CropKit

Specialty Plant Nutrition Management Guide

Capsium Pepper

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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 **Capsicum Pepper Nutrition Management Guide** summarizes the main market requirements and the nutrient management needed to produce high yields of top quality fresh and processing Capsicum peppers.

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.

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Introduction

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

Chapter 1 describes how nutrition management in pepper 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, during which a traditional pepper nutrition programme was compared to a balanced nutrition programme. The demo was carried out in open field grown pepper for the fresh market.

Chapter 10 features a literature overview.

Note on booklet value-expression convention:
(.) Period: indicates thousands.
(,) Comma: demarcates the place of the decimal.
The number 1.500,5, stated in words, is
"One thousand five hundred and five tenths".

1 Crop Nutritional Status as it Relates to Performance

This chapter describes how pepper 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 fertilisation 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.

Fertilisers, whether applied on the aboveground parts or to the soil, should be viewed as nutritional-balance management tools. Fertilisation 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 Pepper Crop Description

This chapter describes the pepper crop with regard to: botanical family, heat, varieties, morphology, world production and crop statistics, climate (temperature, light), water and soil, organic matter and manure, salinity, phenology, 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 pepper crop in general and will help to make proper nutrition management decisions.

2.1 Botanical Name

Capsicum peppers have been grown in Central and South America long before the arrival of Columbus, specifically in Peru and Bolivia.

Capsicum peppers belong to the family of the *Solanaceae*, which includes tomato, potato and eggplant. There are five domesticated species of Capsicum (Dewitt and Bosland, 1996):
Capsicum annuum: Bell Pepper, Serrano Chili, Jalapeños.
Capsicum chinense: Habaneros, Datil.
Capsicum frutescens: Tabasco, Malagueta.
Capsicum baccatum: Christmas Bells, Ajis and Piquins.
Capsicum pubescens: Rocotos.

2.2 Heat

Peppers can be segmented by their heat into sweet pepper and hot pepper:
1. Sweet pepper or bell pepper fruit contains little or no capsaicin. This alkaloid causes a burning sensation when it comes in contact with the sense receptors in your tongue. The capsaicin level determines the heat or pungency of pepper. Therefore bell pepper fruit is sometimes referred to as 'sweet' pepper.
2. Hot pepper or chilis. Collectively, these hot types are sometimes referred to as 'chilis'. Chilis is a generic name, given to a broad range of over 200 varieties of hot peppers. Shapes vary from the large Anaheim and Poblano types to the short, chunky Jalapeño, the small round Habanero, and finally the short, slim Serrano Chili and Thai types. Capsaicin content also varies from mild to extremely hot.

Two methods exist to express the heat or pungency of peppers:
1. Scoville Heat Units (oral test).
2. American Spice Trade Association (ASTA) units (HPLC test).

Mr Wilbur Scoville soaked each different variety of pepper separately in alcohol overnight. Because capsaicin is soluble in alcohol, the soaking extracted the pungent chemicals from the pod. Then he took a precise measure of the extract and to it added sweetened water in incremental portions until the presence of pungency was barely detectable on his tongue. In the case of Japan chilis, it took sweetened water in volumes between 20.000 to 30.000 times the pepper extract before the pungency was barely discernable. He thus rated the Japan chilis 20.000 to 30.000 Scoville Heat Units. If all known peppers were measured using this technique, their scale of pungency would range from 0 Scoville Heat Units, for the bell pepper, to 350.000 units, for the Mexican Habanero (www.tabasco.com, 2006).

The American Spice Trade Association (ASTA) uses the HPLC machine (High Pressure Liquid Chromatograph). Measurements are expressed in so called ASTA units. ASTA Pungency expresses the amount of capsaicin in ppm. Pure capsaicin equals 1 million ppm capsaicin. Figure 1 expresses the conversion from one measurement to the other.

The conversion from ASTA to Scoville Heat Units is:

ppm capsaicin x 15 = Scoville Heat Units.
1 ppm capsaicin = 1 ASTA unit = 15 Scoville Heat Units.
1.000.000 ppm capsaicin (pure capsaicin) = 15.000.000 Scoville Heat Units.

The conversion from Scoville Heat Units to ASTA is:

1.000 Scoville Heat Units equal 66,7 ASTA units.

Figure 1. *The conversion from ASTA to Scoville Heat Units and the conversion from Scoville Heat Units to ASTA units.*

Genetic make-up, growing conditions, maturity at harvest and any stress the plants endure have an effect on pungency. Too little or too much water, temperature extremes, low soil fertility or other stress conditions can significantly increase the capsaicinoid content.

Table 1 on Page 10 gives an overview of selected pepper varieties and their Scoville values.

Table 1. *Selected pepper varieties and their Scoville values. A low Scoville value is referred to as being a sweet pepper, and high Scoville Heat Unit as being a hot pepper.*

Scoville Heat Unit	Type of Pepper
0	Bell Pepper Sweet Italian Pimento
100-500	Pepperoncini
500-1000	New Mexican Anaheim Mulato
1.000-1.500	Española Poblano
1.000-2.000	Ancho Pasilla
1.000-2.500	Cascabel Cherry
1.500-2.500	Rocotillo
2.500-5.000	Jalapeño Mirasol Puya Guajillo
5.000-10.000	Hungarian Wax
5.000-20.000	Serrano
12.000-30.000	Manzano
15.000-30.000	Chile de Arbol
30.000-50.000	Rocoto Cayenne
50.000-100.000	Tabasco Chiltepin Santaka
100.000-200.000	Thai Jamaican
100.000-350.000	Habanero Scotch Bonnet
575.000-600.000	Red Savina
15.000.000	Pure Capsaicin

2.3 Pepper Varieties

Sweet peppers vary in size (bell, elongated, rectangular) and colour. Commercial bell peppers are harvested when green, but if left on the bush, fruit will turn red. Specialty cultivars which ripen to yellow, orange, or purple as well as red have become popular because of the attractive, tender fruit (Figure 2).

Figure 2. *Various shapes and colours of sweet pepper.*

Hereunder follows a description of various hot pepper varieties:

Jalapeño (*Capsicum annuum*) is a mildly hot pepper (Scoville: 4.000–6.000), used for fresh market consumption and processing (pickled, sauces, dried over smoke 'chipotle'). The fruit is maturing from dark green to red (Figure 3).

Figure 3. *Jalapeño pepper.*

Serrano Chili (*Capsicum annuum*) is a mildly hot pepper (Scoville: 4.000–6.000), used for fresh market consumption (fresh table sauce). The pepper fruit is cylindrical with a tapered tip and green to red in colour (Figure 4).

Figure 4. *Serrano Chili pepper.*

Guero (*Capsicum annuum*) is a generic term for yellow chilis. It usually applies to pale yellow tapered chilis such as **Hungarian Wax** or Banana chilis or the Santa Fe grande. Guero type of peppers are mildly hot with Scoville 2.500–4.000 for Banana or Hungarian Wax type of pepper, and Scoville 5.000–8.000 for Santa Fe type. Guero is used for fresh market consumption (Figure 5).

Figure 5. *Guero pepper.*

Ancho (*Capsicum annuum*) or Poblano peppers can be used for fresh market consumption or are dried and used in the manufacture of pastes (mole) and in the extraction of pigment. Ancho, Mulato, Miahuateco and Chorrón chili peppers all belong to the same group of peppers with only small differences in the type of crop, preferred growing conditions and use. Fruit shape, colour and large size are of importance, but more essential are the organoleptic characters of aroma and flavour, particularly in this type of pepper. Thickness of pericarp is an indicator for high dry matter content which produces higher quality upon drying. Peppers are mildly pungent with Scoville: 500–2.000 (Figures 6 and 7).

Figure 6. *Fresh Ancho pepper.*

Figure 7. *Dried Ancho pepper.*

Pasilla (*Capsicum annuum*) is a hot pepper, used for processing (drying – used in the manufacture of "molés" and dark sauces). Peppers are mildly pungent with Scoville: 500–2.000 (Figure 8).

Figure 8. *Pasilla pepper.*

Mirasol (*Capsicum annuum*) is a hot pepper, used for processing. Peppers are mildly pungent with Scoville: 2.500–5.000 (Figure 9).

Figure 9. *Mirasol pepper.*

Puya and **Guajillo** (*Capsicum annuum*) are other types of hot pepper, used for processing (hot sauces, "molés", pigment extraction). Scoville of both peppers is 5.000 (Figures 10 and 11).

Figure 10. *Puya pepper.*

Figure 11. *Guajillo pepper.*

Habanero is the main variety within the *Capsicum chinense* group, followed by **Scotch Bonnet** and **Jamaican Hot**. It is used for fresh consumption and for processing into sauces. Scoville ranges from 100.000-350.000 for these varieties. Habanero and Scotch Bonnet have a strong aroma (Figures 12 and 13).

Figure 12. *Habanero pepper.*

Figure 13. *Scotch Bonnet pepper.*

Rocoto (Scoville 30.000-50.000) is the main variety within the *Capsicum pubescens* group, followed by Manzano pepper (Scoville 12.000-30.000). It is used for fresh consumption (Figures 14 and 15).

Figure 14. *Rocoto pepper.*

Figure 15. *Manzano pepper.*

Tabasco is the main variety within the *Capsicum frutescens* group, followed by **Malagueta** and **Tezpur**. Scoville ranges from 50.000-100.000 (Figure 16).

Figure 16. *Tabasco pepper.*

Ajies Amarillos and **Ajies Cristal** are the main varieties within the *Capsicum baccatum* group (Figure 17).

Figure 17. *Aji Cristal Estandar pepper.*

2.4 Morphology

Figure 18 describes the morphology of the plant.

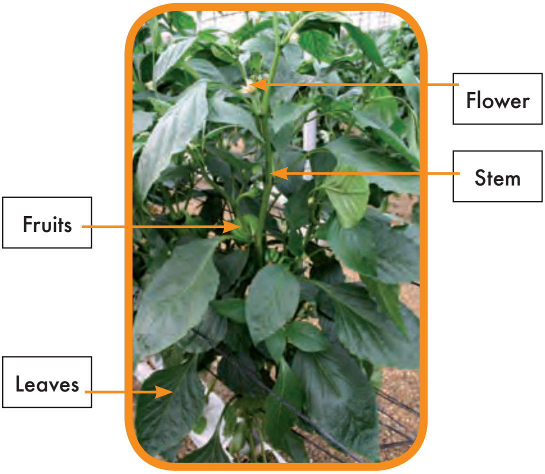

Figure 18. *Morphology of the pepper plant.*

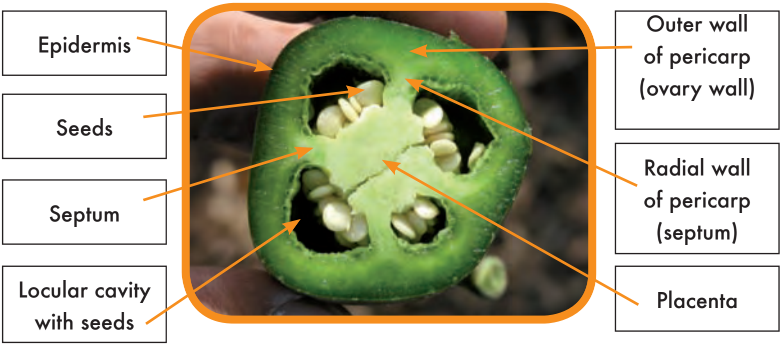

Figure 19. *Cross section of pepper fruit.*

In general, peppers are bilocular, trilocular or tetralocular (as in Figure19), although pentalocular and hexalocular morphotypes also exist. In hot chili peppers, the placental region contains up to 89 percent of the alkaloid capsaicin. This alkaloid causes a burning sensation when it comes into contact with the sense receptors in your tongue.

2.5 Global Production

Six countries are responsible for 76,6% of the world pepper production (in tonnes). China produces 50,1% of the world production (Table 2). Mexico, Turkey, Spain, the USA and Nigeria are accountable for another 26,5% of the world production.

Table 2. *Overview of the major pepper producing countries, their production (x thousand tonnes) and their relative market share (MS) in the global pepper production (%).*

Ranking	Country	Production (* 1.000 t)	MS (%)
1	China	12.028	50,1
2	Mexico	1.854	7,7
3	Turkey	1.790	7,5
4	Spain	1.006	4,2
5	United States of America	978	4,1
6	Nigeria	720	3,0
7	Indonesia	629	2,6
8	Egypt	390	1,6
9	Italy	362	1,5
10	Korea, Republic of	340	1,4
11	Netherlands	318	1,3
12	Ghana	270	1,1
	Subtotal 1-12	**20.685**	**86,2**
	Rest of the world	**3.321**	**13,8**
	TOTAL	**24.006**	**100,0**

Source: FAOSTAT data, 2005.

Five countries are responsible for 65,2% of the world harvested area (Table 3): China, Indonesia, Mexico, Nigeria and Turkey.

Table 3. *Overview of the major pepper producing countries, their harvested area (x 1.000 ha) and their relative market share (MS) in world harvested area (%).*

Ranking	Country	Harvested Area (ha)	MS (%)
1	China	602.500	36,5
2	Indonesia	154.537	9,4
3	Mexico	140.693	8,5
4	Nigeria	91.000	5,5
5	Turkey	88.000	5,3
6	Ghana	75.000	4,5
7	Korea, Republic of	65.000	3,9
8	United States of America	34.400	2,1
9	Benin	27.500	1,7
10	Egypt	26.000	1,6
11	Korea, Dem People's Rep	25.000	1,5
12	Spain	21.800	1,3
	Subtotal 1-12	**1.351.430**	**81,8**
	Rest of the world	**301.086**	**18,2**
	TOTAL	**1.652.516**	**100,0**

Source: FAOSTAT data, 2005.

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

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

Growing system	Yield in t/ha
Average world*	14,5
Open field rain fed	20-50
Open field drip/fertigation	50-80
Greenhouse non-heated (9 months cycle)	100-150
Modern greenhouse Netherlands year round	250-300

Source: FAOSTAT data, 2005.

2.6 Climate

Proper management of climate factors, like day and night temperature, relative humidity and radiation play a fundamental role in the correct generative development of the crop. Knowing their optimal and limiting values and the relationships among these factors will highly facilitate a proper crop management.

2.6.1 Temperature

Pepper is a warm-season crop and needs higher temperatures as compared to tomato, and lower temperatures as compared to eggplant (IFA, 2006).

Ideal temperature range

The ideal temperature for pepper ranges between 18 and 28 °C (Table 5). For this reason, most outdoor crops are grown in temperate climates, between 30th and 40th parallels in both the northern and the southern hemisphere.

The combination of a night and day temperature regime of 15,6-21,1 °C and a high moisture level in the soil gave highest fruit set (Cochran, 1936). A night temperature of 20 °C after flowering enhanced fruit size and number of seeds, and accelerated fruit development. Fruit weight increased along with the increase in the number of seeds per fruit (Rylski, 1973).

Table 5. *Critical temperatures in different growth stages of pepper.*

Growth stage	Temperature (°C)		
	Optimal	Minimum	Maximum
Germination	20-25	13	40
Vegetative growth	20-25 (day) 16-18 (night)	15	32
Flower and fruiting	26-28 (day) 18-20 (night)	18	35

Night temperatures

The night temperatures determine the growth of the pepper plant in general and flowering and fruit set in particular.

Low night temperatures ensured fruit set, but at the same time prevented normal fruit growth and promoted fruit set without or with few seed (Rylski and Spigelman, 1982) (Figures 20 and 21). Low night temperatures (15 °C) increased fruit set in general and that of parthenocarpic (seedless) fruit in particular (Rylski and Spigelman, 1982). The number of seeds produced at low temperature only reached 50% of the potential number of seeds as determined by ovule count (Rylski, 1973). Parthenocarpic fruit is generally smaller than fertile fruit. When conditions are not conducive to fertility, flowers usually abscise; but, occasionally when night temperature after anthesis is low, these flowers set parthenocarpic fruit (Rylski, 1973).

At low day temperatures below 16-18 °C flower formation is negatively affected, while night frost will result in serious crop damage.

***Figure 20.** Abnormal fruit growth (left) and flattened, seedless bell pepper fruit caused by low night temperatures in the winter production season in Almería, Spain (right).*

***Figure 21.** Normal pepper fruit full of seeds (left) as compared to a deformed pepper fruit with almost no seeds (right). Deformed fruit with reduced seed formation can be caused by low night temperatures after anthesis.*

High night temperatures (24 °C) increase blossom drop (Rylski and Spigelman, 1982)(Figure 22). Excessively high, as well as low night temperature results in the production of non – productive pollen. Seedless fruits are generally accompanied by various degrees of deformation in fruit shape (Rylski, 1973).

Figure 22. *Increased flower abortion and blossom drop can be caused by high night and day temperatures.*

High day temperatures

Temperatures above 32 °C in combination with low humidity will lead to flower abortion (Figure 22), while pollen viability is strongly reduced by drying out.

The air temperature at 15 days before anthesis is positively correlated with the percentage of sterile pollen. A daily temperature over 30 °C will result in poor fruit set, while fruit set increases when the daily temperature drops to 20 °C, being the optimal temperature for fruit set. Possible reasons for decreased fruit set at higher temperatures may be found in an excess in transpiration or insufficient sugar translocation.

A balanced plant nutrition programme instead of an unbalanced one has proven to reduce the loss of flower clusters under these high temperature conditions.

2.6.2 Light

Plants absorb radiation of 400-700 nm in their chlorophyll cells and use it as energy for photosynthesis (to transform CO_2 gas into sugars). Therefore radiation of 400-700 nm is called PAR (Photosynthetic Active Radiation, expressed in Joules/s/m^2). PAR 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 pepper yield can be.

PAR accounts for about 45-50% of the global radiation (300-1100 nm). Many control computers use radiation measurements. For instance an irrigation cycle is started when a certain sum of radiation is measured, expressed in J/cm^2 or MJ/m^2 or a derived unit (Nederhoff, 2001).

Pepper is a light demanding species, especially at the beginning of the reproductive phase (Prieto *et al*, 2003).

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.

In greenhouse growing it would be ideal to utilise the light, while keeping the temperatures down and maintaining optimal transpiration for leaf cooling. Shading or whitewashing a greenhouse reduces the temperature, but inadvertently also reduces the light influx. Table 6 shows that shading resulted on average in 42% more flower and bud loss and 13,5 tonne/ha (65%) less yield (Wien, 1994). A better method is to use roof sprinklers (Figure 23), because they cool the roof and the incoming air without reducing the light level (Nederhoff, 2001).

Table 6. *Shading effects on pepper fruit set and yield.*

Variety	Flower and bud loss in %			Yield in tonne/ha		
	Shaded	Unshaded	Difference	Shaded	Unshaded	Difference
Ace	44	13	31	52,8	53,0	-0,2
North Star	86	37	49	39,4	46,8	-7,4
Mayatta	97	46	51	20,8	48,2	-27,4
Merlin	95	46	49	20,6	35,6	-15,0
Shamrock	95	68	27	10,0	27,6	-17,6
Camelot	99	55	44	6,8	20,6	-13,8
Average	**86**	**44**	**42**	**25,1**	**38,6**	**-13,5**

Figure 23. *Roof sprinklers cool the roof and the incoming air without reducing the light level.*

The light intensity inside the greenhouse can be reduced to 65% as compared to the light intensity outside the greenhouse (Figure 24). Crops grown under dirty cover, winter crops grown under double roof and greenhouses with old or dirty polyethylene cover considerably reduce the entrance of light into the greenhouse or under the shading cover (Aloni *et al*, 1999). Shading reduces the sugar concentration in the flower buds, increases ethylene production by the buds and enhances flower bud abscission (Aloni *et al*, 1999).

Figure 24. *Shading can reduce the light intensity inside the greenhouse can be reduced to 65% as compared to the light intensity outside the greenhouse.*

The length of the photoperiod affects the earliness in pepper. Short day varieties with photoperiods around 10 hours will have earlier flowering as compared to 15 or 24 hours. Long day varieties with photoperiods over 16 hours will have earlier flowering as compared to 10 hours (Somos, 1984). However, as day length is not a critical factor in producing peppers, greenhouses occur across a very wide range of latitudes.

2.7 Water and Soil

2.7.1 Water

Proper irrigation management is essential to assure high yield and quality. In open field, pepper may need up to 4.500 m^3/ha of water, in greenhouses up to 8.000 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 fertiliser applications.

Water shortage 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 25). Flowering and fruit setting is negatively affected and clusters might get lost (Katerji *et al*, 1993). Imposing stress up to the first step of fruit growth reduced yield similar to imposing uniform stress throughout the whole crop cycle. Differences in fruit yields among irrigation regimes were due to significant variations in the number of fruits per plant (Pellitero *et al*, 1993).

Water shortage stress affects pepper growth, reducing the number of leaves and the foliar area, resulting in less transpiration (Abou-Hussein, 1984). Water shortage stress affects the growth of green pepper plants so that leaf number and area are reduced and canopy architecture modified. Implications on radiation regime of the canopy may be expected (Giulivo and Pitacco, 1993). Root density is reduced with 20% under water shortage stress conditions, compared to sufficiently irrigated plants (De Lorenzi *et al*, 1993).

Figure 25. *Blossom End Rot in Jalapeño pepper.*

On the other hand, excess of water will cause root death in anaerobic soil conditions, delayed flowering and fruit disorders (cracking, Figure 26).

Figure 26. *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+}).

2.7.2 Soil

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

The root system consists of a deep tap root with branches spreading laterally about 50 cm, and has adventitious roots.

The ideal pH of the soil is 6,0-6,5 (Figure 27). At a pH > 6,5 the metal micronutrients (Fe, Zn, Mn, Cu), boron (B) and phosphorous (P) become less available for plant uptake. At pH < 5,5 phosphorous (P) and molybdenum (Mo) become less available for plant uptake.

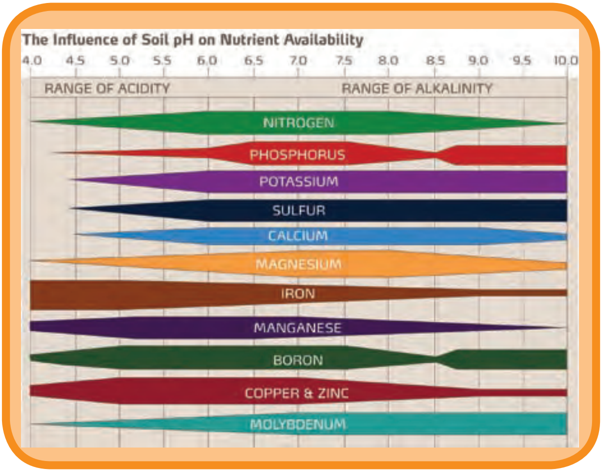

Figure 27. *The influence of soil pH on nutrient availability.*

Alternative growing media in greenhouses are rockwool (Figure 28) and bags filled with coco peat (Figure 29).

Figure 28. *Greenhouse grown pepper on rockwool substrate.*

Figure 29. *Greenhouse grown pepper in bags filled with coco peat.*

2.8 Organic Matter and Manure

Organic matter and manure are applied to increase the water holding capacity of the soil, and 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. Manure of low quality (not fully composted) may contribute to the spread of diseases.

Applications of 10-50 tonne manure/ha will contribute to an essential part of the total nutrient demand. Dry chicken manure (Table 7) is more concentrated than dry cow manure (Table 8). With 10 tonne of chicken manure 243 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 7. *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 8. *The average nutrient contribution in 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 pepper is already in its generative phase, possibly causing uneven ripening, increased risk of BER 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 products.

2.9 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.

Plants grown under saline conditions encounter two problems: to take water from a soil with a negative osmotic potential and to live with high to toxic ionic concentrations of sodium, carbonates and chlorides. The sodium ions compete with the potassium ions for the uptake sites in the roots. This will result in a potassium deficiency imbalance in the plant, leading to a low fruit number per plant. The presence of calcium is fundamental. When sufficient calcium is available, the roots prefer potassium uptake over sodium uptake. Consequently, higher leaf K levels will be present, while sodium uptake will be suppressed (Salisbury and Ross, 1994).

For example, salinity can be caused by wrong fertiliser management, lack of water or lack of rainfall to flush the soil, and/or irrigation water with high EC levels.

Figure 30 shows that salts are moving to the soil surface due to the high evaporation levels and the lack of soil cover to keep the moisture in the soil.

Figure 30. *Fertiliser salt accumulation in the soil surface in Jalapeño pepper in the desert of Torreón in northern Mexico.*

It is not recommended to apply saline organic matter and/or to use fertilisers with chloride and sulphates (KCl, ammonium sulphate, and potassium sulphate) under saline conditions to avoid any further increase of the EC in the soil solution. Saline sodic soils may prohibit any growth at all. The only alternative in that case would be soil-less culture (hydroponics).

Other measures to avoid or to reduce salinity problems include the following:

- Improve the soil drainage capacity.
- Do not use granular fertilisers in base- or side dressing.
- Mix water of bad quality with water of good quality.
- Select salt tolerant varieties (Urtubia, 1997).
- Do single row planting with double line drip irrigation.
- Apply plastic mulching.
- Design the irrigation system for over-irrigation with 35%, i.e. the required volume +35%.

Pepper is relatively sensitive to salinity. In order not to reduce its potential yield, the EC in the saturated soil extract should be: EC_{se} < 1,5 mS/cm and the EC of the irrigation water < 1,0 mS/cm. An EC_{se} = 2,5 mS/cm reduces the potential yield with 10%, an EC_{se} = 3,3 mS/cm reduces the potential yield with 25%, and an EC_{se} = 5,1 mS/cm reduces the potential yield with 50% (Table 9).

Table 9. *Reduction in potential pepper yield, caused by salinity.*

%	EC saturated soil extract (mS/cm)	EC irrigation water (mS/cm)	Necessary lixiviation (%)
0	< 1,5	< 1,0	6
10	2,5	1,5	9
25	3,3	2,2	12
50	5,1	3,4	20

Source: Libro Azul, 2002.

Differences in sensitivity to an excess of NaCl are often linked to differential accumulation of sodium in the shoot, and more particularly, in the leaf blade. Zinc nutrition in plants seems to play a major role in the resistance to salt expressed by several species.

In pepper, Zn concentration generally increased with Na concentration in the leaf blade (Cornillon and Palloix, 1997).

The very high percentages of Zn correspond to low growth, which could be due to different causes:

- Zn toxicity,
- reduced transfer of water in the plant,
- or, a too strong carbonic anhydrase activity.

Mengel and Kirkby (1982) noted that percentages of Zn greater than 120 ppm of dry matter in the leaf blades must be considered as high to excessive in tomato, corn, and apple. When the concentration of Zn in the leaf blade is very high, growth is slowed down.

Table 10 shows the influence of NaCl on the mineral composition of pepper leaf blades. At higher NaCl concentrations, K% decreased, and Na% and Zn% increased.

Table 10. *The influence of NaCl on the mineral composition of pepper leaf blades of four varieties.*

Variety	NaCl (mM)	K (%)	Na (%)	Zn (ppm)
Y.Wonder	0	6,1	0,02	61
	50	6,2	0,84	98
	100	5,7	1,26	190
HDA 103	0	6,0	0,02	56
	50	5,6	1,02	83
	100	4,8	1,50	142
HDA 174	0	5,8	0,05	45
	50	4,2	1,96	62
	100	3,2	3,64	89
SC 81	0	6,2	0,02	75
	50	5,4	0,78	114
	100	4,9	1,22	200

Different levels of salinity did not affect the number of seeds per fruit. This is because the pepper fruit regulates its fruit load in relation to its vegetative growth, without reducing the total number of seeds per individual fruit (Espinoza, 1998). However, there was a clear increase in seed necrosis with the big seeds, when plants are subjected to EC levels of 10 mS/cm (Table 11, Figure 31).

Table 11. *The relation between EC of the soil solution and the number of necrotic big seeds per fruit.*

EC Soil solution (mS/cm)	Number of necrotic big seeds per fruit
2,6	10,9
5,0	8,7
7,5	10,6
10,0	44,3

Figure 31. *Serrano Chili pepper with necrotic seeds due to high EC in the soil solution.*

During a period of water shortage, pepper plants accumulate the aminoacid proline in the leaves and especially in the roots. This is done to maintain sufficient turgor in order to overcome this stress situation (El Sayed, 1992).

Salinity (provoked by NaCl) markedly decreased plant growth. Increasing salinity levels increased stomatal resistance and sodium (Na), chloride (Cl) and proline contents of plants. Potassium (K), total-nitrogen (N) and chlorophyll content of the plants were decreased under high salinity conditions (Gunes and Alpasian, 1996).

2.10 Phenology

Pepper has various development stages in its growth cycle: seedling, transplant (speedling) and young plant establishment, development and vegetative growth, flowering, fruit initiation, fruit development, and ripening and maturation (Figure 32), each stage being different with respect to its nutritional needs. Hereunder the phenological stages for pepper, grown in open field, are discussed. The information is purely indicative, as timing will depend on variety, environmental conditions and crop management.

- **Seedling, transplant (speedling) and young 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.

- **Flowering and fruit set:** depending on the variety, environmental conditions and crop management, flowering and fruit set starts around 20-40 days after transplanting and continues during the rest of the growing cycle.

Pepper plants are usually considered to be a self-pollinated crop, but their ability to cross-pollinate is far greater than expected. Pollination can also be done by bees and wind in order to promote fruit set.

The number of fruits set depends on the following factors:

- Genetics: plants with small fruits have more fruits set (Nuez, 1996).
- Environment (light and temperature):
  - low light intensities reduce fruit set.
  - day temperature is ideally in between 20-25 °C (Quagliotti, 1979) with abortion when T > 34 °C (Cochran, 1936).
  - night temperature is ideally in between 18-21 °C, while abortion takes place at T > 24 °C (Rylski and Spigelman, 1982).
- Physiological load: the presence of fruits in development reduces the proportion of fruits set (Nuez, 1996).
- Hormones: ethylene production favours flower abortion (Tripp and Wien, 1989).
- Nutrition: avoid an excess of nitrogen before the first fruits are set.
- Nutrition: sufficient available B promotes fruit set (Alarcón, 2002).

Fruit development: after flowering and fruit set, 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 pepper).

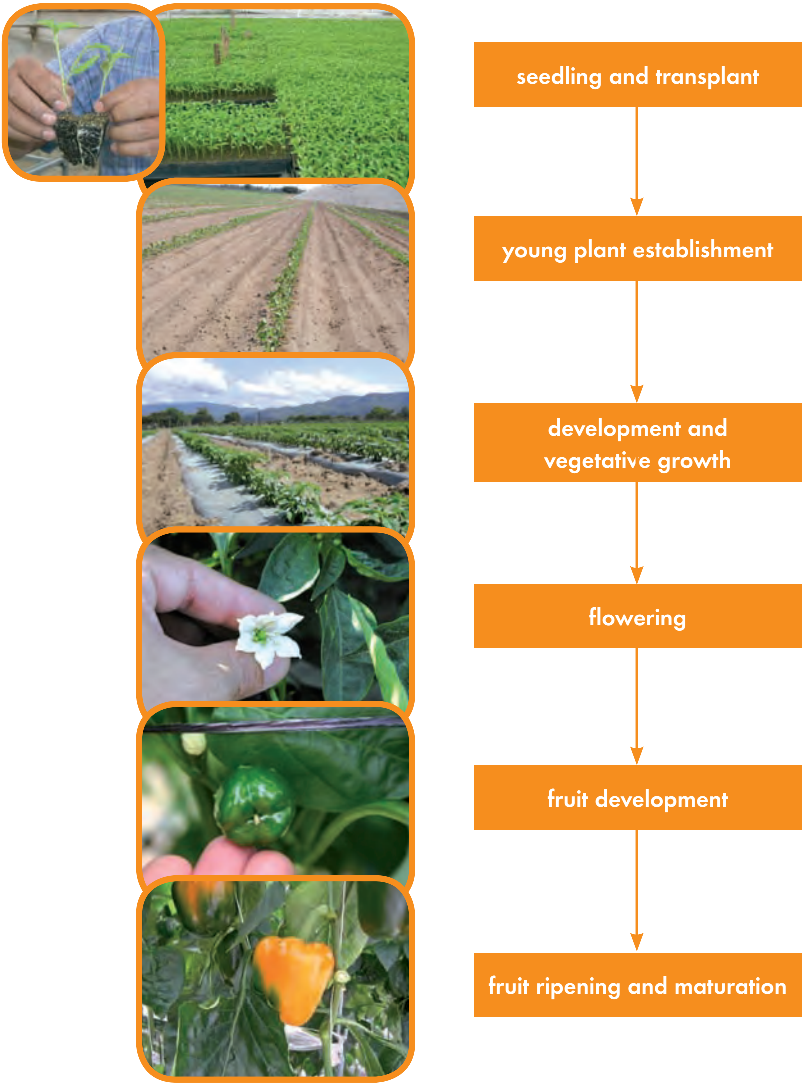

Figure 32. *The phenological stages in pepper.*

2.11 Physiological Disorders

This Chapter describes possible causes and symptoms of various physiological disorders, like cuticular cracking in bell pepper fruit, sunscald, blossom end rot, and pepper spot, black spot or stip. They are mainly caused by extreme environmental conditions (high or low temperatures, high humidity) at critical plant stages (flowering, fruit set). Fruit deformations can also be the result of the absence of seeds, as described in Chapter 2.6. Climate.

2.11.1 Cuticular cracking in bell pepper fruit

Fruit expansion and turgor play a role in the formation of cracks, because expansion of the epidermis cannot keep pace with fruit enlargement.

Cracks in bell peppers may appear as splitting of the pericarp at the end of the fruit (Figure 33) or as longitudinal cracks along the entire fruit (Figure 34). The initiation of fruit cracking in bell pepper is by formation of mini-cracks on the cuticle layer.

Pepper cultivars differ in their sensitivity to cracking, partly because of differences in fruit pericarp thickness. Pepper cultivars with thick-walled fruits (>8 mm) are more susceptible to cracking than cultivars with thinner fruit walls (Jovicich *et al*, 2004).

The predominant factor which causes fruit cracking is inadequate water balance in the fruit. Limitation of night transpiration by high humidity or low temperature enhanced cracking. Likewise, leaf pruning suppressed night transpiration and concomitantly increased cracking (Aloni *et al*, 1998).

In a study about cuticular cracking in bell pepper (*Capsicum annuum L.*) it was concluded that it is the magnitude of the diurnal fluctuations in fruit turgor and diameter, continuing over a long period which may cause the splitting of the cuticle (Aloni *et al*, 1999).

Figure 33. *Sweet pepper fruit with radial, star-shaped cracks.*

Figure 34. *Micro-cracking in bell pepper grown in non-heated greenhouses in the Culiacán Valley in the Northwest of Mexico.*

The percentage of cracked fruits was highest in the greenhouse with the lowest night vapour pressure deficit (VPD) (Table 12). At night, pepper plants transpired at a rate proportional to the vapour pressure difference (leaves to air). Direct radiation and the temperature of the fruit inner space were well correlated with diurnal expansion and shrinkage of the fruit. The fruit with the higher expansion-shrinkage amplitude had more severe cracking symptoms (Aloni *et al*, 1999).

Table 12. *The effect of night temperature and vapour pressure deficit (VPD) on fruit cracking incidence.*

Cracking Incidence	Treatments of Night Temperature and VPD		
	12 °C, low VPD	18 °C, high VPD	18 °C, low VPD
total nº fruits	58	29	62

Source: Aloni et al, 1999.

2.11.2 Sunscald

The total yield with sunscald (Figure 35) was lower with Ca supplement than in those receiving no supplemental Ca. Although in a study of 15 bell peppers cultivars, no difference was found in tissue Ca concentration between sunscald-affected and unaffected fruit tissue (Table 13) (Alexander and Clough, 1998).

Table 13. *The effect of calcium fertiliser rate on sunscald incidence.*

Ca rate	Sunscald Incidence	
(kg/ha)	early yield (tonne/ha)	total yield (tonne/ha)
0	0,28	2,85 a
34	0,18	2,15 b
68	0,13	2,18 b

Figure 35. *Sunscald in pepper.*

2.11.3 Blossom End Rot (BER)

BER is a common physiological disorder in pepper, and occurs mainly during hot weather conditions (Figure 36). Fruits are affected in their early stage of development (10-15 days after fruit set). The cause is related to the speed of calcium supply to the fruit, which is lower than the speed of the fruit growth itself. This results in the collapse of certain tissues in the fruit, demonstrated as BER (Aloni *et al*, 2004).

Factors that favour BER are directly related to limiting the calcium uptake and transport to the fruit, like high salinity, high temperature and high light intensity, and water shortage.

Figure 36. *Blossom End Rot in pepper.*

Under high salinity conditions (EC = 3,2 mS/cm) a clear difference exists in the calcium content of healthy fruits and those affected by BER. Under low salinity conditions (EC = 1,7 mS/cm) fruits with BER have only slightly lower calcium levels as compared to healthy fruits (Figure 37). Therefore, BER is a disorder that cannot only be attributed to the (lack of) calcium supply to the fruit.

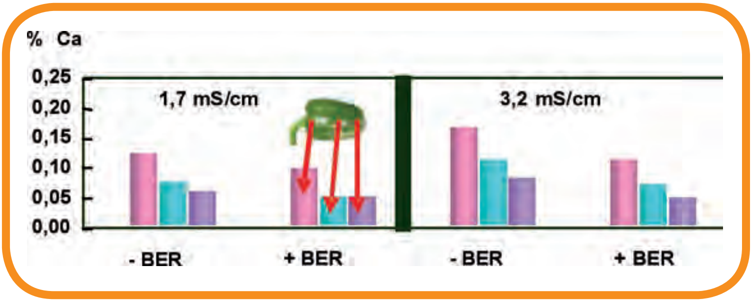

Figure 37. *Calcium content in 3 cross sections of pepper fruit without and with BER, grown under 2 salinity levels.*

Two mechanisms were proposed by Bar-Tal *et al* (2003) for the development of BER under irrigation with saline water, which are related to anti-oxidative minerals, of which Ca can be one.

Low uptake of anti-oxidative minerals (e.g. Mn, Zn, Ca) may impose dual effects:

- It may impair lignin synthesis in the fruit peduncle and fruit organ and may therefore affect xylem function. Consequently, the water and possibly mineral supply to the fruit tip are disturbed.
- In addition, free oxygen radicals and hydrogen peroxide may cause cellular and cell wall rupture in the fruit tip where the levels of anti oxidants are low (anti oxidative enzymes, and minerals).

The differences between cultivar sensitivity may depend on the capacity of the cultivar to combat oxidative stress.

The activity of oxygen radicals in the bell pepper fruits is higher under salinity and in fruits affected by BER (Figure 38) (Bar-Tal *et al*, 2003).

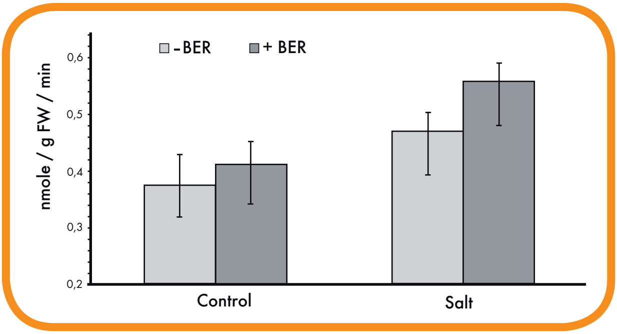

Figure 38. *The activity of oxygen radicals in the bell pepper fruits is higher under salinity and in fruits affected by BER.*

A reduction in the incidence of BER was seen by elevating Mn concentration in the nutrient solution or by foliar application (Figure 39).

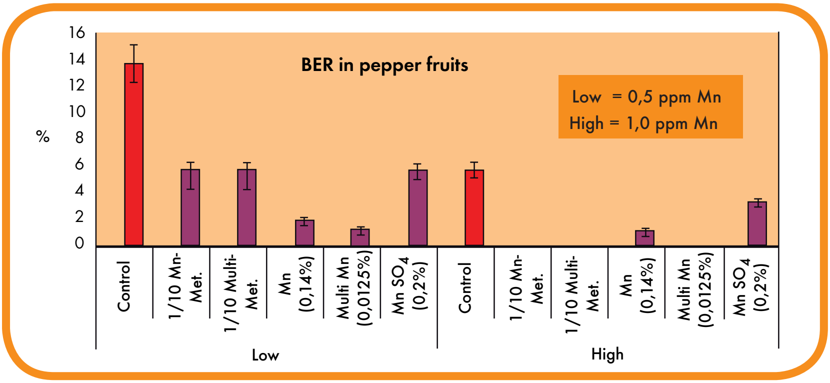

Figure 39. *The effect of elevating the Mn concentration in the nutrient solution or by foliar application on the incidence of BER.*

Table 14 on page 41 shows that a salinity increase reduced Mn concentration in all parts of the fruit, whereas no effect was found on Ca concentration in the fruit. Bar-Tal *et al* (2003) concluded that the results indicated that Mn rather than Ca deficiency may be the major cause for BER under saline conditions.

Table 14. *Dry weight and minerals content distribution in young pepper fruit as affected by salinity.*

Variable	Dry wt. (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)
EC (dS/m)							
0.2 - 2.0	5,06c	3,65	1,08	0,15	0,28b	38,0a	44,9
1,7 - 4,0	5,36b	3,64	1,10	0,16	0,30ab	31,4b	47,3
3,2 - 7,5	5,77a	3,86	1,12	0,15	0,31a	19,6c	44,9
Location							
Dorsal	4,67b	2,99c	1,30a	0,18a	0,33a	34,7a	49,9a
Middle	4,29c	4,04a	1,06b	0,15b	0,27b	30,4b	47,2a
Blossom end	4,67b	4,33a	1,15b	0,12c	0,27b	27,0c	49,7a
Probability of F							
EC	<0,0001	NS	NS	NS	0,0027	<0,0001	NS
Location	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001	<0,0001
EC *Location	NS	NS	NS	NS	NS	0,004	NS

2.11.4 Pepper Spot, Black Spot or Stip

Pepper Spot, Black Spot or Stip is shown in the fruit as grey/black spots, which develop under the skin in the fruit wall about the time the fruit attain a size diameter of 8 centimeters or more (Figure 40). As the fruits ripen, the spots slightly enlarge and turn green or yellow. Stip is a Ca disorder, by excess of N-NH_4 and K rates. Susceptibility greatly varies by variety.

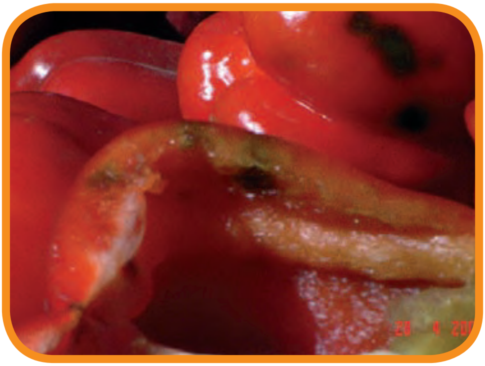

Figure 40. *Pepper Spot, Black Spot or Stip is shown in the fruit as grey/black spots, which develop under the skin in the fruit wall.*

2.12 Pests and Diseases

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 Anthracnose (caused by the fungus *Colletotrichum gloeosporioides* and *C. capsici*) and other fungi (Figures 41 and 42).

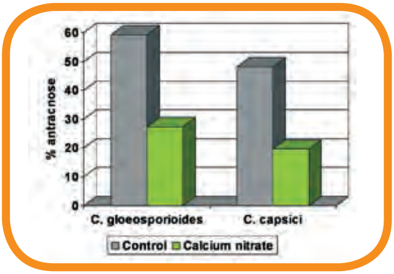

Figure 41. *The addition of calcium nitrate to the fertiliser programme reduced the incidence of Anthracnose in pepper fruit. Anthracnose is caused by the fungi Colletotrichum gloeosporioides and C. capsici.*

Figure 42. *Pepper fruit affected by Anthracnose, caused by the fungi Colletotrichum gloeosporioides and C. capsici.*

2.13 Quality Parameters for the Fresh and the Industry Pepper 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, such as for example a high lycopene content. Balanced plant nutrition plays a key role in meeting the quality standards of the fresh market and of the pepper industry (powder, sauces, sliced pepper freezing industry).

2.13.1 Quality Parameters for the Fresh Pepper Market

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

- Well-coloured and bright (non-green varieties without immature green spots or blotches).
- Uniform in shape (Figure 43).
- Texture or firmness of bite (firmer peppers are less prone to damage and have a longer shelf life).
- Flavour and aroma, which are determined by the presence of pyrazines.
- Pungency: from mild to extremely hot.
- Clean and free of external defects and holes.
- Only small defects are allowed for Class 1.

Figure 43. *Class I high quality yellow, green, red and orange pepper fruit mix.*

2.13.2 Quality Parameters for the Pepper Industry – Powder

Paprika powder is obtained by the grinding of pods from the dried sweet red peppers (*Capsicum Annuum*). The quality of paprika, used for producing powder, is described by:

- Organoleptic characteristics (colour, flavour and aroma).
- The cleanliness of the product (including light filth and microbiology). The cleanest dried peppers are dried inside under controlled conditions and sterilized. Paprika from many origins is routinely made from raw material dried outdoors, in the sun, thus often unclean.

Only the highest quality, ripe, intensely coloured pods are used to make paprika powder. Such pods have the highest content of carotenoids such as capsanthin, capsorubin, carotene, criptoxanthin, and zeaxanthin and xantophyll in traces. Several grindings are necessary to achieve the correct powder texture. This aromatic powder is deep red to red-orange in colour; its flavour is mildly sweet and non pungent.

The recommended colour method for paprika is the ASTA Official Method 20.1, Extractable Colour in Capsicums and Their Oleoresins. Paprika is normally classified by its extractable colour (see ASTA Colour Rating in Table 15). Paprika with a brighter red colour will normally have a higher extractable ASTA Colour (measured in units) and is more expensive. Lighter colour product (more orange-red) will have a lower ASTA Colour rating and consequently a lower price. Some producers even offer paprika which has ASTA Colour 50. That quality has mostly a culinary application, where colour of the product is not the most important parameter. What paprika quality will be used is determined by the final application. If the final product colour is the main organoleptic attribute, the highest quality paprika and the more expensive one will be used and vice versa (www.astaspice.org, www.occidentalfoods.com, www.ntfkii.uni-lj.si).

Paprika Classification in ASTA Colour Units
Minimum 160 (160-180)
Minimum 140 (140-160)
Minimum 120 (120-140)
Minimum 100 (100-120)
Minimum 80 (80-100)
Minimum 60 (60-80)

Table 15. *Paprika classification by its extractable colour, measured in extractable ASTA Colour units.*

2.13.3 Quality Parameters of Sliced Pepper for Freezing Industry

The following quality parameters are important for sliced pepper for freezing industry:

- Well-coloured.
- Free of external defects (before and after the industrial process).
- 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 all nutrients for a well-balanced nutrition programme.

3.1 Potassium

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

3.1.1 Potassium for Quality and Quantity

Essential roles of potassium are to be found in the protein synthesis, the photo-synthetic 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 50 % of K absorbed by the plant is found in the fruit (Table 16). The action of potassium on protein synthesis enhances the conversion of absorbed nitrate into proteins contributing to a better efficiency of the N fertiliser supplied.

Table 16. *Nutrient accumulation in the dry matter of different plants parts in % of nutrients uptake by plant.*

Plant Parts	Nutrients Content in % of Dry Matter				
	N	P	K	Ca	Mg
Marketable crop	50	60	50	15	25
Fruit set	7	9	7	3	5
Subtotal generative parts	**57**	**69**	**57**	**18**	**30**
Foliage	25	17	21	60	45
Stem	13	10	18	17	21
Roots	5	4	4	5	4
Subtotal generative parts	**43**	**31**	**43**	**82**	**70**
Total plant parts	**100**	**100**	**100**	**100**	**100**

Source: Somos, 1984.

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, pepper 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, responsible for the red colour of the pepper fruit.

Summary of the role of potassium in the pepper 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 44).
- Prolongs and intensifies assimilation period (higher fruit quality).
- Improves the efficiency of N fertilisers.
- Improves the water use efficiency (less water needed per kg per plant mass).
- Regulates the opening and closure of stomata (guard cells).
- Is responsible for the synthesis of lycopene (red colour).

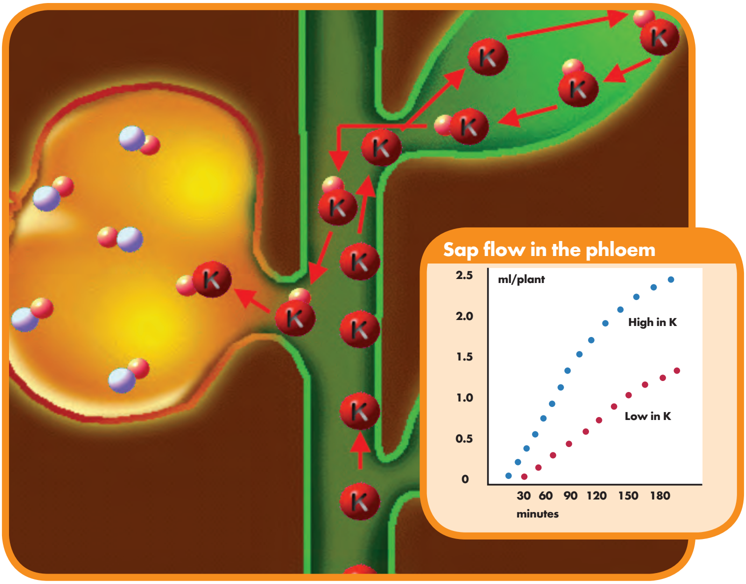

Figure 44. *K intensifies the transport and storage of assimilates from the leaf to the fruit, as shown here as an example in tomato.*

3.1.2 Effects of Increased Potassium Levels in Pepper

Research has shown that increased potassium levels in pepper will lead to the following effects:

- Improved number of fruit and weight per fruit (Pimpini, 1967).
- Increased wall thickness (Pimpini, 1967).
- Higher proportion of high quality fruit (Iley and Ozaki, 1967).

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 pepper 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 45). On the other hand, fruits with a low transpiration rate are poorly supplied with calcium. Only 15% of the calcium goes to the fruit (Table 16). 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.

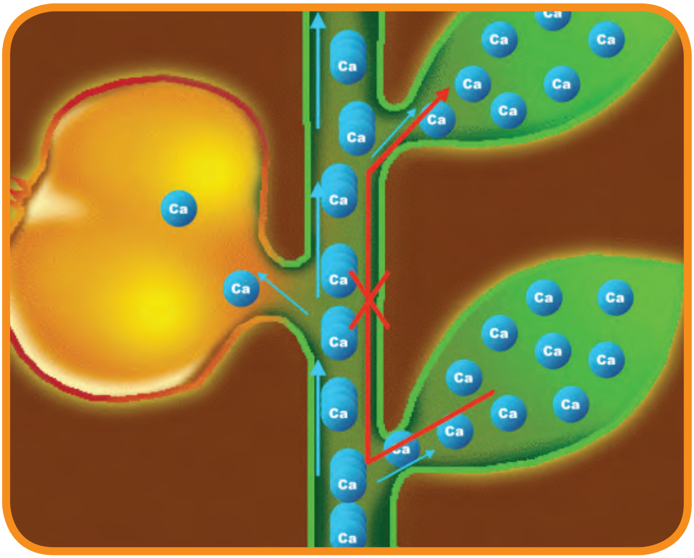

Figure 45. *Calcium transport in the plant, as shown here as an example in tomato.*

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 Pepper Growing in Relation to a Lack of Potassium and Calcium

Table 17 describes the main problems in pepper growing, which are related to a deficiency imbalance of potassium and calcium.

Table 17. *The main problems in pepper growing and their relation to a deficiency imbalance of potassium and calcium.*

	Main problems in pepper growing	Related to	
		K	Ca
Plant Performance	Low yield	x	x
	Heterogeneity in size, uneven ripening	x	
	Limited fruit set	x	
	No bulking / small pepper fruit	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 Effect of Plant Nutrition on Pepper Growth and Development Characteristics

The moment of flowering and number of flowers is affected by ammonium. Ammonium supply enhances flowering. Ammonium changes the phytohormone level in general and of cytokinins (CYT) in particular (Marschner, 1995). P supply is positively correlated with flower formation (Menary and Van Staden, 1976). The positive correlations between the number of flowers and CYT level on the one hand, and between the P supply and CYT level on the other hand, provide additional evidence that CYT also contributes to the enhancing effect of P on flower formation (Marschner, 1995).

The number of seeds and/or fruits is related to N (Hassan *et al*, 1993) (Schon *et al*, 1994), P, B, and Zn (Marschner, 1995).

There is a highly positive relation between fruit size and number of seeds per fruit (Rylski, 1973), whereas the number of seeds is related to P and B.

Wall thickness is positively related to K and Ca.

3.5 Summary of the Main Roles of Nutrients

Table 18 summarizes the main roles of all nutrients.

Table 18. *The main roles of all nutrients.*

Nutrient	Symbol	Main Roles
Nitrogen	N	Chlorophyll and protein synthesis (growth and yield).
Phosphorous	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, fruit set 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 pepper grown in soil, grown on wood fibre and on rockwool in a greenhouse are given.

Nutrient absorption curves describe the nutrient uptake per nutrient per phenological phase. The nutrient uptake curve is the base for a fertiliser recommendation.

4.1 Nutrient Uptake and Nutrition of Soil Grown Pepper

4.1.1 Nutrient Uptake of Soil Grown Pepper in a Greenhouse

Table 19 describes the uptake of N, P, K, Ca and Mg during the growing cycle of soil grown pepper for an estimated yield of 100 tonne/ha (Rincón *et al*, 1993).

Table 19. *The uptake of N, P, K, Ca and Mg during the growing cycle of soil grown pepper for an estimated yield of 100 tonne/ha.*

Period	N	P_2O_5	K_2O	CaO	MgO	N	P_2O_5	K_2O	CaO	MgO
days	kg/ha/day					kg/ha/period				
0-35	0,05	0,009	0,10	0,06	0,025	2	0	3	2	1
35-55	0,35	0,07	0,80	0,35	0,17	7	1	16	7	3
55-70	1,20	0,23	2,25	0,98	0,45	18	3	34	15	7
70-85	1,30	0,23	2,60	0,98	0,41	20	3	39	15	6
85-100	2,60	0,78	4,82	2,80	1,41	39	12	72	42	21
100-120	2,75	0,57	5,50	1,12	1,16	55	11	110	22	23
120-140	3,75	1,08	4,82	1,40	1,00	75	22	96	28	20
140-165	3,15	0,78	4,80	1,68	1,19	79	19	120	42	30
Total/100 t						**294**	**73**	**491**	**173**	**111**
Total/t						**2,9**	**0,7**	**4,9**	**1,7**	**1,1**
						N	**P**	**K**	**Ca**	**Mg**
Total/100 t						**294**	**32**	**407**	**123**	**67**
Total/t						**2,9**	**0,3**	**4,1**	**1,2**	**0,7**

4.1.2 Nutrition of Soil Grown Pepper in a Greenhouse

Table 20 shows the target values for base dressing in the 1:2 volume extract in water for greenhouse grown sweet pepper in soil in The Netherlands. The amounts of nutrients that are lacking to match the target values for base dressing are applied with fertilisers in the base dressing. P is normally applied with the base dressing at a rate of 0-920 kg P_2O_5/ha, depending on the P soil reserve and availability. Except for B, all other trace elements are only applied in case of a proven deficiency imbalance. B is applied during fertigation.

Table 20. *Target values for base dressing in the 1:2 volume extract in water for greenhouse grown sweet pepper in soil in The Netherlands.*

Pepper soil	N	K	Ca	Mg	SO_4	H_2PO_4
	mmole/l					
Target values base dressing	4,5	2	2,5	1,2	2	0,1
Pepper soil	$N\text{-}NO_3$	K	Ca	Mg	S	P
	ppm					
Target values base dressing	63	78	100	29	64	3

Source: Van den Bos et al, 1999.

Table 21 demonstrates the standard nutrient solution for side dressing for greenhouse grown sweet pepper in soil in The Netherlands. No P is needed when P > 0,10 mmole/l in the 1:2 volume extract. B is applied during fertigation at a rate of 0-40 µmole/l depending on soil and water analysis. Standard dose is 10 µmole B/l. All other trace elements are only applied in case of a proven deficiency imbalance.

Table 21. *Standard nutrient solution for side dressing for greenhouse grown sweet pepper in soil in The Netherlands.*

Pepper soil	NO_3	K	Ca	Mg	SO4	H_2PO_4	NH_4	B
	mmole/l							µmole/l
Standard nutrient solution	8,4	4	2	1	1		0,4	10
Pepper soil	$N\text{-}NO_3$	K	Ca	Mg	S	P	$N\text{-}NH_4$	B
	ppm							ppm
Standard nutrient solution	118	156	80	24	32	0	6	0,11

Source: Van den Bos et al, 1999.

The goal is to maintain the desired nutrient target values in the soil (Table 22) by using the recommended standard nutrient solution. Hereto each 4-6 weeks a soil sample is taken to verify the nutrient status. If necessary, corrections should be made in the standard nutrient solution. Guidance tables are available to make these corrections. No P is needed when P > 0,10 mmole/l in the 1:2 volume extract. 10 µmole B/l is applied when B (measured in the 1:2 volume extract) is 21-40 µmole/l. The target EC = 1,1 mS/cm in the 1:2 volume extract.

Table 22. *Desired nutrient target values in the soil as measured in the 1:2 volume extract.*

Pepper	N	K	Ca	Mg	SO_4	H_2PO_4	B
soil				mmole/l			µmole/l
Target values 1:2 volume extract	4,5	2	2,5	1,2	2	>0,1	21-40

Pepper	$N\text{-}NO_3$	K	Ca	Mg	S	P	B
soil				ppm			ppm
Target values 1:2 volume extract	63	78	100	29	64	>3	0,23-0,43

Source: Van den Bos et al, 1999.

4.2 Nutrient Uptake and Nutrition of Greenhouse Grown Pepper in Substrates

4.2.1 Nutrient Uptake of Pepper, Cultivated in Wood Fibre

Figures 46 and 47 describe the uptake of macro- and micronutrients during the growing cycle of pepper, cultivated in wood fibre.

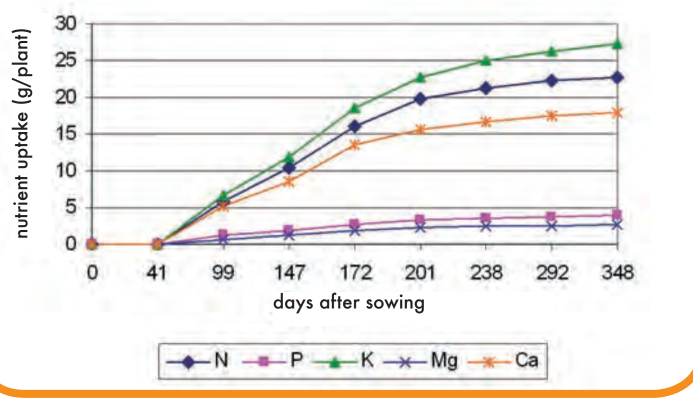

Figure 46. *The uptake of macronutrients during the growing cycle of pepper, cultivated in wood fibre (Heuberger and Schnitzler, 1998).*

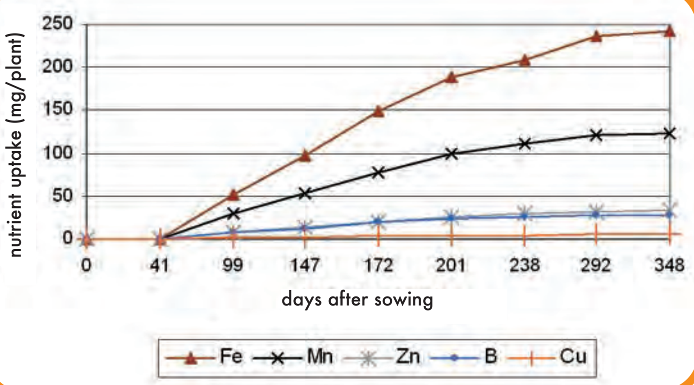

Figure 47. *The uptake of micronutrients during the growing cycle of pepper, cultivated in wood fibre (Heuberger and Schnitzler, 1998).*

4.2.2 Nutrition of Greenhouse Grown Pepper in Inert Substrates

The standard nutrient solution for greenhouse grown pepper on rockwool with open drain and changes per phenological stage is presented in Table 23. The EC = 2,1 mS/cm. The changes are expressed in mmole/l and ppm (as the diluted nutrient solution goes to the plant).

Table 23. *The standard nutrient solution (EC = 2,1 mS/cm) for greenhouse grown pepper on rockwool with open drain and changes per phenological stage.*

Sweet pepper open drain	NO_3	K	Ca	Mg	SO_4	H_2PO_4	NH_4	Fe	Mn	Zn	B	Cu	Mo
rockwool, 1 cycle/year	mmole/l							µmole/l					
Standard nutrient solution	15,5	6,75	5	1,5	1,75	1,25	0,5	15	10	5	30	0,75	0,5
Changes per phenological phase													
1 saturation rockwool slabs	16,5	4,8	5,8	2,3	1,8	1,3	0,5	15	10	5	46	0,75	0,5
2 starter scheme (first weeks)	15,5	5,8	5,5	1,5	1,8	1,3	0,5	15	10	5	30	0,75	0,5
3 until harvest first fruits	15,3	6,8	5,0	1,5	1,8	1,5	0,5	15	10	5	30	0,75	0,5
4 heavy fruit load	16,5	7,8	5,0	1,5	1,8	1,3	0,5	15	10	5	30	0,75	0,5

Sweet pepper open drain	$N\text{-}NO_3$	K	Ca	Mg	S	P	$N\text{-}NH_4$	Fe	Mn	Zn	B	Cu	Mo
rockwool, 1 cycle/year	ppm							ppm					
Standard nutrient solution	217	263	200	36	56	39	7	0,84	0,55	0,33	0,32	0,048	0,048
Changes per phenological phase													
1 saturation rockwool slabs	231	185	230	55	56	39	7	0,84	0,55	0,33	0,50	0,048	0,048
2 starter scheme (first weeks)	217	224	220	36	56	39	7	0,84	0,55	0,33	0,32	0,048	0,048
3 until harvest first fruits	214	263	200	36	56	47	7	0,84	0,55	0,33	0,32	0,048	0,048
4 heavy fruit load	231	302	200	36	56	39	7	0,84	0,55	0,33	0,32	0,048	0,048

Adapted from: Bemestingsadviesbasis substraten, 1999.

The goal is to maintain the desired nutrient target values in the rooting zone in the substrate (Table 24) by using the recommended standard nutrient solution. Hereto each 2 weeks a substrate solution sample is taken to verify the nutrient status. If necessary, corrections should be made in the standard nutrient solution. Guidance tables are available to make these corrections.

In sweet pepper, B should accumulate to high levels in the root environment (80 µmole/l), to force the plants to absorb sufficient quantities of this element. In tomato the target value in the rooting zone is 50 µmole/l.

Table 24. *Desired nutrient target values (EC= 2,7 mS/cm) in the rooting zone for greenhouse grown pepper on rockwool with open drain.*

Sweet pepper open drain	NO_3	K	Ca	Mg	SO_4	H_2PO_4	NH_4	Fe	Mn	Zn	B	Cu
rockwool, 1 cycle/year	mmole/l							µmole/l				
Target values in the rooting zone	17	5	8,5	3	3	1,2	<0,5	15	5	7	80	0,7

Sweet pepper open drain	$N\text{-}NO_3$	K	Ca	Mg	S	P	$N\text{-}NH_4$	Fe	Mn	Zn	B	Cu
rockwool, 1 cycle/year	ppm							ppm				
Target values in the rooting zone	238	195	340	73	96	37	< 7	0,84	0,27	0,46	0,86	0,045

4.3 Summary of Nutrition of Pepper, Grown in Open Air or in a Greenhouse

Table 25 shows the nutrient requirement of the whole plant to produce 1 tonne of fresh fruit for different varieties, grown in open air or in greenhouses, according to various authors.

Table 25. *Nutrient requirement of the whole plant to produce 1 tonne of fresh fruit for different varieties, grown in open air or in greenhouses, according to various authors.*

Author and growing condition	Variety	N	P_2O_5	K_2O	CaO	MgO
		kg/tonne fresh fruit				
Open air	Doux des Landes	3,7	1,0	5,0	3,0	0,6
Open air	Bola y negral	3,3	0,9	5,8		
	Belrubi y Datler	2,3	0,7	4,5		
Open air (1)	Morrón de Conserva	2,3	0,8	3,6		
Greenhouse (2)	Yolo Wonder	4,1	0,5	5,1	3,8	0,5
	Heldor	5,3	0,7	6,7	4,8	0,6
Greenhouse (3)	Lamuyo	2,9	0,8	4,6	1,7	1,1
Greenhouse, rockwool , recirc. with 100% efficiency, 250 t/ha/yr (4)		3,4	1,9	6,1		
Greenhouse, wood fibre (5)		2,5	1,0	3,6	2,8	0,5
Average		**3,31**	**0,92**	**4,99**	**3,21**	**0,65**

Sources:

1. Martínez-Raya and Castilla, 1989.

2. Graifenberg et al, 1985.

3. Rincón et al, 1993.

4. Voogt, 2003.

5. Heuberger and Schnitzler, 1998.

4.4 Nitrogen Management in Pepper

Nitrogen is the main nutrient responsible for the development of leaf area and should be present from the first stages of plant development onwards. Therefore the nitrogen applied as fertiliser 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. In hydroponic systems the maximum recommended ammonium level should not exceed 7% of the total N input in order to avoid BER (Table 26).

Table 26. *The maximum recommended levels of ammonium in hydroponics and soil to avoid BER.*

Pepper 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.

Figure 48 shows that pepper plant growth is reduced when plants are fed only with ammonium nitrogen as compared to a mix of ammonium and nitrate-nitrogen.

Figure 48. *Pepper plant growth is reduced (plant on the right side) when plants are fed only with ammonium nitrogen as compared to a mix of ammonium and nitrate-nitrogen (plant on the left side).*

4.5 Leaf Norms for Pepper

Table 27 presents guideline data for the macro- and micronutrient content in the leaf dry matter. The total iron content in the leaf is not a reliable indicator for Fe status.

Table 27. *Guideline data for the macro- and micronutrient content in the leaf dry matter.*

	% Leaf Dry Matter		
	deficient	normal	high
N	2,0-2,5	3,0-4,0	4,0-5,0
P	0,25	0,3-0,4	0,4-0,6
K	2	3,5-4,5	4,5-5,5
Ca	1	1,5-2,0	5,0-6,0
Mg	0,25	0,25-4,0	0,4-0,6
Na		0,1	

	Ppm Leaf Dry Matter		
	deficient	normal	high
Fe	50-100	200-300	300-500
Mn	25	80-120	140-200
Zn	20	40-50	60-200
Cu	5-10	15-20	20-40
B		40-60	60-100
Mo		0,4	0,6

Source: Weir and Cresswell, 1993.

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.

Nitrogen deficiency imbalance results in:

- Stunted growth, the leaves being small and light yellowish green (Figure 49).
- Stems are less branched and thinner.
- The proportion of flowers that set is reduced.
- The number of fruits formed is reduced.
- The fruit is yellow-green in colour.

Figure 49. *N deficiency imbalance, shown as stunted growth, the leaves being small and light yellowish green.*

N excess imbalance provoked by an excess of ammonium generating and ammonium containing fertilisers will lead to increased vegetative growth, more BER, delayed fruit formation and colouring problems in non-green picked peppers.

P deficiency imbalance is shown in the plant as follows (Figure 50):

- Growth is restricted and, in contrast to N-deficiency, the foliage remains dark green.
- The leaves of P-deficient plants are small and dark grey-green in colour and the margins tend to curl upwards and inwards.
- Overall growth is weak (Miller, 1961).
- Fruits are reduced in both diameter and length, many of which were misshapen (Miller, 1961). Less fruits are formed per plant, while harvesting is delayed (Vereecke, 1975).

Figure 50. *P deficiency imbalance.*

In case of K deficiency imbalance, growth is restricted and small reddish-brown spots develop on the mature leaves (Figure 51). On young plants these spots usually spread from the leaf tips. Leaf margins turn yellow.

Figure 51. *K deficiency imbalance.*

In case of Ca deficiency imbalance, there is marginal yellowing of the youngest leaves, which usually develops first near the leaf tips, then spreads interveinally.

Pale brown sunken areas develop on the fruit, usually near the blossom end (Figure 52).

Figure 52. *Ca deficiency imbalance.*

When Mg deficiency imbalance occurs, the mature leaves develop interveinal yellowing. An interveinal yellow-green chlorosis develops on mature leaves, though some dark green areas may remain beside the main veins (Figure 53).

Figure 53. *Mg deficiency imbalance.*

S deficiency imbalance manifests itself through a pale yellow-green colour in the younger leaves (Figure 54) and growth is restricted. The new leaves may become narrow and more pointed.

Figure 54. *S deficiency imbalance (pepper plant on the right).*

In case of Fe deficiency imbalance, the youngest leaves are yellow and may turn almost white (Figure 55). The tips remain green at first whilst the yellowing spreads from the base of the leaf. On mature plants, an interveinal yellowing develops near the base of the leaves.

Figure 55. *Fe deficiency imbalance.*

When Zn deficiency imbalance occurs, the dark green leaves develop small purple areas which are scattered at random interveinally. These areas turn pale brown as they enlarge (Figure 56).

Figure 56. *Zn deficiency imbalance.*

In case of Mn deficiency imbalance, the young leaves turn bright yellow-green and may develop dark brown interveinal areas. Small, somewhat diffuse yellow areas develop on the mature leaves; these may turn brown later. Persistence of a uniform dark green veinal network in the yellow leaves is characteristic for this deficiency (Figure 57) and distinguishes it from Fe-deficiency.

Figure 57. *Mn deficiency imbalance, shown in the leaf as diffuse yellow areas within a uniform dark green veinal network.*

Figure 58 describes Mn excess imbalance. The oldest leaves turn yellow-orange and die prematurely.

Figure 58. *Mn excess imbalance.*

The new leaves of young plants become distorted when the supply of B is inadequate. Yellowing on the tips of the mature leaves gradually spreads around the margins, and the main veins turn reddish-brown (Figure 59).

Figure 59. *B deficiency imbalance.*

Figure 60 describes boron excess imbalance symptoms with severe marginal scorch.

Figure 60. *B excess imbalance.*

In case of Cu deficiency imbalance, growth is restricted, but the leaves remain dark green. The leaf margins tend to curl upwards, but no other characteristic foliar symptoms have been identified.

In case of Mo deficiency imbalance, the foliage turns yellow-green, and growth is somewhat restricted. The deficiency occurs most commonly on acidic ($pH < 5,0$) substrates.

Figures 61 and 62 show NaCl (salt water) and sodium excess imbalances.

Figure 61. *NaCl (salt water) excess imbalance.*

Figure 62. *Na (sodium carbonate) excess imbalance.*

6 SPN Product Characteristics Regarding Imbalance Rectification Effectiveness

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

6.1 Fertiliser Selection

There are various possibilities to select fertilisers for pepper fertilisation. 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 pepper growing (e.g. rain fed, flood irrigation, drip irrigation).
- Economy (cost:benefit ratio).
- Access to the fertiliser.
- 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 fertilisers will undergo different processes in soils (Figure 63).

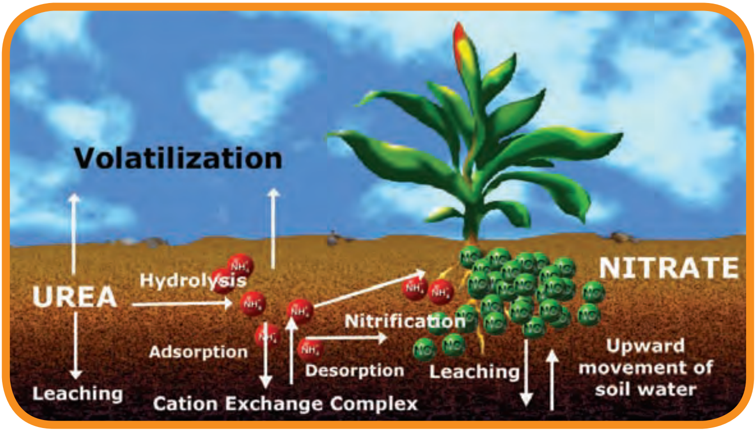

Figure 63. *The chemical transformation process in the soil when using urea, ammonium and nitrate containing fertilisers.*

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 will not 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 (Figures 25 and 52), resulting from a shortage of calcium in fruits, even if ample calcium 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 fertilisers 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 64). 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.

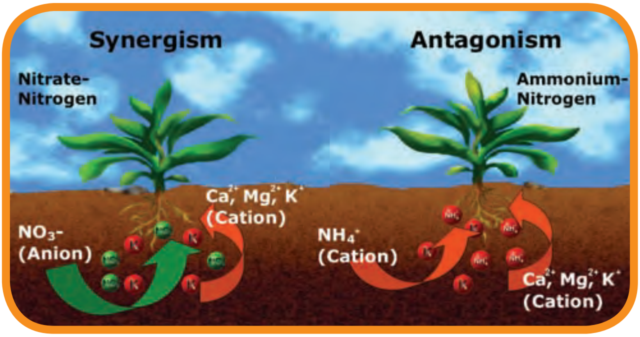

Figure 64. *Synergism and antagonism in the nutrient uptake in the rooting zone of the plant between cations and nitrate or ammonium as nitrogen source.*

6.2.1.4 Specialty Plant Nutrition Products Containing Nitrogen

Nitrate containing fertilisers 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 partly provides ammonium nitrogen which can be enough for pH control in hydroponics. Ammonium nitrate is used in small quantities in greenhouses for pH control in the rooting zone and in open field fertigation as part of the total nitrogen fertilisation (Table 28). Urea is the less preferred N-source because of its inefficiency.

Table 28. *The main nitrogen fertilisers split per type of nitrogen.*

Main N-form in the fertiliser	Common name	Formula
Nitrate	Potassium nitrate	KNO_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	$CO(NH_2)_2$
	Urea phosphate	$CO(NH_2)_2.H_3PO_4$

6.2.2 Phosphorous

Table 29 describes the most common phosphate fertilisers. All phosphate fertilisers 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 phosphorous fertiliser should be used is mainly decided in function of its desired effect on pH of water and soil, and its solubility.

Table 29. *Characteristics of phosphorous fertilisers.*

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
Urea phosphate	$CO(NH_2)_2.H_3PO_4$	strong acidifier in solid form
Phosphoric acid	H_3PO_4	strong acidifier in liquid form

In fertigation systems phosphate must not be mixed with calcium in the highly concentrated mother solution. This would result in the precipitation of calcium phosphates. However, urea phosphate may be mixed with calcium nitrate at certain concentrations.

6.2.3 Potassium

Table 30 presents the most common potassium fertilisers and their characteristics.

Table 30. *Characteristics of potassium fertilisers.*

Common name	Formula	Characteristics
Potassium nitrate	KNO_3	Is the ideal K fertiliser during all growth stages and also supplies part of the nitrate demand of the plant. High solubility of 320 g/l at 20 °C.
Potassium sulphate	K_2SO_4	Ideal fertiliser 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 fertilisers).
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 31 presents the most common calcium fertilisers and their characteristics.

Table 31. *Characteristics of calcium fertilisers.*

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 not recommended in pepper growing, because pepper is sensitive to high salt concentrations in the rooting zone. The use of Cl containing fertilisers will lead to competition for the uptake sites of the root with other anions (NO_3^-, $H_2PO_4^-$, SO_4^{2-}), resulting in nutrient imbalances.

6.2.6 Magnesium

Table 32 presents the most common magnesium fertilisers and their characteristics.

Table 32. *Characteristics of magnesium fertilisers.*

Common name	Formula	Characteristics
Magnesium sulphate	$MgSO_4.7H_2O$	The most used Mg source. It must not 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 fertiliser sources at the normally recommended doses.

6.2.7 Sulphur

Table 33 presents the most common sulphur fertilisers and their characteristics.

Table 33. *Characteristics of sulphur fertilisers.*

Common name	Formula	Characteristics
Magnesium sulphate	$MgSO_4.7H_2O$	To complete the sulphate and magnesium demand.
Potassium sulphate (SOP)	K_2SO_4	Can be used to supply the remainder of the S demand and part of the K demand in pepper 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 must not be mixed with calcium in the highly concentrated mother solution. This would result in the precipitation of calcium sulphate (gypsum).

6.2.8 Water-Soluble and Granular NPKs

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

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

Table 34 summarizes the most used water-soluble and granular fertilisers and their possible restrictions for use in fertigation. The table should be read as follows: Each crosspoint of a row and a column represents a fertiliser. For example: where nitrate and potassium cross, the fertiliser is potassium nitrate; where P and K cross, the fertiliser is mono potassium phosphate, etc.

Table 34. *Summary of most used water-soluble and granular fertilisers and their possible restrictions for use in pepper 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 (prefered source)			X (prefered source)				X (source with restricted use)	
$N\text{-}NO_3$	nitrate	X (prefered source)		X (source with restricted use)			X (prefered source)	X (prefered source)	X (prefered source)		
$N\text{-}NH_4$	ammonium		X (source with restricted use)			X (prefered source)				X (source with restricted use)	
$N\text{-}NH_2$	urea				(not recommended)	X (source with restricted use)					
P	phosphor	X (prefered source)		X (prefered source)	X (source with restricted use)		X (prefered source)				
K	potassium		X (prefered source)			X (prefered source)				X (prefered source)	(not recommended)
Ca	calcium		X (prefered source)								(not recommended)
Mg	magnesium		X (prefered source)							X (prefered source)	(not recommended)
S	sulphur	X (source with restricted use)		X (source with restricted use)			X (prefered source)		X (prefered source)		
Cl	chloride						(not recommended)	(not recommended)	(not recommended)		
NPK			X (prefered source)	X (source with restricted use)	(not recommended)	X (prefered source)	X (prefered source)		X (prefered source)		

X prefered source
X source with restricted use
■ not recommended

6.2.10 Micro-Nutrients

Table 35 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 and EDDHMA (pH > 7). In case of EDDHA and EDDHMA 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 35, numerous trace element mixes and other specialty products are available. Contact your local SQM agronomist or distributor to learn more about these products.

Table 35. *Summary of the main sources of micro-nutrients used in fertigation, foliar and field applications.*

Symbol	Nutrient	Main sources	Remarks
Fe	Iron	EDTA	When pH<6 and as foliar.
		DTPA	When pH<7.
		EDDHA, EDDHMA	When pH>7.
Zn	Zinc	EDTA Sulphate	EDTA dissolves easier than sulphate.
Mn	Manganese	EDTA Sulphate	EDTA dissolves easier than sulphate.
Cu	Copper	EDTA Sulphate	EDTA dissolves easier than 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 nutrition programme for open field pepper and for greenhouse pepper 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 fertiliser recommendation for soil grown pepper.

To make a fertiliser recommendation for soil grown pepper 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 fertiliser programme.
- The fertiliser 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, fertilisers 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, fruit set), or to analyze the soil solution via alternative methods on a regular base and correct the fertiliser dose if necessary.

Table 36 shows the nutrient demand of pepper in relation to an expected yield of 100 tonne of pepper/ha under drip irrigation. The data for nutrient need of pepper were copied from Table 25 and adapted for an expected yield of 100 t/ha.

Table 36. *Nutrient demand of 100 tonne pepper/ha under drip irrigation.*

1 Nutrient need pepper plant	Unit	N	P_2O_5	K_2O	CaO	MgO	S
Nutrient need (canopy + fruit production) for 100 t/ha	kg/ha	331	92	499	321	65	65

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 (step 2 in Table 37). These 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 nutrient uptake efficiency under drip irrigation (step 3 in Table 37).

Table 37. *Example deducting nutrient reserves from nutrient demand for 100 tonne pepper/ha under drip irrigation and correction for the efficiency of each nutrient applied via drip irrigation.*

2 Assumption	Unit	N	P_2O_5	K_2O	CaO	MgO	S
Total (canopy + fruit production)	kg/ha	331	92	499	321	65	65
Reserves in soil and water/ base dressing	kg/ha	55	50	82	110	30	37
Remainder to be applied via fertigation	kg/ha	276	42	417	211	35	28

3 Nutrient uptake efficiency under drip irrigation	Unit	N	P_2O_5	K_2O	CaO	MgO	S
	%	80	30	85	60	60	60
	kg/ha	345	140	491	352	58	47

In step 4 the nutrients have to be divided per phenological phase. Table 38 is showing a split per nutrient per phenological phase. Multiplying the total nutrient application (step 3) (kg/ha) and the nutrient application per phenological phase (step 4) (%) results in the nutrient need per phenological phase expressed in kg nutrient/ha (step 5). From Table 38 the amount of water-soluble fertiliser/ha can be calculated per phenological phase (step 5). Check with your local SQM agronomist to see which products are best suited to match this calculation.

Table 38. *Split of nutrients per phenological phase expressed in percentages and in kg/ha for drip irrigated open field pepper with an estimated yield of 100 tonne/ha.*

4 Fertiliser application phases	DAT	N %	P_2O_5 %	K_2O %	CaO %	MgO %	S %
Transplant establishment and early development	0-45	17	34	15	20	20	20
From flower initiation to fruit formation	45-90	40	33	40	40	45	45
From fruit formation to final harvest	90-150	43	33	45	40	35	35
Total	**0-150**	**100**	**100**	**100**	**100**	**100**	**100**

5 Fertiliser application phases	DAT	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	CaO kg/ha	MgO kg/ha	S kg/ha
Transplant establishment and early development	0-45	59	48	74	70	12	9
From flower initiation to fruit formation	45-90	138	46	196	141	26	21
From fruit formation to final harvest	90-150	148	46	221	141	20	16
Total	**0-150**	**345**	**140**	**491**	**352**	**58**	**47**

A similar calculation can be made for dry applied granular fertilisers in rain fed or flood irrigated pepper. In that case the following nutrient efficiency percentages can be used in Table 37 under step 3 (Table 39).

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

Table 39. *Nutrient efficiency percentages for dry applied fertilisers under rain fed or flood irrigation pepper.*

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

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 base dressing, followed by higher doses during the vegetative growth and fruit formation phase.

Sulphur may be fully applied in the base dressing.

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 researches 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 effect on K, Ca and Mg uptake in various plant parts of sweet pepper when fertilised with nitrate or ammonium fertilisers.

The highest levels of K, Ca and Mg in several plant organs of sweet pepper were found with nitrate being the N source (Table 40) (Xu *et al*, 2001).

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

Table 40. *The effect on K, Ca and Mg uptake in various plant parts of sweet pepper when fertilised with nitrate or ammonium fertilisers.*

Effect of varying nitrogen form and concentration during the growing season on sweet pepper flowering and fruit yield.

Flowering and fruit set of sweet pepper is sensitive to environmental condition and nitrogen nutrition status. To clarify the N fertilisation effect on flowering, fruiting and yield, four levels of total N concentrations and four nitrate-nitrogen and ammonium-nitrogen ratios were supplied in three distinct physiological stages of sweet pepper: Stage I – vegetative; Stage II – fruit set during cross pollination; and Stage III – fruit developing period.

Gradually increasing the total N concentration with the progressing physiological stages from 3 to 6 to 9 mM increased the total set of flowers and fruits, and produced the highest total fruit yield (3.444 g/plant).

From Autumn to Winter, Low N Induces Early Flowering

Table 41 shows that low N during all growth stages (3-3-3) gave the lowest values for set flowers and fruits. Low N concentration during the vegetative growing stage before fruit set tended to set more early flower and fruits. Gradually increasing the N concentration (3 to 9 mM) yielded the highest number of set flowers and fruits (Xu *et al*, 2001).

Table 41. *Effect of varying nitrogen concentration during the season on pepper flower and fruit set.*

Autumn-Winter								
N (mM) in growing stage			Duration of cross pollination (days)			Duration of fruit set (days)		
I	II	III	1-12	26-37	Total	1-12	26-37	Total
			Number of set flowers per plant			Number of set fruits per plant		
3	6	9	7,6 a	11,5 a	29 a	7,1 a	2,7 a	12,4 a
6	6	6	4,5 b	8,9 a	22,8 b	4,2 b	2,9 a	11,0 ab
9	6	3	6,3 ab	7,7 a	22,8 ab	5,4 ab	2,1 ab	11,5 ab
3	3	3	7,2 ab	6,6 a	20,6 b	6,8 ab	1,0 b	9,2 b

I from transplanting to initial of cross pollination
II during cross pollination
III fruit developing after pollination
$N\text{-}NH_4$ constituted 15% N-total
Same letter in each column represented no significantly difference at 5% probability level.

From Spring to Summer, High N Reduces the Number of Set Fruits

Table 42 shows that the N concentration did not significantly affect the early flowering and fruit set in the first 12 days of cross pollination. High N concentration (12-12-12 mM) increased the flower set at the later cross pollination but significantly reduced the number of set fruits (6,1 fruits out of 22,3 flowers per plant).

Table 42. *Effect of varying nitrogen concentration during the season on pepper flower and fruit set.*

Spring-Summer								
N (mM) in growing stage			Duration of cross pollination (days)			Duration of fruit set (days)		
I	II	III	1-12	22-33	Total	1-12	22-33	Total
			Number of set flowers per plant			Number of set fruits per plant		
3	6	9	6,3 a	14,9 b	29,6 a	3,4 a	10,2 a	18,6 a
6	6	6	6,8 a	16,3 b	30,9 ab	5,0 a	7,7 ab	17,6 a
9	6	3	7,4 a	17,4 b	32,4 ab	4,2 a	6,9 b	16,6 a
12	12	12	6,9 a	22,3 a	37,1 b	3,4 a	6,1 b	17,8 a

I from transplanting to initial of cross pollination
II during cross pollination
III fruit developing after pollination
$N\text{-}NH_4$ constituted 15% N-total
Same letter in each column represented no significantly difference at 5% probability level.

Effect of Changing N-NH_4 Ratio During the Autumn-Winter Season

Table 43 demonstrates the effect of ammonium nitrogen concentration during three growth stages of pepper on duration of cross pollination (days) for the number of set flowers per plant, and on duration of set fruits (days) for the number of set fruits per plant in the autumn to winter period. N-total was 6 mM. N form did not significantly affect the flowering and fruit set in the first 12 days of cross pollination. The increasing N-NH_4 ratio (0-15-30, %) severely impaired the set of later cross-pollinated flowers and fruits during the 26 to 37 days after the beginning of the pollination period (2,8 flowers and 0,2 fruits per plant).

Table 43. *Effect of changing ammonium N ratio during the season on pepper flower and fruit set.*

Autumn-Winter								
N-NH_4 (%) in growing stage			Duration of cross pollination (days)			Duration of fruit set (days)		
I	II	III	1-12	26-37	Total	1-12	26-37	Total
			Number of set flowers per plant			Number of set fruits per plant		
0	0	0	7,2 a	7,3 a	24,9 a	5,9 a	2,4 a	11,8 a
0	15	30	7,9 a	2,8 b	16,0 b	6,9 a	0,2 b	9,7 b
30	15	0	6,4 a	8,5 a	23,6 a	5,6 a	2,3 a	10,9 ab
30	30	30	5,7 a	8,1 ab	22,8 ab	4,7 a	1,6 ab	10,1 ab

I from transplanting to initial of cross pollination
II during cross pollination
III fruit developing after pollination
N-NH_4 constituted 15% N-total
Same letter in each column represented no significantly difference at 5% probability level.

Effect of Changing N-NH_4 Ratio During the Spring-Summer Season

Table 44 shows the effect of ammonium nitrogen concentration during three growth stages of pepper on duration of cross pollination (days) for the number of set flowers per plant, and on duration of set fruits (days) for the number of set fruits per plant in the spring to summer period. N-total was 6 mM. High N-NH_4 (30% and 50% over N-total) in the vegetative stage significantly stimulated the early flowering and fruit set in the first 12 days of cross-pollination. High N levels in all stages (50-50-50) impaired the flower setting in late cross pollination. Low total fruit set (13,4/plant) was observed when N-NO_3 was supplied as sole N source.

Table 44. *Effect of changing ammonium N ratio during the season on pepper flower and fruit set.*

Spring-Summer								
N-NH$_4$ (%) in growing stage			Duration of cross pollination (days)			Duration of fruit set (days)		
I	II	III	1-12	22-33	Total	1-12	22-33	Total
			Number of set flowers per plant			Number of set fruits per plant		
0	0	0	5,1 b	16,8 ab	28,9 a	3,8 c	6,2 a	13,4 b
0	15	30	6,3 b	14,7 ab	32,1 a	4,4 bc	7,2 a	17,4 a
30	15	0	7,6 a	19,5 a	33,6 a	6,6 a	7,8 a	18,0 a
30	30	30	7,3 a	14,1 b	31,7 a	5,4 ab	5,7 a	14,0 ab

I from transplanting to initial of cross pollination
II during cross pollination
III fruit developing after pollination
N-NH$_4$ constituted 15% N-total
Same letter in each column represented no significantly difference at 5% probability level.

Figure 65 describes pepper fruit ripening as affected by varying N concentration along the season.

In the **autumn-winter season**, the low N supply (3-3-3, mM) produced the highest fruit yield during the first 28 days of picking. Limiting N supply induced early ripening of fruits. High N concentration early and low N later in the season (9-6-3, mM) severely reduced the yields of both early ripening and total fruits.

The highest total fruit yield in the winter season was obtained by gradually increasing the supply (3-6-9, mM). In the pepper growing season from autumn to winter, low N induces early flowering and high N later in the season is needed to supply the nutrient to the developing fruits (Figure 65).

In the **summer season**, most of the cross-pollinated fruits were obtained in the first three pickings (extended 10 days). Particularly the treatment when 9 mM N were supplied before fruit set stimulated the early ripening of fruits.

In the summer season no significant difference of total number of fruit set and yield was found between the four N regimes (Table 42). It seems that during the hot and long day growing season, changing the N distribution during the growing stages affects the duration of flowering and fruit set ratio (Table 42), time of fruit developing (Figure 65) more than the total number of set fruits and total fruit yield.

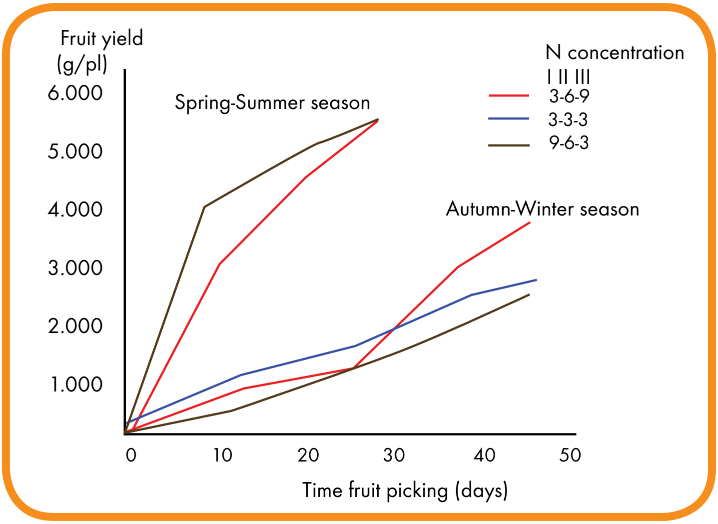

Figure 65. *Pepper fruit ripening as affected by varying N concentration along the season.*

When NH_4-N was 30% during the vegetative stage and gradually reduced to 0% (only NO_3-N) during fruit filling period, the total fruit yield was significantly higher than the other N form treatments in the autumn-winter season (Figure 66).

The beneficial effect on fruit yield of NH_4-N supply in a gradually decreasing order with plant development (30-15-0, %) was also obtained in the spring-summer season (Figure 66).

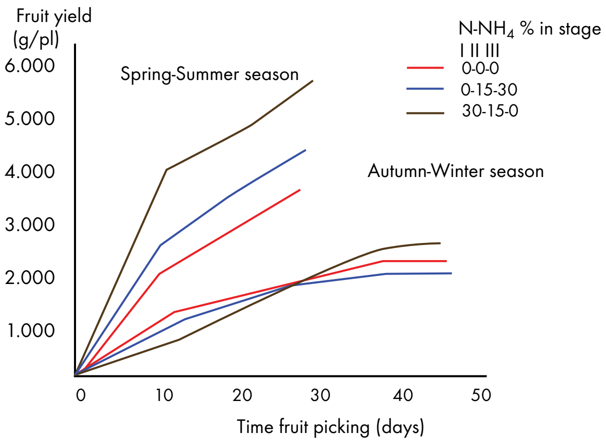

Figure 66. *Pepper fruit ripening as affected by changing NH_4-N ratio along the season.*

In conclusion, high yield of early ripening pepper fruits in hot and long photoperiod season needs the supply of relative high concentration of N (9-6 mM N) and partial NH_4-N (30-15%) during vegetative growing and fruit set stages. In spite of the difference of climate condition between seasons, both high total fruit yield and N-use efficiency for pepper plant require the decrease of NH_4-N ratio from high (30%) in the vegetative growing stage to only NO_3-N during the fruit developing stages.

Calcium * boron interaction

There is a calcium * boron interaction. Table 45 shows the effect of Ca and B and high salt levels on yield and BER on pepper. Highest marketable yield and no BER incidence were found under relatively high levels of calcium and boron.

Table 45. *The interaction of different calcium and boron levels under saline conditions on the marketable yield and BER incidence.*

Calcium/ Salts (ppm)	Boron (ppm)	Marketable Yield (kg)	BER incidence
150/1.000	0,5	1,25	-
50/1.000	0,5	0,55	++
150/1.000	0	0	+

Sources: Geraldson, 1957; Marsh and Shive, 1941.

9 Proven Cost Effectiveness of Balanced Nutrition Programmes

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

The first example is a trial in pepper for the fresh market, grown in open field. SQM's fertiliser programme was compared to a traditional fertiliser programme in bell pepper, grown in Sinaloa in Mexico.

A second example is a trial in "Kapia" pepper for the industry, grown in the open field. SQM's fertigation programme was compared to a traditional fertiliser programme in pepper, grown in Izmir area in Turkey (Table 50).

Table 46 describes the growing phases of bell pepper in the first trial.

Table 46. *Growing phases of bell pepper.*

Date	Crop Stage		Accum. Days
12-09-2001	1	Transplant	0
29-11-2001	2	Start Harvest	77
08-03-2002	3	End Harvest	175

The SQM programme (Table 47) included higher amounts of potassium and calcium, and lower amounts of phosphorous as compared to the traditional programme (Table 48).

Table 47. *SQM fertilisation programme.*

Crop stage	SPN	N° Appli-cations	Applied/ appli-cation (kg/ha)	Total applied (kg/ha)	Nutrient input (kg/ha)					
					N	P_2O_5	K_2O	S	CaO	MgO
Base Dressing	Qropmix™ 22-31-0	1	400	400	88	124				8
Side dressing 1	Ultrasol™ MAP	1	18	18	2	11				
	Ultrasol™ Micro B	1	1,8	2						
	Urea	1	36	36	17					
	Ultrasol™ Calcium	1	25	25	4				7	
	Ultrasol™ K	1	100	100	12		45			
Side dressing 2	Ultrasol™ MAP	11	18	198	24	121				
	Ultrasol™ Micro B	11	1,8	20						
	Urea	11	36	396	182					
	Ultrasol™ Calcium	11	25	275	43				72	
	Ultrasol™ K	11	100	1.100	132		495			
Side dressing 3	Ammonium Nitrate	2	50	100	34					
Total nutrient input				2.670	537	256	540	0	78	8

Table 48. *Traditional fertilisation programme.*

Crop stage	Products	N° Appli-cations	Applied/ appli-cation (kg/ha)	Total applied (kg/ha)	Nutrient input (kg/ha)					
					N	P_2O_5	K_2O	S	CaO	MgO
Base Dressing	Mix 24-33-0	1	400	400	96	132				8
1	Ammonium Nitrate	1	300	300	102					
2	Potassium Sulphate	6	70	420			210	71		
	Magnesium Nitrate	6	30	180	20					27
	Urea	6	80	480	221					
	10-34-0	6	100	600	60	204				
3	Ammonium Nitrate	2	100	200	68					
Total nutrient input				2.580	567	336	210	71	0	35

Figure 67 shows the yield differences, expressed in export boxes of 20 kg per hectare. The SQM programme resulted in higher yields during each harvesting date as compared to the traditional programme.

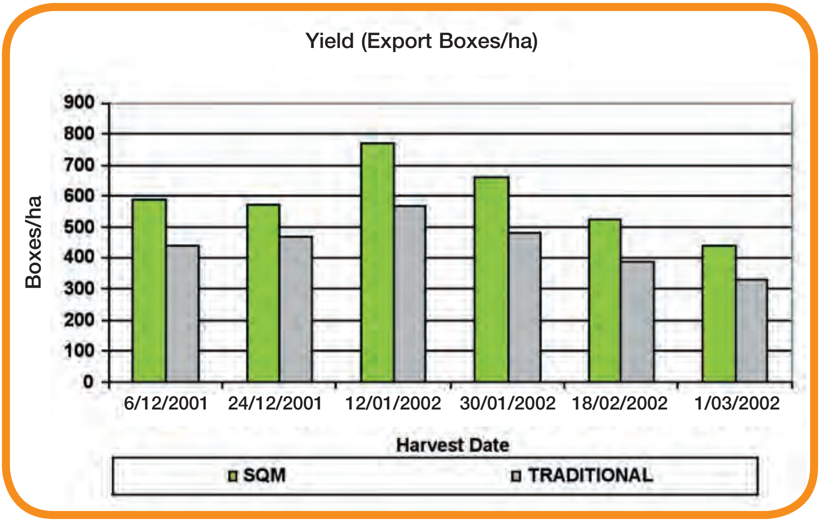

Figure 67. *Comparison of the yields between the SQM programme and the traditional programme.*

Although the total fertiliser cost increased with 50%, after deducting the extra cost of fertilisers, the SQM fertigation programme resulted in 6.139-340= 5.799 US$/ha more net income as compared to the traditional fertiliser programme. The benefit:cost ratio was 18,1:1, which means that for every 1 US$ extra investment, 18,1 US$ extra income was generated (Table 49).

Table 49. *Comparison of the results between the SQM and traditional fertiliser programme.*

	SQM	Traditional
Fertiliser Cost (US$/ha)	1.020	680
Difference (US$/ha)	340	
Boxes/ha	3.550	2.673
Revenues (7 US$/box)	24.850	18.711
Difference (US$/ha)	6.139	
Total yield (kg/ha)	71.000	53.460
Benefit:cost ratio	18,1:1	

Another trial is presented in "Kapia" pepper for the industry, grown in open field. SQM's fertigation programme was compared to a traditional fertiliser programme in pepper, grown in Izmir area in Turkey (Tables 50, 51, 52 and 53).

Figure 68. *Kapia pepper is the most used pepper variety for the industry in Turkey.*

The SQM trial plot received higher quantities of fertilisers, with especially higher doses of potassium, calcium and boron, which was reflected in the NPK ratios.

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

Table 50. *SQM fertilisation programme.*

Fertilisers	Dose kg/ha	Kg/ha						
		N	P_2O_5	K_2O	CaO	MgO	S	B
Qrop™ SOP	80			41			14	
Qrop™ DAP	200	36	92					
Ultrasol™ K	80	11		36				
Subtotal base dressing	360	47	92	77	0	0	14	
Ultrasol™ K	520	70		239				
Ultrasol™ MAP	90	11	55					
Ultrasol™ Calcium	420	65			111			
Borax	4							0,61
Ammonium nitrate	280	92						
Subtotal fertigation	1.314	239	55	239	111	0	0	0,61
Grand total	1.674	285	147	316	111	0	14	0,61
Nutrient ratio		1,9	1,0	2,2	0,8	0	0,1	0,004

Table 51. *Traditional fertilisation programme.*

Fertilisers	Dose kg/ha	Kg/ha						
		N	P_2O_5	K_2O	CaO	MgO	S	B
15-15-15	600	90	90	90				
DAP	100	18	46					
Subtotal base dressing	700	108	136	90	0	0	0	0
Ultrasol™ K	160	22		73				
Urea	150	69						
Ultrasol™ Calcium	30	4			8			
Ammonium nitrate	240	79						
Subtotal fertigation	580	173	0	73	8	0	0	0
Grand total	1.280	281	136	163	8	0	0	0
Nutrient ratio		2,1	1,0	1,2	0,1	0	0	0

Table 52. *Differences between SQM and traditional fertilisation programme.*

	Dose kg/ha	Kg/ha						
		N	P_2O_5	K_2O	CaO	MgO	S	B
Difference SQM-Traditional	394	4	11	154	103	0	14	1
Difference SQM-Traditional	31%	1%	8%	94%	1.300%			

Table 53. *Comparison of the cost:benefit ratios with fertiliser input in a traditional and a balanced nutrition programme in open field Kapia pepper for the industry.*

	Unit	Traditional	SQM	Difference	
				Absolute	%
Total Fertiliser Cost	$/ha	501	1.061	559	112
Yield	MT/ha	32,0	41,3	9,3	29
Price	$/MT	196	196	0	0
Gross Income	$/ha	6.285	8.111	1.827	29
Net Income	$/ha	5.783	7.051	1.267	22

Increased Income	22%
Increased Yield	29%
Benefit:cost ratio	2,27:1

Yield was increased with 29% or 9,3 tonne/ha with the SQM fertilisation programme. Although the total fertiliser input increased with 31%, and the total fertiliser cost more than doubled in the SQM plot, after deducting the extra cost of fertilisers, the farmer earned 1.267 US$/ha extra net income. For every 1 US$ extra investment in fertiliser, 2,27 US$ extra income was generated, which gives a return on investment of 227%.

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