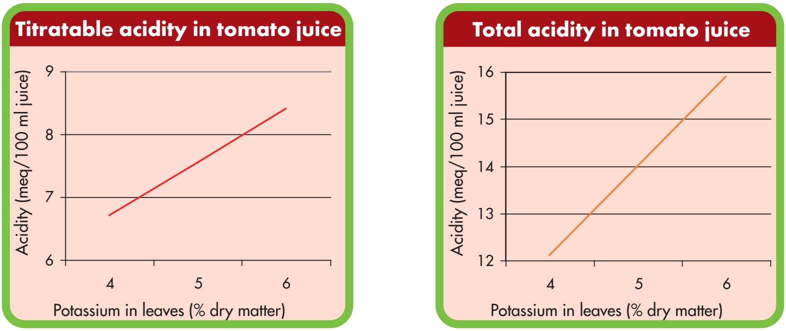


Figure 66. *Relation between the potassium content of tomato leaves and the titratable (left) and total acidities (right) of the fruit juices.*

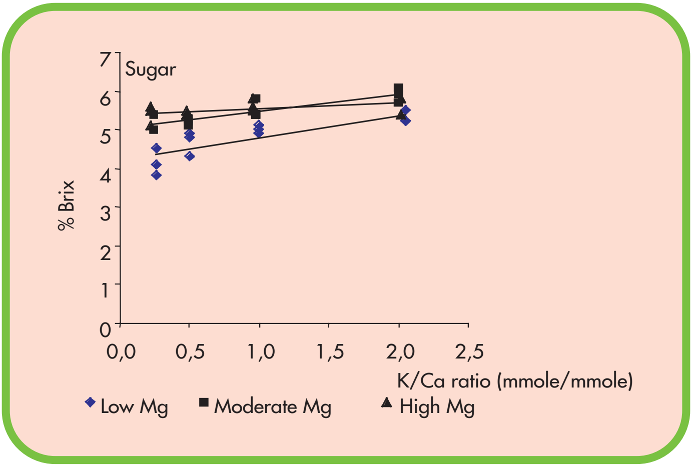
Table 30 describes the effect of the EC-value on fruit quality of tomato (Sonneveld and Voogt, 1990). At higher EC (which corresponded with a higher fertilizer application) there was a better colouring, longer shelf life, and higher acidity and °Brix.

Table 30. *The effect of the EC-value on fruit quality of tomato.*

EC root environment mS/cm	Lack of colour %	Shelf life in days	Fruit sap EC mS/cm	Fruit sap Acidity mmole/l	Fruit sap Sugar °Brix
0,75	21	6,2	4,5	5,9	4,1
2,50	17	6,6	5,1	6,6	4,1
5,00	2	9,1	5,5	7,6	4,6

+

Figure 67 shows that a higher K/Ca ratio (mmole/mmole) in the nutrient solution led to more °Brix and increased shelf life. It also demonstrates that independent of the K/Ca ratio, the higher the Mg level, the more °Brix and the longer the shelf life.



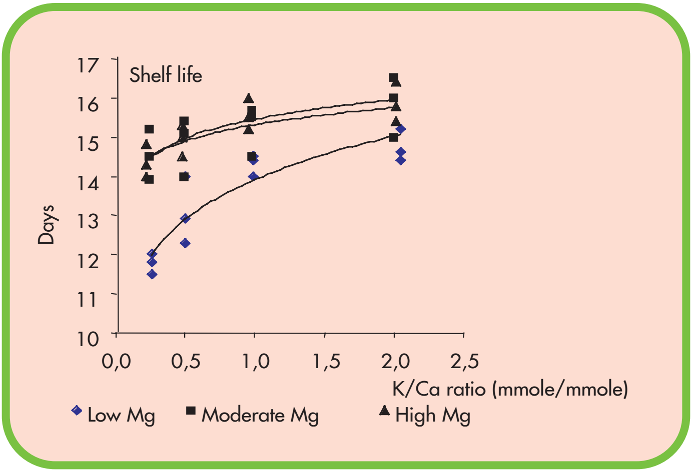


Figure 67. *The sugar content and shelf life of tomato at different K, Ca and Mg ratios (Voogt, 2002).*

Potassium is responsible for lycopene synthesis in tomato. Lycopene is:

- A carotenoid that gives the red colour to tomatoes.
- An antioxidant and anti-cancer (prostate, lung, skin, cervix, bladder).
- Present in tomato ketchup, paste, sauce and juice.

A trial with the tomato paste industry in Turkey proved that more K led to a higher lycopene content (Table 31). The industry's target is to achieve 14 ppm lycopene.

Table 31. *The effect of the dose of KNO_3 on the lycopene level in the fresh tomato fruit.*

Dose KNO_3 in kg/ha	Lycopene in ppm
100	10,3
200	13,3

Soils might contain high amounts of Ca. This is mainly $CaCO_3$, which is not available for plant growth. A study in Turkey (Table 32) showed that even in a clay loam soil, with pH 7.45 and 4.400 ppm Ca, an application with calcium nitrate resulted in higher yield, more °Brix and more fruit firmness.

Table 32. *The effect of CN application on yield, °Brix and fruit firmness on a clay loam soil in Turkey (Kilinc and Tuna, 1996).*

CN dose kg/ha	Yield t/ha	°Brix	Firmness kg/cm²
0	64	5,25	2,25
100	63	5,55	2,26
200	71	5,82	2,38
300	87	6,05	2,54
F	*	**	**

F = probability

** = significant at 0.05 level*

*** = significant at 0.01 level*

A high K/Ca ratio (mmole/mmole) and high Mg levels in the nutrient solution compete with the Ca uptake of the plant. A lack of calcium results in BER (Figure 68).

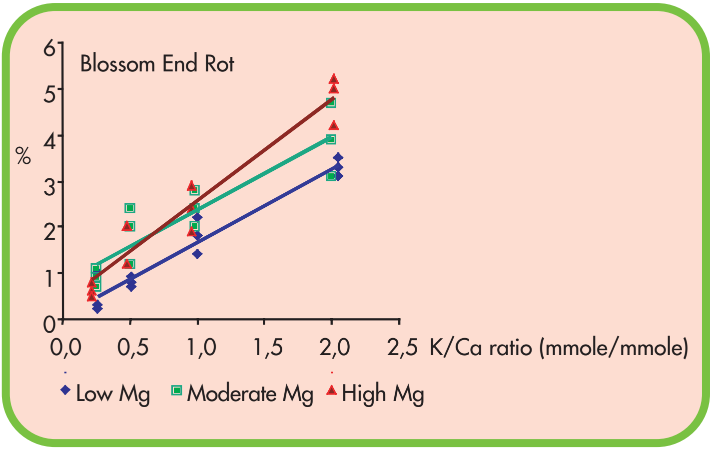


Figure 68. *The effect of different K, Ca and Mg ratios in the nutrient solution on BER (Voogt, 2002).*

Calcium excess imbalance symptoms

Goldspeck is a symptom of an excess imbalance of calcium. Unbalanced plant nutrition with a relatively high level of calcium and low levels of K and Mg in the nutrient solution (in mmole) promotes the incidence of goldspeck (Figure 69). Increased Cl levels promote Ca-uptake and increase goldspeck incidence (but reduce BER). Fruits affected by goldspeck have a shorter shelf life.

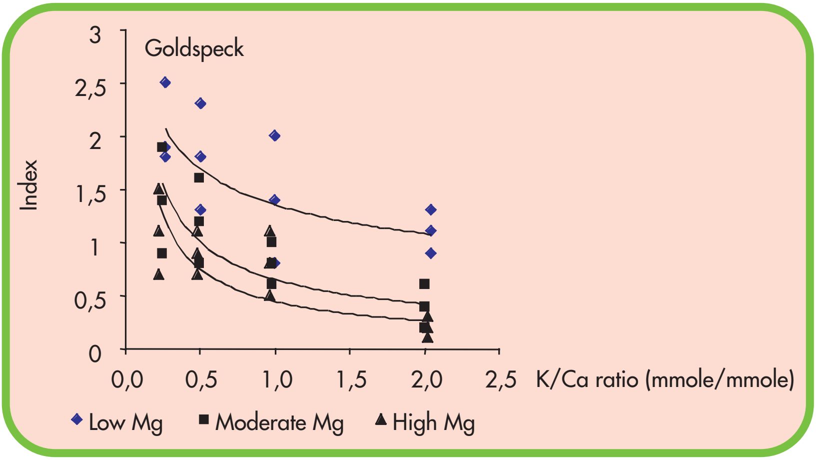


Figure 69. *The effect of different K, Ca and Mg ratios in the nutrient solution on the incidence of goldspeck (Voogt, 2002).*

9 Proven Cost Effectiveness of Balanced Nutrition Programmes

Demonstration plots in many countries worldwide in open field tomato (fresh market, industry) and in greenhouses have confirmed that a higher use of base-dressing and water soluble fertilizers in a more balanced nutritional programme result in a higher financial income for the farmer after deducting the extra costs of fertilizers.

The summary of the demo fields in fresh market tomato grown in open field with drip irrigation is presented below. SQM balanced nutritional programme is compared with the farmers programme. Although the total fertilizer input almost doubled (Table 33), after deducting the extra cost of fertilizers, the farmer earned on average 4.700 US$/ha extra income (Table 34).

The main results were:

- Cost/beneficial.
- Higher yields.
- Earlier harvest, which resulted in higher market, prices.
- Higher prices because of better colour, size and shape.
- More °Brix and lycopene (important for the industry).
- Less BER.
- Less susceptible to diseases *(Verticillium)*.
- Increased stress resistance (no loss of clusters under very hot weather conditions).

Table 33. *Comparison of fertilizer input in a traditional and a SQM balanced nutritional programme for fresh market tomato grown in open field with drip irrigation.*

Fertigation Water Soluble SPN	SQM kg/ha	Farmer kg/ha	Difference kg/ha
Total	3.520	1.881	1.639

The results of the demos in the open field grown tomato for the fresh market are presented in Table 34. For every 1 US$ extra investment 5,1 US$ extra income was generated, which gives a return on investment of 515%.

Table 34. *Comparison of the cost benefit ratios of demos with fertilizer input in a traditional and a balanced nutritional programme in open field tomato, grown for the fresh market.*

Parameter Average over 8 trials	Unit	Farmer programme	Balanced nutrition	Difference absolute	%
Yield	t/ha	87	116	29	33
Price tomato	US$/t	152	163	11	7
Gross income	US$/ha	13.276	18.927	5.651	43
Total fertilizer cost	US$/ha	2.026	2.945	919	45
Net income	US$/ha	11.250	15.982	4.732	42
Benefit/cost ratio				5,1	515

The result of a demo in the open field grown tomato for the industry is presented in Table 35. For every 1 US$ extra investment 3,6 US$ extra income was generated, which gives a return on investment of 364%.

Table 35. *Comparison of the cost benefit ratio of a demo with fertilizer input in a traditional and a balanced nutritional programme in open field tomato, grown for the industry.*

Parameter	Unit	Farmer programme	Balanced nutrition	Difference absolute	%
Yield	t/ha	86	109	24	27
Price tomato	US$/t	67	67	0	0
Gross income	US$/ha	5.749	7.323	1.575	27
Total fertilizer cost	US$/ha	212	552	340	160
Net income	US$/ha	5.537	6.772	1.235	22
Benefit/cost ratio				3,6	364

The results of the demos in the greenhouse grown tomato for the fresh market are presented in Table 36. For every 1 US$ extra investment 7,9 US$ extra income was generated, which gives a return on investment of 794 %.

Table 36. *Comparison of the cost benefit ratios of demos with fertilizer input in a traditional and a balanced nutritional programme in greenhouse grown tomato.*

Parameter Average over 5 trials	Unit	Farmer programme	Balanced nutrition	Difference absolute	Difference %
Yield	t/ha	167	189	22	13
Price tomato	US$/t	406	406	0	0
Gross income	US$/ha	67.931	76.696	8.765	13
Total fertilizer cost	US$/ha	2.744	3.724	980	36
Net income	US$/ha	65.187	72.972	7.785	12
Benefit/cost ratio				7,9	794

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