Knowledge grows

Fertigation Manual

Fertigation Manual

Yara is committed to providing specialist crop nutrition advice and products to growers worldwide. Increasingly, this includes the use of fertigation to ensure efficient, productive growth, with minimal environmental impact.

This **Fertigation Manual** summarizes the basic principles and practices of fertigation systems to ensure accurate and efficient crop nutrition.

It is not a formal textbook, but a practical compilation of the approaches required for successful fertigation, based on the field experience of Yara's agronomists.

Thus, the manual focuses on the agronomic value of fertigation practice and provides the reader with best practice advice.

It is primarily aimed at those with a limited knowledge of fertigation, but it will also serve as an update, and practical day-today guide, for those already actively involved in fertigation.

This manual is an integral part of Yara's fertigation training programme, as well as supporting the on farm use of the company's fertigation software - FAST.

Through adopting the practices outlined in this Fertigation Manual, growers and their advisors will be better placed to achieve optimum yields of high quality crops.

Contents

Introduction

Low volume irrigation systems, such as micro sprinklers or jets and also drip irrigation systems, were originally developed to make best use of limited water resources.

However, at the same time, these systems also improved performance where water quality was poor and on soils where irrigation was traditionally difficult to manage, such as sands and clays. A natural development of this has been the use of these systems to deliver nutrients and chemicals to the plant - fertigation and chemigation.

As a result, fertigation has now been adapted for use across many different crops, soil types and climates and is increasingly popular worldwide (Figure 1).

Currently, the area under micro irrigation is about 5.5 million hectares worldwide. The USA and Spain have the largest areas with 1.6 and 0.9 million ha respectively and the top 10 countries total 4.7 million ha. However, while the USA has double the area of land under micro irrigation than any other producer, a greater proportion of the available land area of countries such as Spain, Italy and Israel are cropped using the technique.

Undoubtedly, the area under micro irrigation will continue to increase rapidly as the amount of water available to agriculture declines and the demands for urban and industrial use increase.

Micro irrigation is also one of the few techniques that enables growers to overcome the salinity problems that currently affect 12.5m ha worldwide. As this area increases, so too will the use of micro irrigation to maintain crop production.

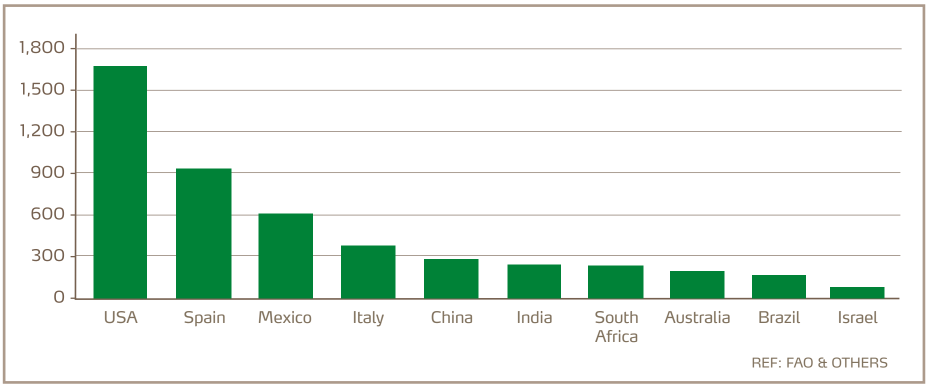
In addition, because growers are looking to reduce cost of production but at the same time improve crop quality, the improved efficiency provided from fertigation technology will become increasingly important.

This manual mainly concentrates on surface applied drip irrigation, which is the most widely used system worldwide.

However, where appropriate, details of other micro irrigation systems (e.g. subsurface drip and micro sprinkler) are quoted in the data and figures used.

Figure 1

Micro Irrigation Area ('000ha)
Top 10 Countries



Fertigation Principles

Fertigation is the combined application of water and nutrient (fertilizer) to a plant. It can be adapted to all types of crop, but is most common in high value horticultural and fruit crops, rather than broad-acre arable crops.

Micro sprinklers, tapes and drips are the most commonly used micro irrigation systems and each one suits a different environment or range of conditions.

Micro sprinkler

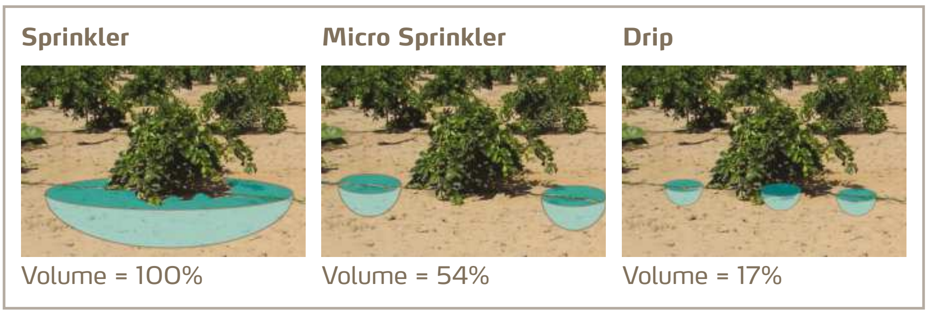
Micro jet

Drip

In all cases, the technique requires specific equipment and systems (Figure 61, page 73) that accurately apply water and nutrients under pressure.

Figure 2

Typical Wettable Bulb Volumes - Different Irrigation Systems



Compared to traditional surface irrigation systems, fertigation targets a small volume of soil. Normally, only 20-30% of the total volume of soil is wetted, and some crops and techniques require an even smaller volume.

With drip irrigation, the wetted area is bulb shaped and called the 'wetted bulb'. This is the area of soil where water and nutrients are targeted.

The size and shape of this wetted bulb depends on the type of soil and the micro irrigation system used (Figure 2). Different systems use different volumes of water and create different patterns according to the texture and condition of the soil (See photographs on page 7). Because water and nutrients are supplied to the wetted bulb area, active feeder root development is also concentrated to this zone. This improves the efficiency of absorption of both water and nutrients. In trees, rooting depth is greater and those roots outside the wetted bulb largely serve as anchorage for the crop.

Rain gun in potatoes

Fixed sprinkler in bananas

'Wetted bulb' shape at the soil surface

Roots are concentrated in the wetted bulb

Centre pivot in garlic

The key principle of fertigation is that application programmes should match a crop's nutrient demand.

This - 'just in time'- approach, allows frequent manipulation of nutrient input, maximizing efficiency and minimizing leaching.

Crop potential is maximized, because the nutrients are supplied and available exactly when they are needed, increasing both yield and quality in a range of crops (Figures 3 & 4).

Figure 3

Citrus Crop Yield (kg/tree)

Israel and USA

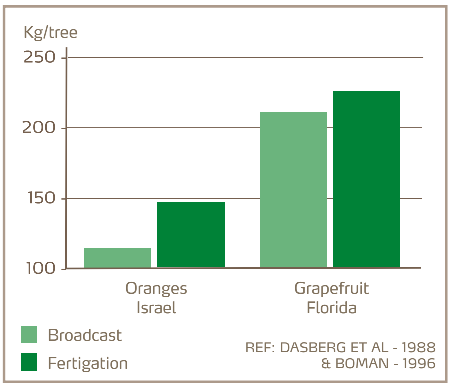
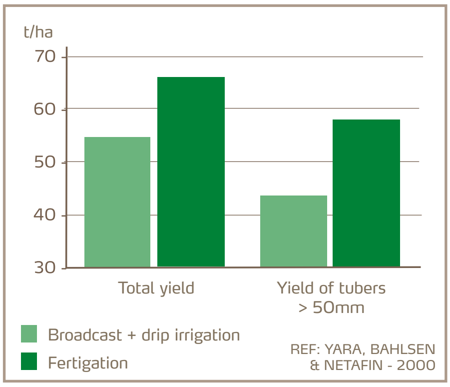


Figure 4

Potato Crop Yield (t/ha)

Germany

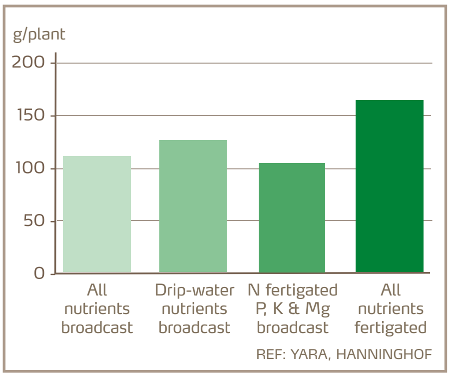


The best results are achieved when all nutrients are applied regularly across the season. This 'balanced nutrition' approach is the key to high crop productivity (Figure 5).

Figure 5

Strawberry Yield (g/plant)

Germany



Fertigation is particularly suitable under saline conditions, allowing salinity to be more easily managed by altering the irrigation volume and by leaching toxic nutrients out of the wetted bulb.

Salt accumulation at edge of the wetted bulb

Ionic (cation or anion) balances can more easily be manipulated inside the wetted bulb, ensuring, for example, that the balance between K & Ca, or Ca & Mg, is corrected for optimum crop performance. Under salinity conditions this balance may be between Ca & Na, or NO_3 & Cl.

Soil and Water Management

The chemical and physical properties of the soil or substrate significantly influence fertigation practice.

Sandy soil, bigger wetted bulb

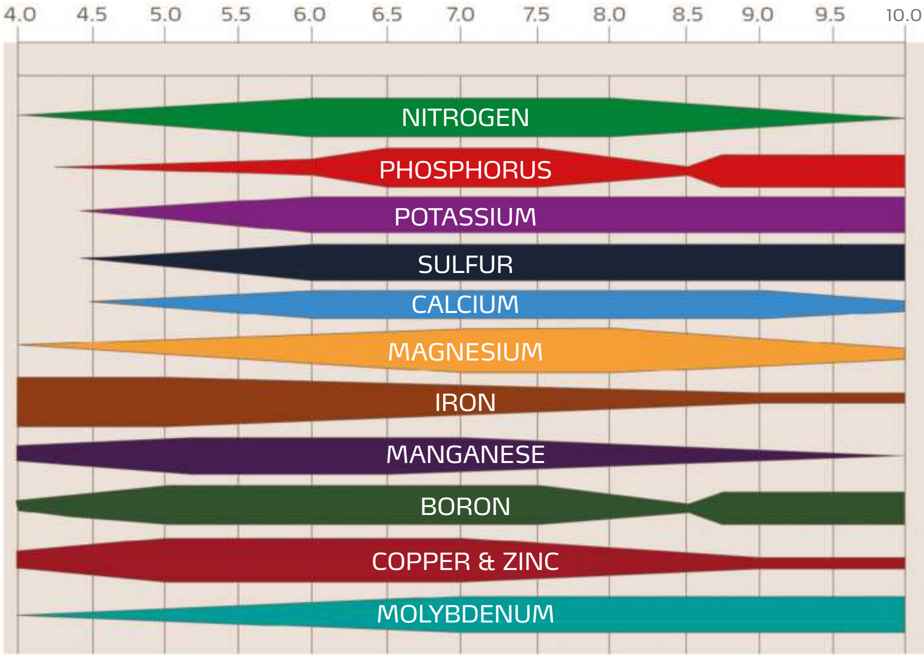
Clay soil, smaller wetted bulb

Only a small 'soil' volume is used in fertigation, and this has a major impact on nutrient balance and water availability.

As a result, it is important to ensure that conditions in this root zone don't limit growth, but maximize water and nutrient potential for productive growth.

While soil fertility is less important under fertigation, because most of the needed elements are provided directly to the root zone, extremes of pH will reduce nutrient availability (Figure 6).

Figure 6
The Influence of Soil pH on Nutrient Availability

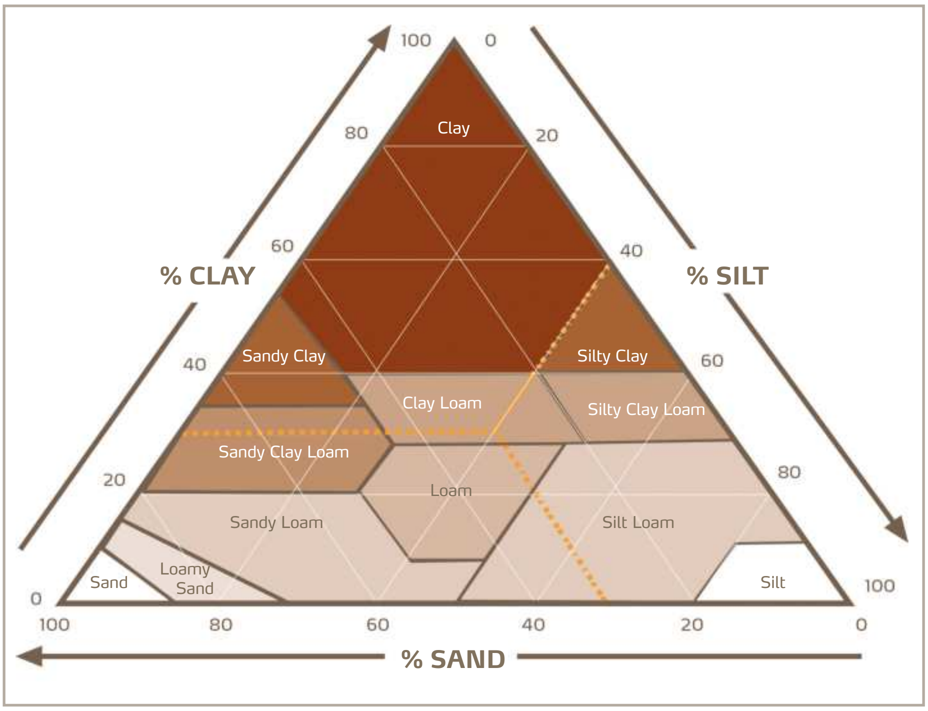


In addition, soils with a high clay or organic matter content will also fix some nutrients (e.g. K or NH_4, see Figures 28 & 31), again reducing availability to the plant.

The texture and structure of a soil will also affect moisture availability as well as the total water holding capacity of the soil profile (Figure 7).

Soils with a higher clay or silt content generally have a higher water holding capacity than sands or light loams.

Figure 7
Soil Texture



The structure of the soil (the arrangement of soil aggregates) also influences water movement through the soil. Those with a more open structure and sandy texture drain more freely and hence are more likely to lose nutrients through leaching. A more compact soil is less quick to drain, but also restricts root development.

A wide range of different pressure forces (potentials) have been identified, all of which influence the water status of soils. They are important to the understanding of water movement through the soil. Some definitions are given below:

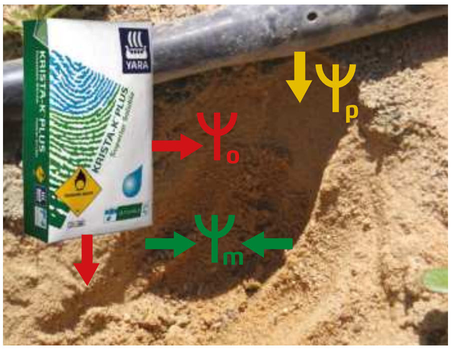
The **Osmotic Potential** (Ψo) is a measure of the levels of salts in the solution. A soil with a high level of salts in solution has a high osmotic potential and is the one most likely to cause salinity problems in plants. The osmotic pressure that a fertigation water will create in a soil (cbar) can be estimated by multiplying the EC of the water (dS/m) by 0.36.

The **Matric Potential** (Ψm), is a measure of the adsorption forces holding the water to soil particles. This occurs mainly within the micro-pores of the soil.

Finally, the **Pressure Potential** (Ψp) is a measure of the gravitational force. This varies according to the soil type and the depth from surface. Under fertigation, when the solution is injected into the soil, the pressure potential is almost zero at the soil surface.

The total potential is called **Hydraulic Potential** (Ψh), and is the sum of all the other potentials in the soil - $\Psi h = \Psi o + \Psi m + \Psi p$ (Figure 8).

Figure 8
Soil Potentials



The relative potentials in the soil will change as the moisture content changes.

All potentials are measured as negative forces and expressed as atmospheric units, Pascal (Pa) or as kilo Pascal (KPa) or mega Pascal (MPa), or, most frequently in irrigation, bars (cbars = bar 10^{-2}) or meters of water column height (mwc), where 1bar = 10mwc.

Water moves through the soil from areas of high potential to areas of low potential and because these potentials have a negative value, -10cb is a bigger potential than –50cb.

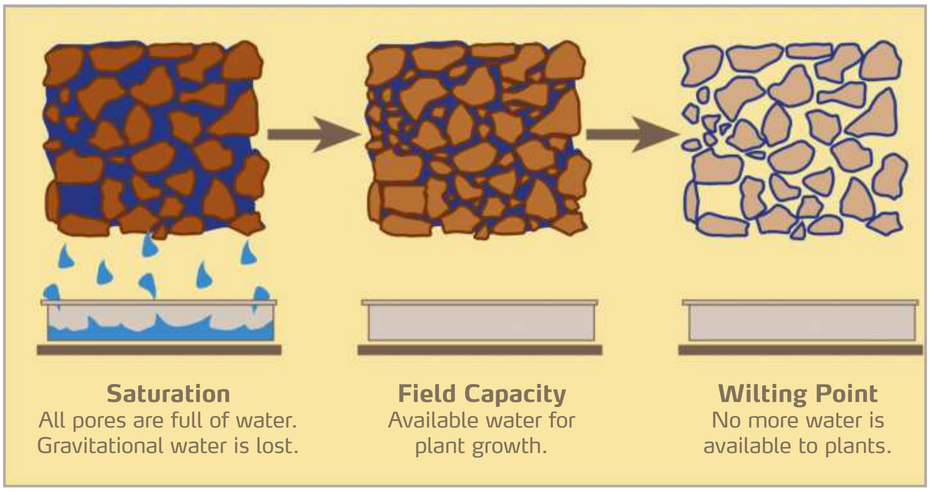
Water held by micro-pores has a high matric potential and so is not easily available for plants.

The most readily available water in the soil comes from the macro-pores, with their lower matric potential, but this water is often most easily lost through drainage, particularly in sands.

Plants use energy to counteract these forces and absorb water from the soil. For example, plants growing in soils with a high matric potential, or a high salinity (high osmotic potential), need to use more energy to absorb available water (see page 57, Table 40 for example).

When it is no longer possible for the plant to extract the water, the plant wilts. This is known as the **'wilting point'** (Figure 9) and is different for each soil.

Figure 9
Available Soil Water
Loam Soil



At the other end of the scale, after rainfall or irrigation, the soil is saturated with water, and all the pores (macro and micro) are full. This is known as **'saturation point'.**

Saturated soil will drain and settle down until it reaches an equilibrium state where the pull of gravity is balanced by the total potential of the soil. This point is known as **'field capacity'.**

At any one time, the total potential amount of water available to a plant from the soil is the difference between that water at wilting point and that held at field capacity.

Different soils have different levels of available water (Table 1). Available water is expressed in pressure units (cbars), mm of water, or as a percentage related to the weight of dry soil.

Fertigation practice, and most importantly dripper selection and spacing, needs to take into account all these above soil factors, as well as the specific crop's rooting depth and the level of nutrients needed within the wetted bulb. Examples of different layouts for garlic are shown in the photos opposite.

Table 1

Water Availability in Different Soils

As % of dry soil and at different hydraulic potentials

	Moisture content in % dry soil						Moisture content in (mm/m)			
	Field Capacity		Wilting point		Available water		Soil hydraulic potential (atm*)			
Soil Type	Range	Average	Range	Average	%	(mm/m)	0.2 atm	0.5 atm	2.5 atm	16 atm
Sandy	6 - 12	9	2 - 6	4	5	85	60	30	20	0
Sandy Loam	10 - 18	14	4 - 8	6	8	120	130	80	30	0
Loam	18 - 26	22	8 - 12	10	12	170	200	150	70	0
Clay Loam	25 - 31	27	11 - 15	13	14	190	160	120	70	0
Silty Clay	27 - 35	31	13 - 17	15	16	210	190	170	100	0
Clay	31 - 39	35	15 - 19	17	18	230	180	150	80	0

**atm = atmosphere*

REF: CADAHIA - 1998

Fertigation layout depends on soil and climatic conditions as shown in the 3 garlic crops above

Infiltration rate, and hence maximum application rate, varies according to soil type (Table 2). In a course sandy soil, with a depth of 1.8m, an application rate of 50mm/hr will only wet 0 - 5% of this profile before run off occurs.

If an emitter discharges at a greater rate than the soil can absorb, the water will run off leading to water-loss and erosion.

In a uniform soil, the wettable area from a dripper spreads evenly in a bulb-shaped pattern (Figure 10).

Table 2

Maximum Application Rates Before Run Off Occurs

Soil - texture and depth	Maximum application rate (mm/h) 0-5%	5-8%	8-12%	12-16%
Coarse sandy soil to 1.8m	50.0	38.0	25.0	13.0
Coarse sandy soils over more compact soils	38.0	25.0	19.0	10.0
Light sandy loams to 1.8m	25.0	20.0	15.0	10.0
Light sandy loams over more compact soils	19.0	13.0	10.0	8.0
Silt loams to 1.8m	13.0	10.0	8.0	5.0
Silt loams over more compact soils	8.0	6.0	4.0	2.5
Heavy textured clays or clay loams	4.0	2.5	2.0	1.5

REF: YARA

Figure 10

Typical Wettable Bulb Shape and Water Infiltration Rate

Infiltration rate during one hours irrigation and until steady state is reached

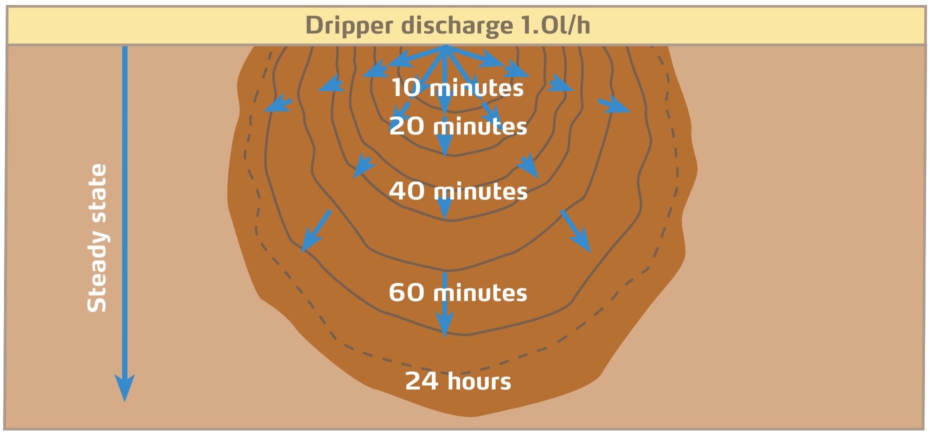
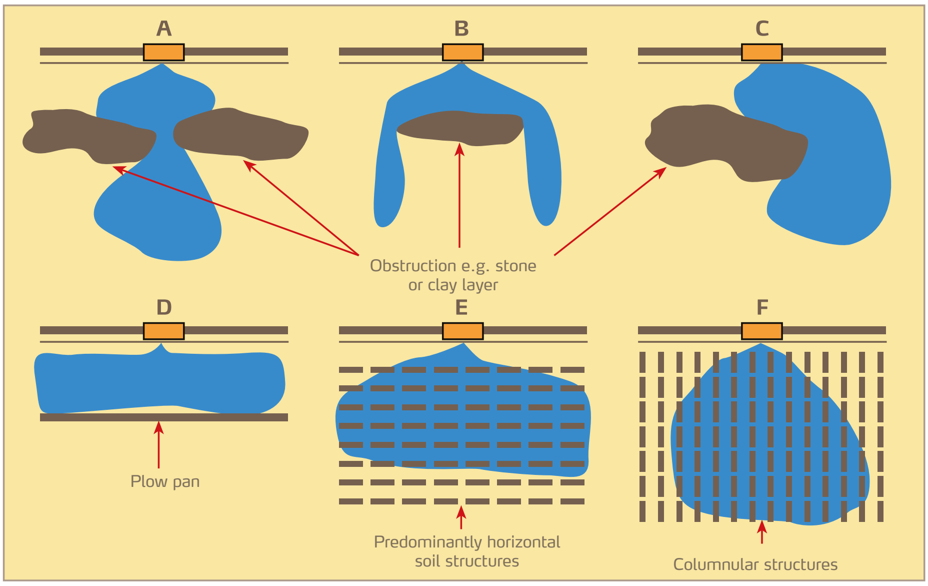


Figure 11
Soil Conditions and Wetted Bulb Patterns



However, bulb shape can vary according to structure and the presence of different soil horizons or different textures (Figure 11).

A higher discharge rate leads to more horizontal water flow (Figure 12) while a lower discharge rate leads to more flow into a greater depth of soil for the same amount of water given. This effect may vary with infiltration rate (Figure 13).

In general, infiltration rate is lower in clay soils and higher in sandy soils (Figure 14). Achieving deep infiltration of water is difficult in clay soils. Equally, in sandy soils with a fast infiltration rate, it is difficult to increase the area of wettable bulb in the upper layers of soil. This is why micro sprinklers are often preferred on free-draining, sandy soils.

Figure 12
Wetted Bulb and Drip Discharge.
Different Volumes of Water Applied Over Same Time Scale

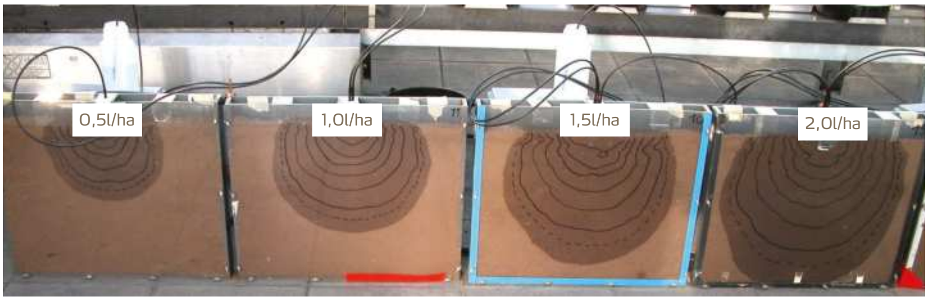
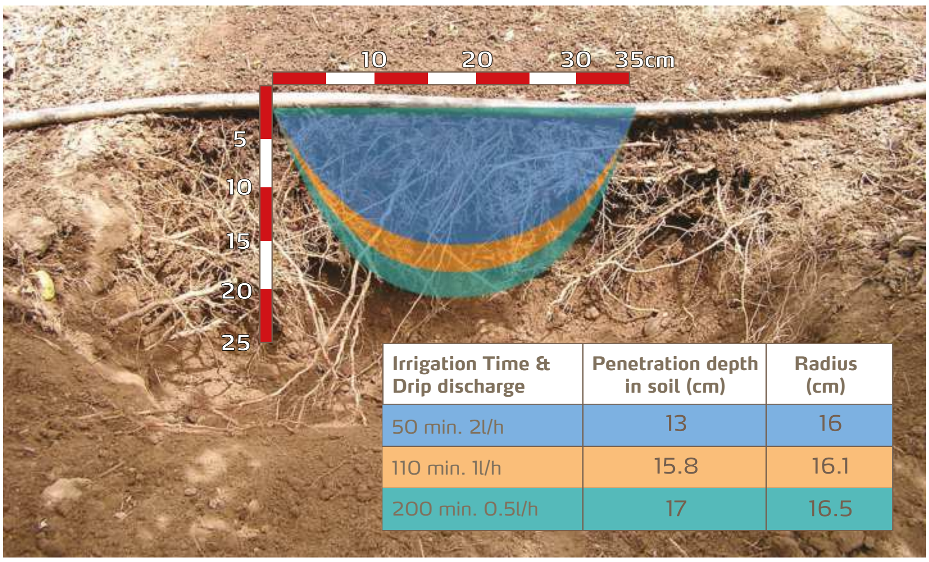


Figure 13
Wetted Bulb and Drip Discharge.
Same Volume of Water - Different Lengths of Irrigation



Irrigation Time & Drip discharge	Penetration depth in soil (cm)	Radius (cm)
50 min. 2l/h	13	16
110 min. 1l/h	15.8	16.1
200 min. 0.5l/h	17	16.5

REF: ADAPTED FROM J LI ET AL - 2004

Figure 14
Clay and Sandy Soil Infiltration Patterns

Wetted bulb shape at the soil surface

Soil Aeration

For optimum root respiration and microbiological activity, oxygen levels need to be maintained at around 10% within the soil atmosphere. Below this, anaerobic processes predominate.

While low O_2 levels may temporarily occur during initial irrigation with no permanent adverse effect, longer periods of flooding can lead to an O_2 deficit (anoxia) and significant plant damage.

Anoxia significantly reduces plant vigor; leaves will exhibit various nutrient deficiencies, especially nitrogen. In addition, damage to the roots is often extensive even when no symptoms are visible.

Crops vary in their tolerance to anoxia (Table 3). There is a close correlation between O_2 and CO_2 concentration - increasing one will decrease the other.

Table 3
Crop Sensitivity to Soil Oxygen Levels

High Tolerance O_2 : 0 - 1%	Paddy rice
	Sugar cane
	Several pastures
Medium Tolerance O_2 : 5%	Oat
	Barley
	Onion
	Cotton
	Citrus
	Soya bean
	Apple
Low Tolerance O_2 : 10%	Maize
	Peas
	Faba bean
	Tobacco

REF: A DOMINGUEZ VIVANCOS - 1996

In fertigation, proper water management is crucial, as anoxia can be easily reached, especially in heavier clay soils.

Salinity also increases the risk of anoxia both chemically and also physically, through its effect on soil structure.

When the soil is waterlogged, nutrients may be reduced to a different form and become unavailable e.g. iron.

Anoxia causes N deficiency in carnations

Salinity toxicity in banana

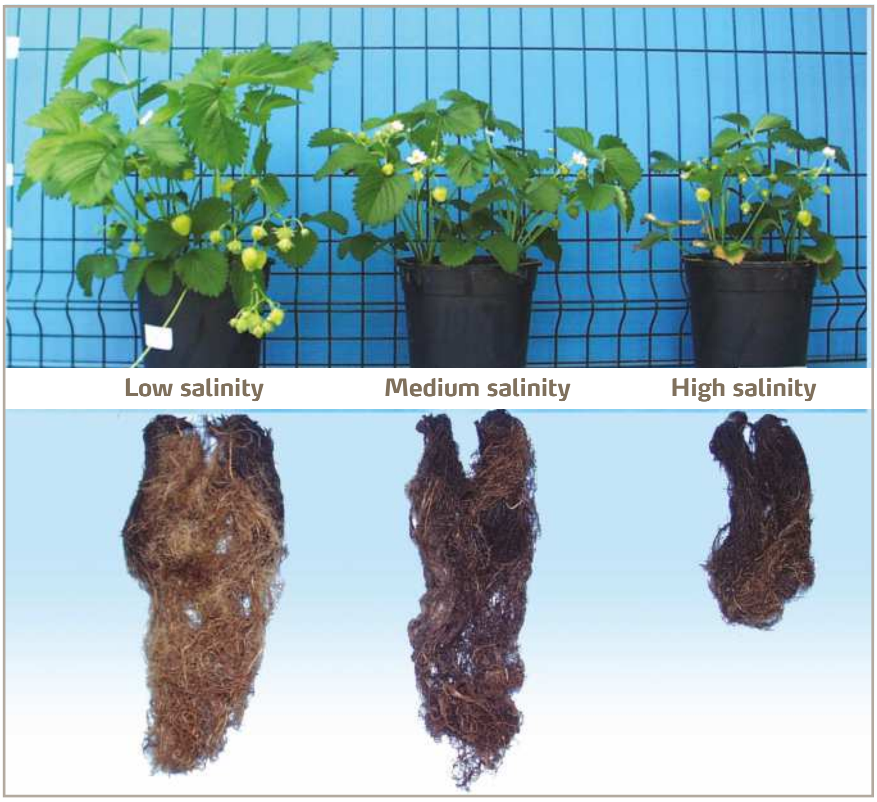
Salinity and Sodicity

Salts can have a negative effect on yield and quality. Crops differ in their sensitivity to salinity and some commonly illustrate specific toxicity symptoms.

However, even where toxicity symptoms are not seen, once threshold levels have been reached, yield loss is incurred, and the higher the level of salinity, the greater the drop in crop performance.

Yield loss as a result of salt toxicity can be assessed using the following equation:

$\mathbf{Y = 100 - b\,(EC_e - a)}$, where Y is the relative crop yield (%), $\mathbf{EC_e}$ is the salinity of the saturated soil extract in dS/m, **a** is the threshold value for maximum, 100% production, and **b** is the yield loss in percentage per unit increase in salinity.



Low salinity = 0 g NaCl added to nutrient solution | *Medium salinity = 0.9 g NaCl added to nutrient solution* | *High salinity = 2.8 g NaCl added to nutrient solution*

Crops vary in their sensitivity to salinity and nutrient toxicities, e.g. boron and chlorine (Tables 4 - 6).

Thus, it is important to evaluate the salinity and sodium status or 'sodicity' status of soils by testing soil solutions for pH, ECex, SAR and ESP (Definitions and examples follow on pages 15 to 17).

Generally, saline soils have an ECex above 4 dS/m, pH below 8,2 and ESP < 15 (Table 7). And, in saline-sodic soils, pH is above 8.2, ECex is above 4 and ESP above 15.

While these indices give no indication of the type of salinity, further soil analysis can confirm whether it is sodium chloride, sodium sulfate, magnesium sulfate or even carbonates, that are causing the problem. Chlorine, sodium and boron toxicity will also reduce yield.

Identifying the type of salinity - through soil and water analysis - is the key to managing the soil nutrient status.

Where salinity is an issue, fertigation can used to help minimize the problem by altering specific cation balances in the wetted bulb, and leaching problem salts out of the main root zone.

Boron toxicity in tomato

Table 4
Crop Sensitivity to Salinity

			100%		90%		75%		50%		0%	
	a*	b*	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw
Squash, zucchini *(Courgette) (Cucurbita pepo melopepo)*	4.7	9.7	4.7	3.1	5,8	3.8	7.4	4.9	10	6.7	15	10
Squash, scallop *(Cucurbita pepo melopepo)*	2.1	16.1	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli *(Brassica oleracea botrytis)*	1.9	8.9	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato *(Lycoperiscon esculentum)*	1.7	9.5	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber *(Cucumis savitus)*	1.7	13.3	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach *(Spinacia oleracea)*	1.3	7.7	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery *(Apium graveolens)*	1.2	6.2	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage *(Brassica oleracea capitata)*	1.2	9.8	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potato *(Solanum tubersum)*	1.1	12.0	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Pepper *(Capsicum annuum)*	1.0	14.1	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce *(Lactuca sativa)*	0.9	13.0	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Radish *(Raphanus sativus)*	0.8	13.0	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9
Onion *(Allium cepa)*	0.8	16.1	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Carrot *(Daucus carota)*	0.7	14.1	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Bean *(Phaseolus vulgaris)*	0.7	18.9	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Turnip *(Brassica rapa)*	0.6	9.0	0.9	0.6	2.0	1.3	3.7	2.5	6.5	4.3	12	8.0
Date palm *(Phoenix dactylifera)*	2.7	3.6	4.0	2.7	6.8	4.5	11	7.3	18	12	32	21
Grapefruit *(Citrus paradisi)*	1.2	16.1	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8.0	5.4
Apples *(Malus silvestris)*	1.1	15.9	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Orange *(Citrus sinensis)*	1.1	15.9	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Peach *(Prunus persica)*	1.1	20.8	1.7	1.1	2.2	1.5	2.9	1.9	4.1	2.7	6.5	4.3
Apricot *(Prunus armeniaca)*	1.1	23.8	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Grape *(Vitus sp.)*	1.0	9.5	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Almond *(Prunus dulcis)*	1.0	18.9	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.8	6.8	4.5
Plum, prune *(Prunus domestica)*	1.0	17.9	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.9	7.1	4.7
Blackberry *(Rubus ulmifolius)*	1.0	22.2	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Boysenberry *(Rubus ursinus)*	1.0	22.2	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Strawberry *(Fragaria sp.)*	0.7	33.3	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4	2.7

REF: MASS & HOFFMAN - 1977

**See equation on page 11.*

Table 5
Crop Sensitivity to Boron

	Boron Sensitivity	
Very sensitive (<0.5 mg/l)	Lemon	*Citrus limon*
	Blackberry	*Rubus spp.*
Sensitive (0.5 - 0.75 mg/l)	Avocado	*Persea americana*
	Grapefruit	*Citrus X paradisi*
	Orange	*Citrus sinensis*
	Apricot	*Prunus armeniaca*
	Peach	*Prunus persica*
	Cherry	*Prunus avium*
	Plum	*Prunus domestica*
	Persimmon	*Diosypros kaki*
	Grape	*Vitis vinifera*
	Walnut	*Juglans regia*
	Pecan	*Carya illinoiensis*
	Onion	*Allium cepa*
Sensitive (0.75 - 1.0 mg/l)	Garlic	*Allium sativum*
	Strawberry	*Fragaria spp.*
	Artichoke, Jerusalem	*Helianthus tuberosus*

	Boron Sensitivity	
Moderately sensitive (1.0 - 2.0 mg/l)	Pepper red	*Capsicum annum*
	Carrot	*Daucus carota*
	Radish	*Raphanus sativus*
	Potato	*Solanum tuberosum*
	Cucumber	*Cucumis sativus*
Moderately tolerant (2.0 - 4.0 mg/l)	Lettuce	*Lactuca sativa*
	Cabbage	*Brassica oleracea capitata*
	Celery	*Apium graveolens*
	Turnip	*Brassica rapa*
	Artichoke	*Cynara scolymus*
	Tobacco	*Nicotiana tobacum*
	Squash	*Cucurbita pepo*
	Muskmelon	*Cucumis melo*
Tolerant (4.0 - 6.0 mg/l)	Tomato	*Lycopersicon lycopersicum*
Very tolerant (6.0 - 15.0 mg/l)	Cotton	*Gossypium hirsutum*
	Asparagus	*Asparagus officinalis*

REF: MASS - 1984

Table 6
Crop Sensitivity to Salinity

Chlorine Sensitivity			Rootzone	Irrigation water
Crop		**Rootstock or Cultivar**	**(me/l)**	**(me/l)**
Avocado	*Persea americana)*	West Indian	7.5	5.0
Avocado	*(Persea americana)*	Guatemalan	6.0	4.0
Avocado	*(Persea americana)*	Mexican	5.0	3.3
Citrus	*(Citrus spp.)*	Sunki Mandarin	25.0	16.6
Citrus	*(Citrus spp.)*	Sampson Tangelo	15.0	10.0
Citrus	*(Citrus spp.)*	Citrumelo 4475	10.0	6.7
Grape	*(Vitis spp.)*	Salt Creek 1613-3	40.0	27.0
Grape	*(Vitis spp.)*	Dog Ridge	30.0	20.0
Stone fruits	*(Prunus spp.)*	Marianna	25.0	17.0
Stone fruits	*(Prunus spp.)*	Lovell, Shalil	10.0	6.7
Stone fruits	*(Prunus spp.)*	Yunnan	7.5	5.0
Berries	*(Rubus spp.)*	Boysenberry	10.0	6.7
Berries	*(Rubus spp.)*	Olallie Blackberry	10.0	6.7
Berries	*(Rubus spp.)*	Indian Summer Raspberry	5.0	3.3
Grape	*(Vitis spp.)*	Thompson Seedless	20.0	13.3
Grape	*(Vitis spp.)*	Perlette	20.0	13.3
Grape	*(Vitis spp.)*	Cardinal	10.0	6.7
Grape	*(Vitis spp.)*	Black Rose	10.0	6.7
Strawberry	*(Fragaria spp.)*	Lassen	7.5	5.0
Strawberry	*(Fragaria spp.)*	Shasta	5.0	3.3

REF: MASS - 1984

Table 7
Criteria for Saline and Sodic Soils

Saline Soils	Sodic Soils	Saline-Sodic Soils
ECe > 4 dS/m	ECe < 4 dS/m	ECe > 4 dS/m
ESP < 15	ESP > 15	ESP > 15
SAR < 13	SAR > 13	SAR > 13

REF: UNIVERSITY OF ARIZONA

EC - Electrical Conductivity of saturated soil paste extract
ESP - Exchangeable Sodium Percentage – exchangeable Na /cation exchange capacity
SAR - Sodium Adsorption Ratio – comparative concentrations of Na, Ca and Mg in soil solution

For instance:

- Adding highly soluble calcium into the wetted bulb will increase leaching of sodium, thereby ameliorating a sodic and or saline soil and improving plant growth and yield (Figures 15 and 16).
- By maintaining a fairly constant level of soil moisture in the wetted bulb, salts that have accumulated on the boundaries of the root zone can be kept where they are, so minimizing their effects on plant growth.

Figure 15

Calcium Ameliorates Saline Conditions

Oso Grande - Strawberry

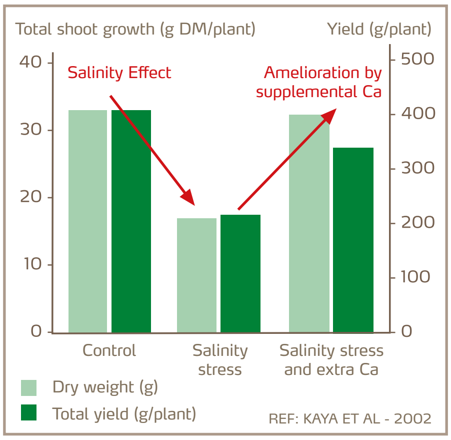


Figure 17

Nitrate-N Reduces Chloride Uptake

Cleopatra Mandarin Rootstock

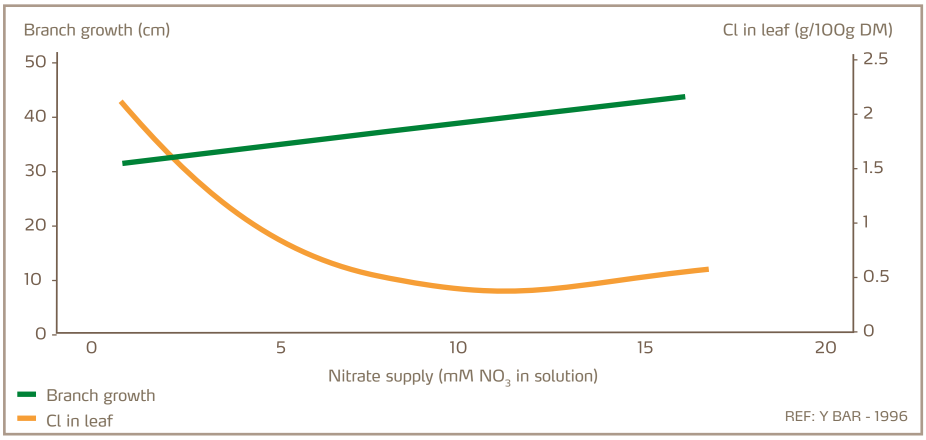
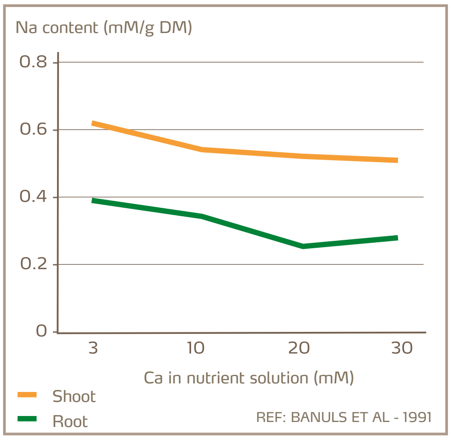


Figure 16

Calcium Reduces Sodium Uptake

Salt Sensitive Citrus

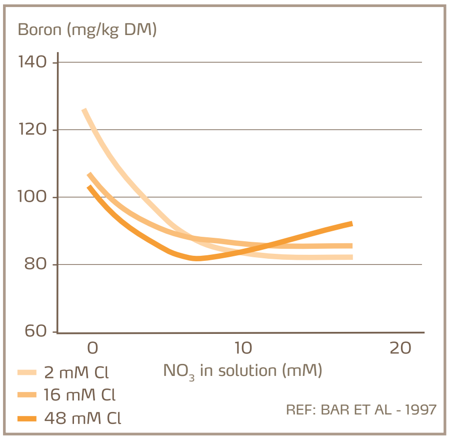


- The toxic effects of Cl, Na, or B can be reduced by frequent applications of fertilizers containing nutrients such as nitrate-N, which will compete for absorption with these toxic elements (Figures 17 and 18). The effectiveness of this strategy varies with crop type.

Figure 18

Nitrate-N Reduces Boron Toxicity

Citrus



- Fertilizer source is also important. Calcium nitrate, for example is a more effective source of calcium than gypsum, including micro-fine gypsum sources, in a fertigation system (Figures 19a & b).

High levels of salinity also affect soil structure and therefore water infiltration, leading to water run off and, in severe instances, soil erosion.

This is as a result of high levels of sodium, which disperse clay particles and create an unstable soil structure that is more likely to compact, thereby slowing water infiltration. It can be avoided by maintaining high levels of calcium in the wetted bulb.

Figure 19a

Calcium Source and Salinity Amelioration

Fertigated Tomato - Spain

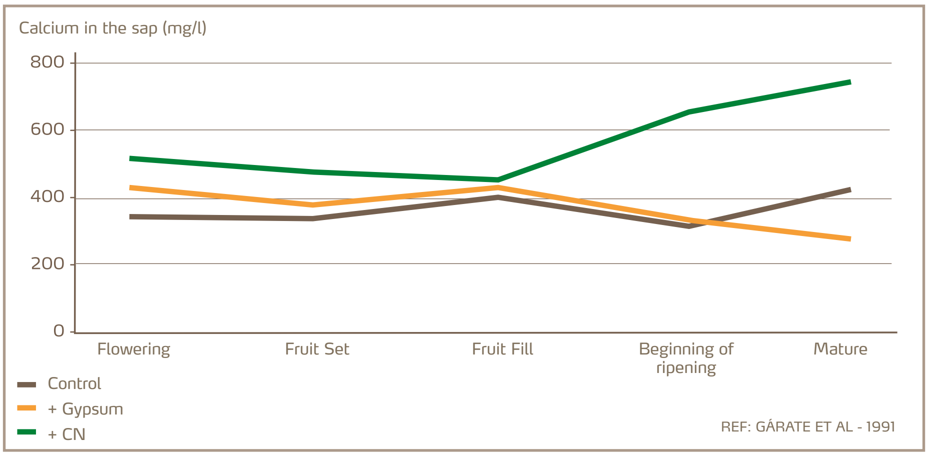
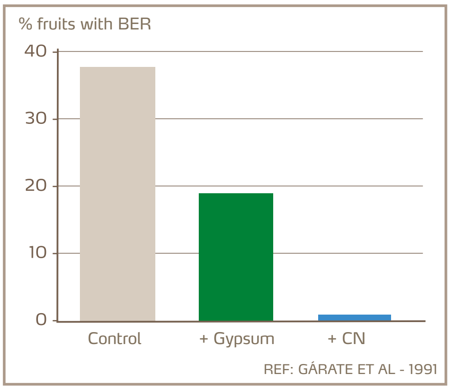


Figure 19b

Calcium Source and Blossom End Rot
Fertigated Tomato - Spain



Irrigation Water Quality

It is important to assess the quality of the water to be used for fertigation as this has a direct effect on nutrient availability and on a number of soil properties.

It is only through proper analysis that the system can be modified to suit crop type, local climate and soil variability.

On farm reservoirs

Salinity causes infiltration problems

Soil structural problems due to sodicity

It is important to check the following factors that influence water quality:

ECw - the total salts status of the water. It is a useful guide to the effect of the water on crops. When an EC rises to levels of above 0.7dS/m in water (at 25°C), water use becomes more restrictive, potentially leading loss in yield, and/or crop damage (Table 8).

Table 8

EC and Water Use Restriction (EC in dS/m at 25°C)

None	Sight to Moderate	Severe
< 0.7	0.7 - 3.0	> 3.0

REF: FAO

pH should be between 6.5 and 7.5 to prevent nutrient interactions in the solution.

The **Osmotic Potential** that the water will create in the soil solution can be estimated by the relationship **$\Psi o = -0.36 \times EC$,** where the osmotic pressure is in Bars and the EC in dS/m at 25°C.

The level of **total salts** or total dissolved solids (TDS) in mg/l can be also estimated from the EC (dS/m-25°C) value by multiplying the EC value by a factor of 0.64.

When the level of total dissolved solids rises above 450mg/l, water use is more restricted (Table 9). At levels of over 2000mg/l, the problems are classed as severe.

Table 9
TDS and Water Use Restriction

None	Sight to Moderate	Severe
< 450	450 - 2000	> 2000

REF: FAO

The **Sodium Absorption Ratio** (SAR) is another important water quality characteristic. Alongside ECw, the SAR provides an indication of the likely effect of the water's quality on the structure of the soil and specifically the replacement of calcium and magnesium in the soil by sodium.

It is normally reported and recorded as SAR. More accurate measurements of this effect can be achieved by modifying this index by taking into account carbonate and bicarbonate levels in the water and the relationship with the Ca and Mg in the soil. This is known as corrected SAR, (SARc).

The most severely restricted soils have a high SAR combined with a lower ECw (Table 10).

Table 10
SAR and ECw - Water Use Restriction

SAR	ECw		
	None	Moderate	Severe
0 - 3	> 0.7	0.7 - 0.2	< 0.2
3 - 6	> 1.2	1.2- 0.3	< 0.3
6 - 12	> 1.9	1.9 - 0.5	< 0.5
12 - 20	> 2.9	2.9 - 1.3	< 1.3
20 - 40	> 5.0	5.0 - 2.9	< 2.9

REF: FAO

Some water may have other **toxic elements**, which can also affect crop growth (Table 11). For example, when levels of chloride are above 7meq/l, water use becomes much more restricted.

Table 11
Toxic Elements and Water Use Restriction

	Low	Normal	High
Chloride (meq/l) Cl-	< 3	3 - 7	> 7
Sodium (meq/l) Na	< 2	2 - 6	> 6
Boron (mg/l)	< 0.7	0.7 - 3	> 3

REF: FAO

Salts in soil after growing season

Other indices used to check water quality include:

SCR: Sodium Carbonate Residual: a measure of the amount of carbonates and bicarbonates in the water, not precipitated with the Mg and Ca, which are available to combine with sodium and thus increase the salinity of the soil. The best water should have a SCR of <1.25 (Table 12). However, when the SCR is above 2.5, most of the carbonates and bicarbonates in solution are free to combine with the sodium and remain in the soil solution.

Table 12
SCR and Water Use Restriction

Good	Not Advisable	Not Suitable
< 1.25	1.25 - 2.5	> 2.5

REF: FAO

Scott index or Alkali index: is the amount of water, measured as inches (K), that will leave, after evaporation, sufficient alkali from a given depth of soil, e.g. 4 feet (1.2m), to stop growth of sensitive plants. Ratios are then established to show the likely effect on plant growth (Table 13). The best water has a K index of greater than 18.

Table 13
Scott Index and Water Use Restriction

Good water	Acceptable water	Medium	Bad
K > 18	K 6 - 18	K 1.2 - 6	K > 1.2

REF: FAO

There is also a series of indices used to assess the tendency of the water to clog or cause scaling in the system. These include:

Langelier index. This index calculates the theoretical pH (pHc) for the water and compares this value with the real pH of the water (pHw).

If the pHc index is positive (above zero) there is trend for the salts to precipitate out of the water causing problems with scaling. When below zero, salts are likely to remain in solution.

Scaling on a micro sprinkler

Table 14 lists a range of other factors likely to influence clogging and scaling in irrigation pipes and emitters.

Table 14
Water Clogging Hazard Classification

Parameter	Minor Risk	Moderate Risk	Severe Risk
Temperature (°C)	15 - 30	10 - 15 and 30 - 50	< 10 and > 50
pH	< 7	7.0 - 8.0	> 8
Dissolved solids (mg/l)	< 500	500 - 2000	> 2000
Manganese (mg/l)	< 0.1	0.1 - 1.5	> 1.5
Iron (mg/l)	< 0.2	0.2 - 1.5	> 1.5
Hydrogen sulfide (mg/l)	< 0.2	0.2 - 2.0	> 2.0

REF: NAKAYAMA & BUCKS - 1991

A number of countries have adopted a series of water quality standards based on a range of the parameters outlined above. For example in Holland, four water standards are categorized based on the EC and levels of Na and Cl (Table 15). Other countries may have their own local standards.

Table 15
Dutch Standards of Water Quality for Horticultural Use

	Standard 1	Standard 2	Standard 3	Standard 4
EC in mS/cm	< 0.5	< 1.0	< 1.5	> 1.5
Na^+ in mmol/l (mg/l)	< 1.5 (< 35)	< 3.0 (< 69)	< 4.5 (< 104)	> 4.5 (> 104)
Cl^- in mmol/l (mg/l)	< 1.5 (< 53)	< 3.0 (< 106)	< 4.5 (< 160)	> 4.5 (> 160)

Standard 1.
Water quality is suitable for most crops, or can be made suitable for all purposes of irrigation.

Standard 2.
Intermediate water quality. Not suitable for crops with limited root volume (hydroponics, pot plants), which cannot be flushed with sufficient water during the season.

Standard 3.
The water quality is not suitable for irrigation of salt sensitive crops, and also less salt sensitive crops with limited root volume (hydroponics, pot plants).

Standard 4.
The water is not suitable for crops in greenhouses. Irrigation with this water quality could decrease the yield or the quality of the crop. When using this water quality, it is essential to frequently flush the soil to prevent accumulation of salt.

SOURCE: PPO NAALDWIJK

Nutrient Principles

Nutrient Mobility and Availability in Fertigation Systems

For optimum growth across the whole crop area, nutrients need to be evenly distributed inside the wetted bulb, ensuring optimum root absorption for every plant.

Compared with rainfed soils, the nutrient concentration and mobility are higher and changes occur at a faster rate in the wetted bulb. Therefore, constant monitoring is important.

The movement of nutrients inside the wetted bulb is controlled by various mechanisms:

- Most nutrients are mobile and move with **mass flow**, i.e. they move with the flow of the water.
- The mobility of other elements – notably P and K – is influenced more by **diffusion**. Without other outside forces at work, these elements will move/diffuse from a more concentrated environment to a less concentrated environment.
- A third process at work within the wetted bulb is **dispersion**. This process, caused by the differences in flow velocity through the various different pore sizes in the soil, also generates local differences in nutrient concentrations.

Modern Greenhouse

The relative importance of these processes for each major and secondary nutrient was detailed in a maize trial (Table 16).

In the absence of other soil factors:

- Nitrate, calcium, sulfur, chlorine
- and magnesium are highly mobile (Figure 21).
- Phosphorus has little mobility (Figure 21).
- Potassium is intermediate in its movement (Figure 21).

Figure 20
Key to Following Wetted Bulb Diagrams

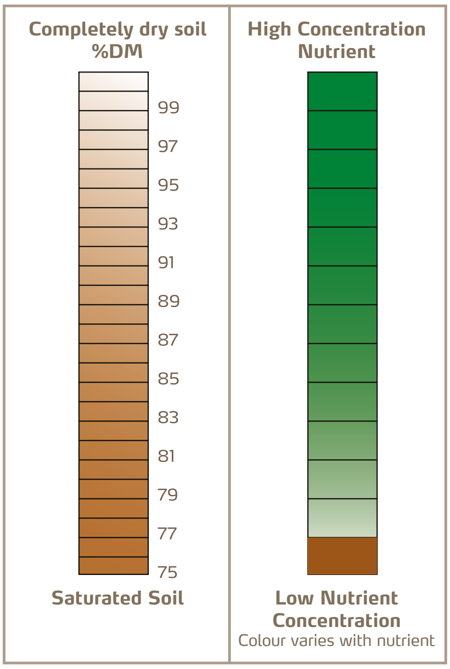


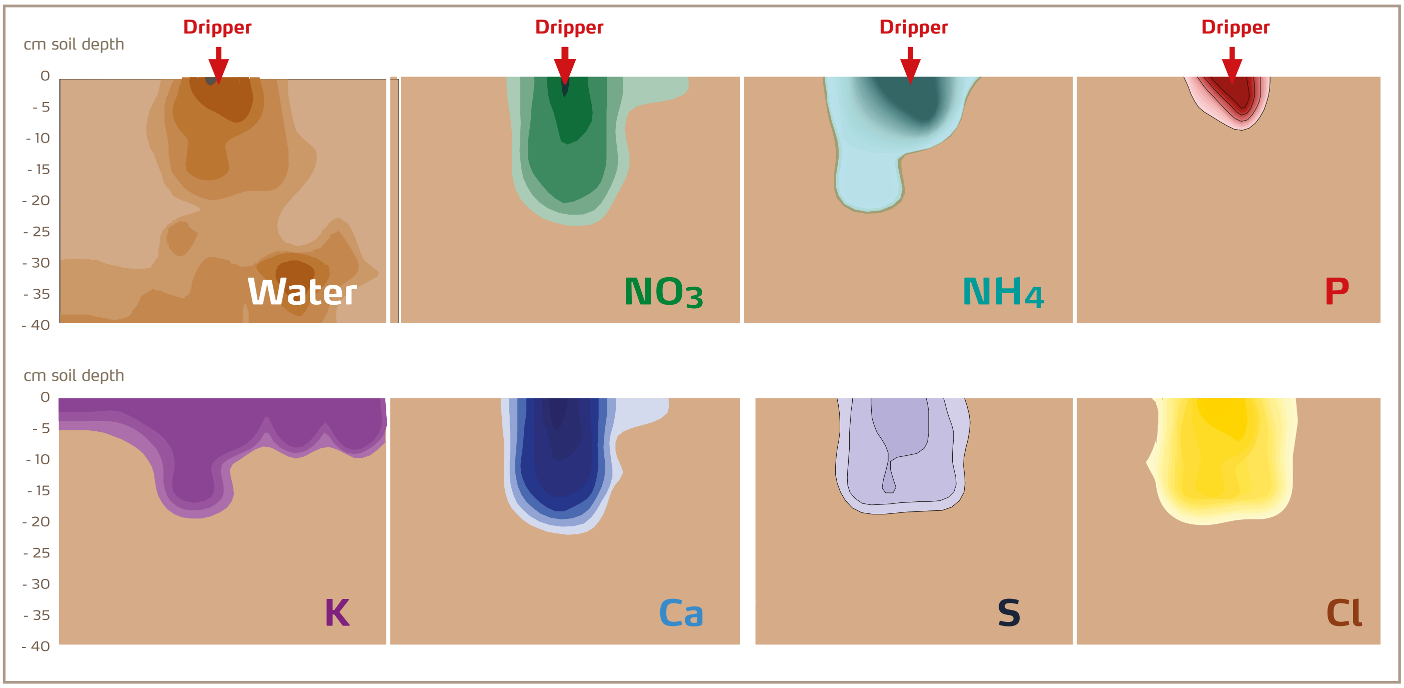
Table 16
Relative Importance of Different Transport Processes in Nutrient Movement

	kg/ha	Approximate amount supplied by:		
	Amount needed for 9.5 t/ha	Root interception	Mass Flow	Diffusion
Nitrogen	190	2	150	38
Phosphorus	40	1	2	37
Potassium	195	4	35	156
Calcium	40	60	150	0
Magnesium	45	15	100	0
Sulfur	22	1	65	0

REF: ADAPTED FROM JUNGK, 1996

Figure 21

Relative Mobility of NO_3, NH_4, P, K, Ca, Mg, S and Cl in Sandy Soil (9% clay)



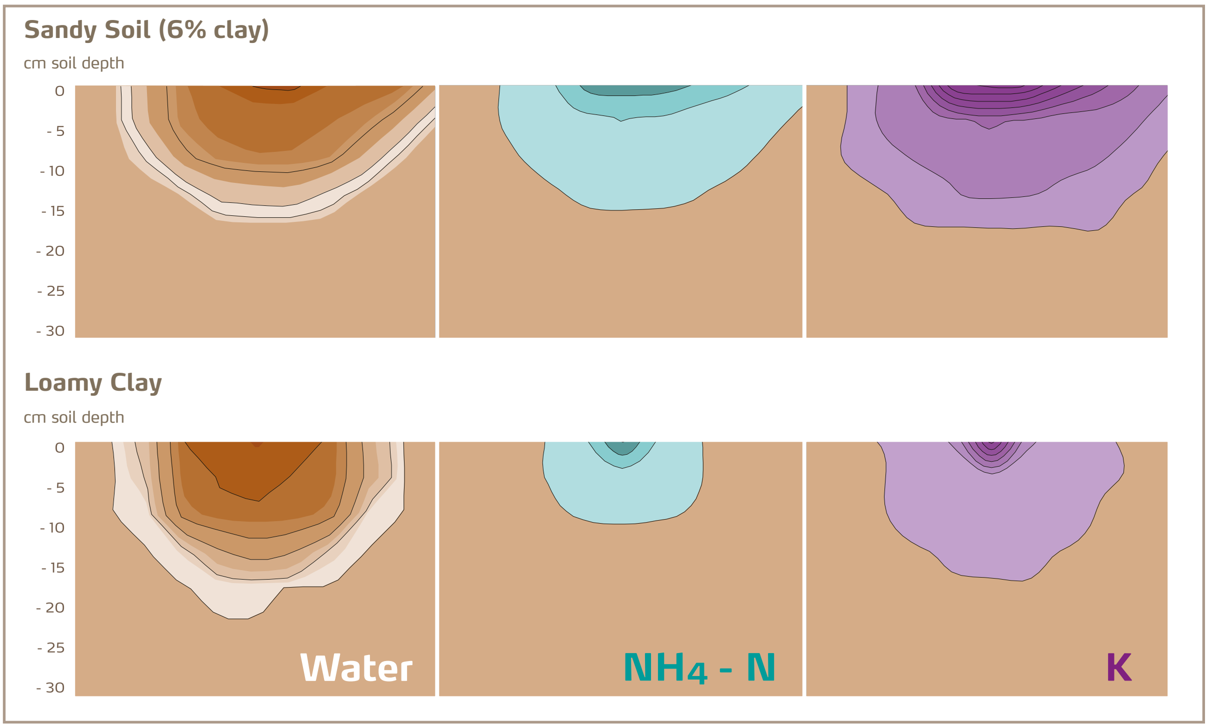
However, the availability of different elements is also affected by various soil characteristics, most notably their absorptive potential.

For example: Positively charged ammonium or potassium, can be absorbed by negatively charged clays in soils (Figure 22). As a result,

while concentrations of both NH_4 and K levels may be high near the soil surface, they are less available, deeper within the wetted bulb.

Figure 22

Relative Mobility of Ammonium and Potassium in Different Soils



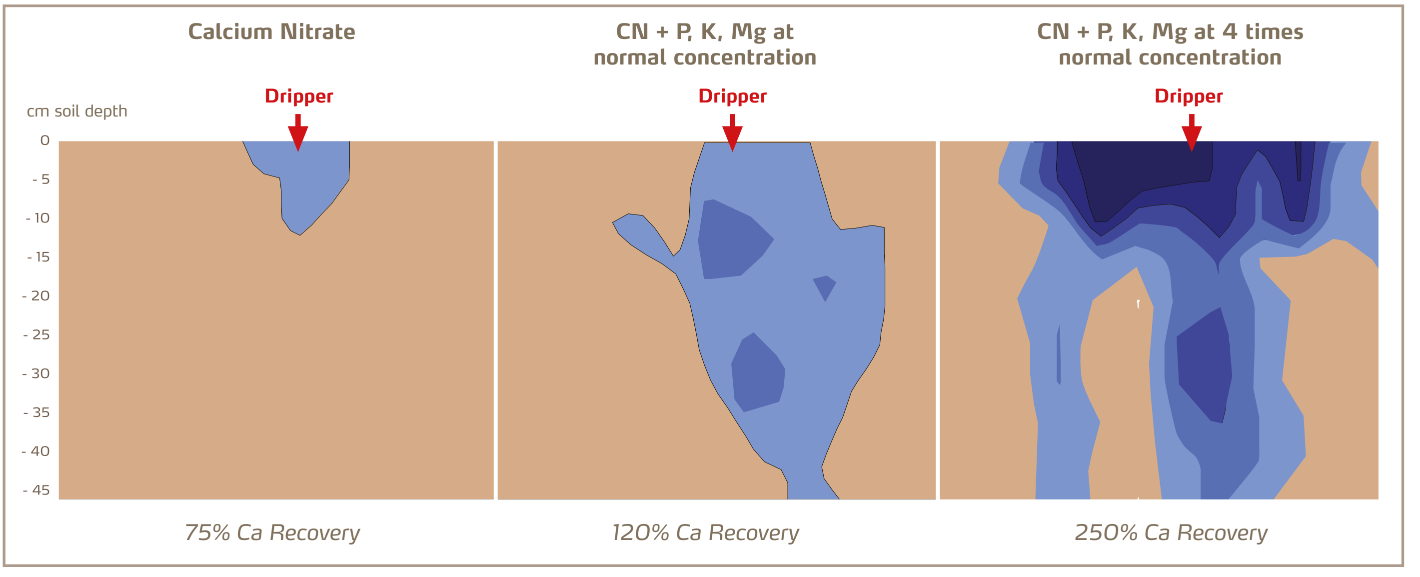
Various elements will also react with other elements in the soil; e.g. fertigation programmes with high levels of K and Mg can release calcium from soils leading to leaching (Figure 23).

When Ca is mobilized and then leached early in the growth cycle there can be shortages later, especially under permanent crops, unless Ca is applied/ replaced in the fertigation programme (Figure 25).

The distribution of elements is not uniform in the wetted bulb. An experiment with two soil types shows the variation in distribution, measured as EC, of all elements in the nutrient solution (Figure 26).

Figure 23

Calcium Loss Under Different Fertigation Programmes



High rates of Mg and/or K and high levels of salinity (Figure 24) can displace Ca from the soil leaving it more susceptible to leaching and therefore less available to the plant.

Figure 24

Saline Water and Calcium Displacement

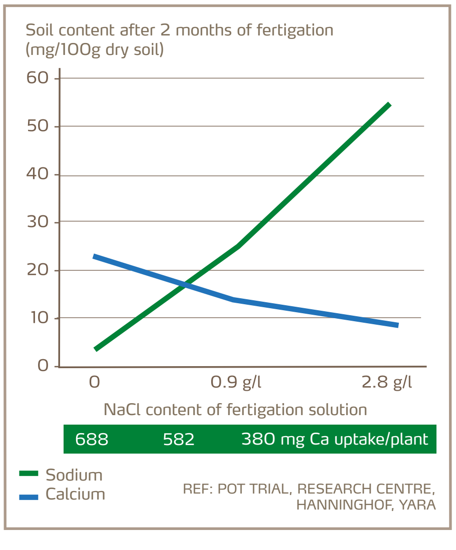


Figure 25

Calcium Depletion as a Result of Leaching and the use of Fertigation Solutions with no Ca

Citrus - Argentina

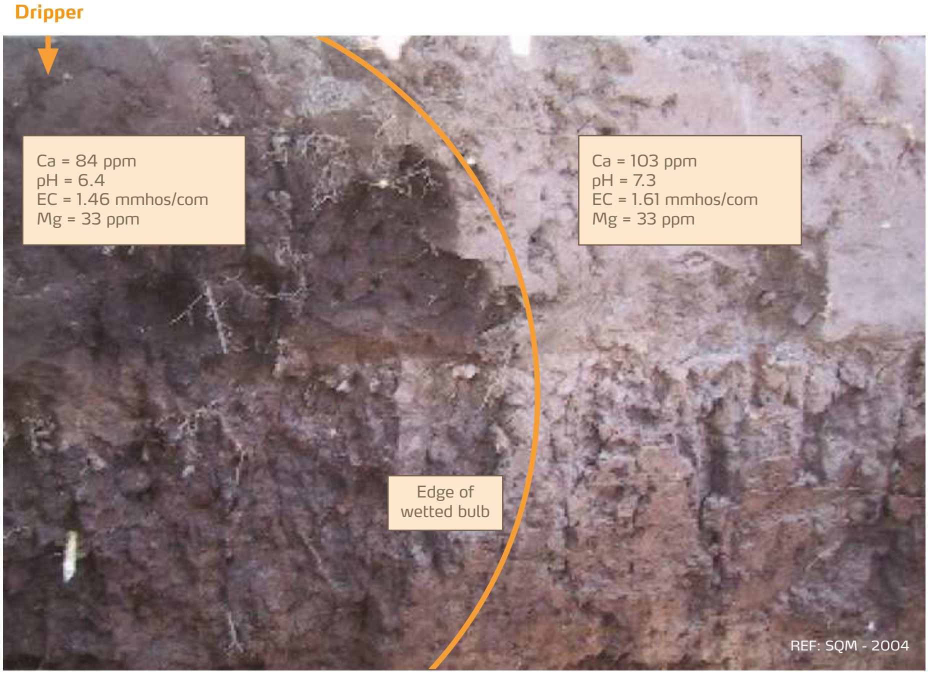
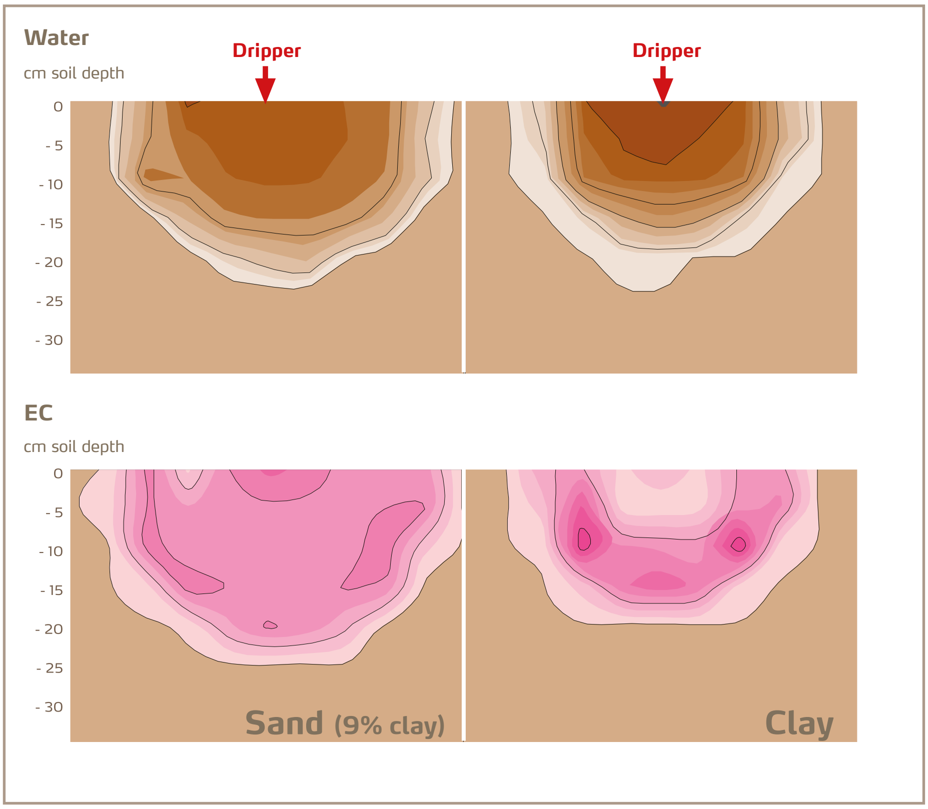


Figure 26

Total Nutrient Distribution - Soil Texture



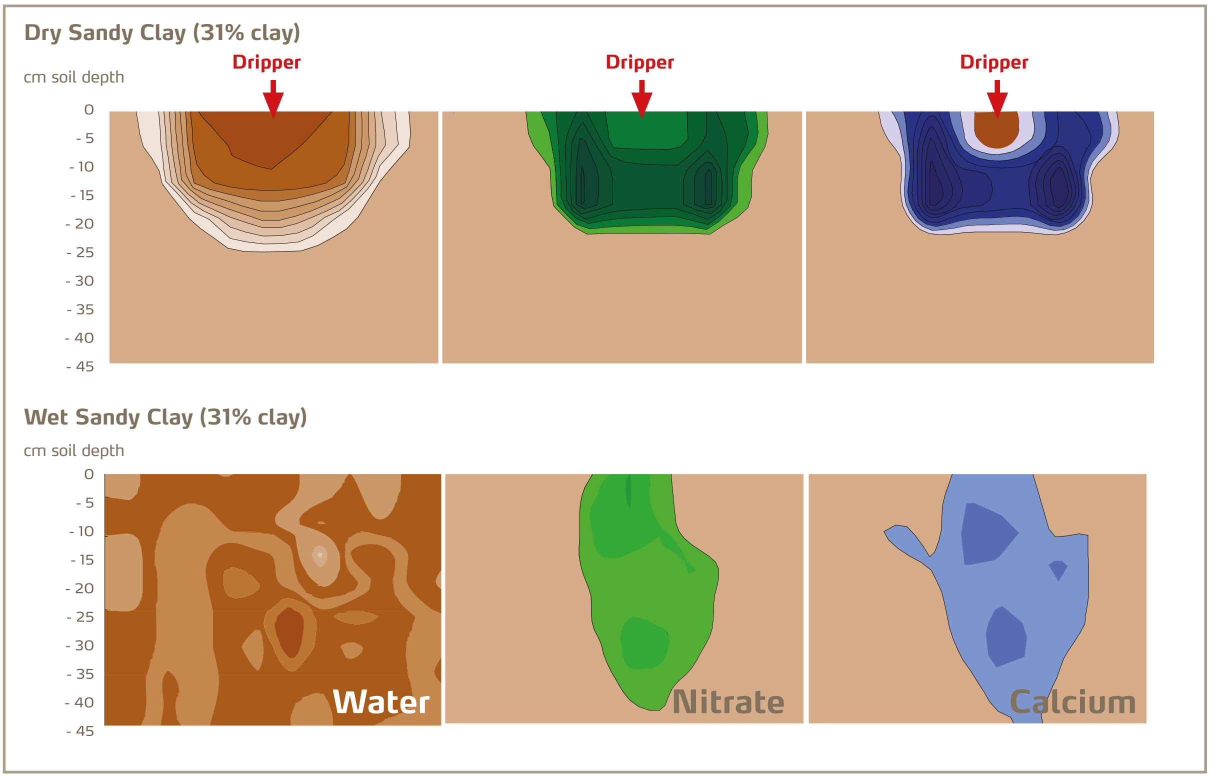
The moisture content of the soil at the start of a fertigation cycle will also affect the nutrient distribution pattern (Figure 27). Nutrients will reach a greater depth in wet soils.

Also, the relative mobility of the nutrients will affect their distribution patterns (Figure 21, page 19).

Soil texture affects nutrient and moisture distribution

Figure 27

Nutrient Distribution - Dry and Wet Soils



N Nitrogen

The form of nitrogen supplied to the crop has a marked affect on its distribution in the wetted bulb.

Nitrate

While NO_3-N is very mobile in the soil moving with the flow of water, ammonium remains near the top layers of the soil profile (Figure 28).

The excellent mobility of nitrate-N ensures good N distribution throughout the whole wetted bulb.

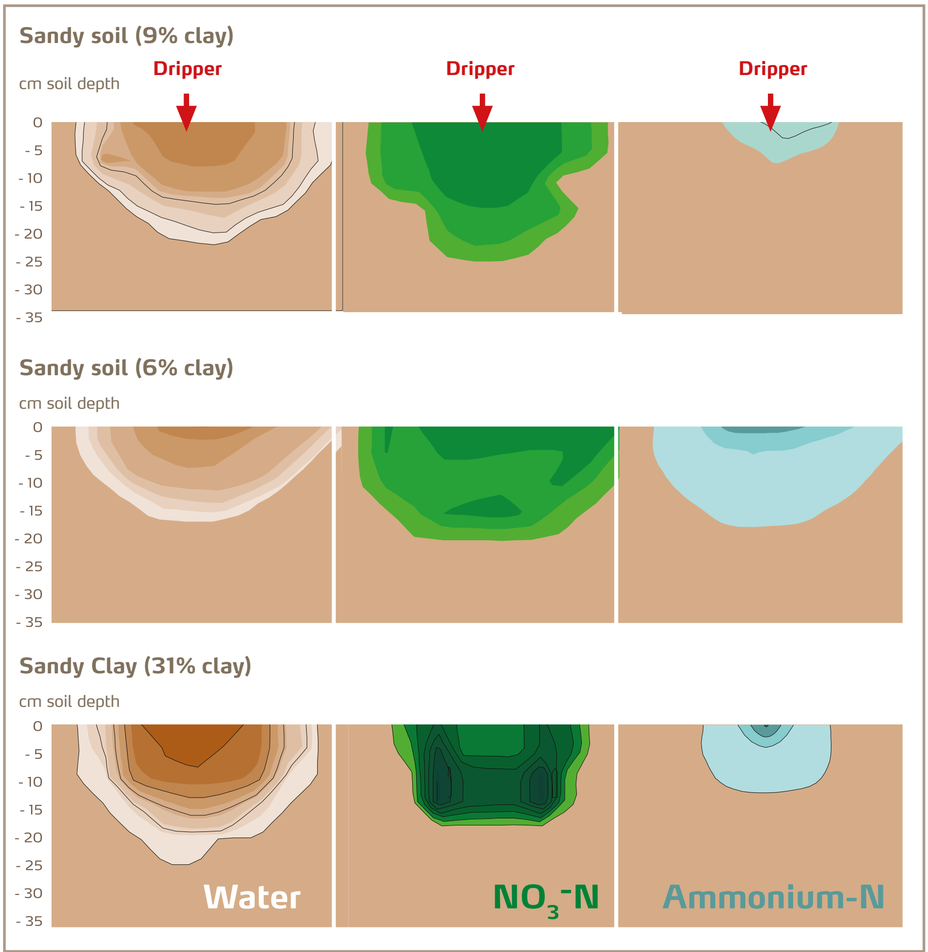
However, care is needed in managing water flow to avoid leaching of nitrate from the wetted bulb and away from the growing roots.

In practice, the application of low rates of nitrate-N, adjusted to meet plant demand, minimizes the risks of leaching and creates a greater root density, but smaller root system in the wetted bulb.

The use of nitrate-N also provides a small increase in the pH of the wetted bulb.

Figure 28

Relative Movement of Nitrate and Ammonium



Ammonium

Conversely, care needs to be taken with ammonium-N applications. They can accumulate in the top layers of the soil, eventually becoming toxic to the plant.

Furthermore, in clay soils the ammonium can be 'fixed' in the soil (Figures 22 & 28) and become unavailable for plant growth.

Also, because the ammonium-N is in the topsoil, it is more prone to volatilization, especially in high pH soils under warm conditions (Figure 29).

Volatilization losses are around 10% where the soil pH is around 8.2 and rise to 50% in high pHs such as 9.2.

While ammonium-N will be converted to nitrate-N in the soil, this process acidifies the soil. Because of the high nutrient concentrations found in the wetted bulb, this effect of pH change can be quite significant locally.

This effect is greatest in soils with a low buffer capacity, but is less important in high pH soil with higher levels of carbonates or bicarbonates; here the reduction in pH, if any, is only transitory.

When using water with a low salt content, fixation of ammonium-N can also have a negative impact on soil structure.

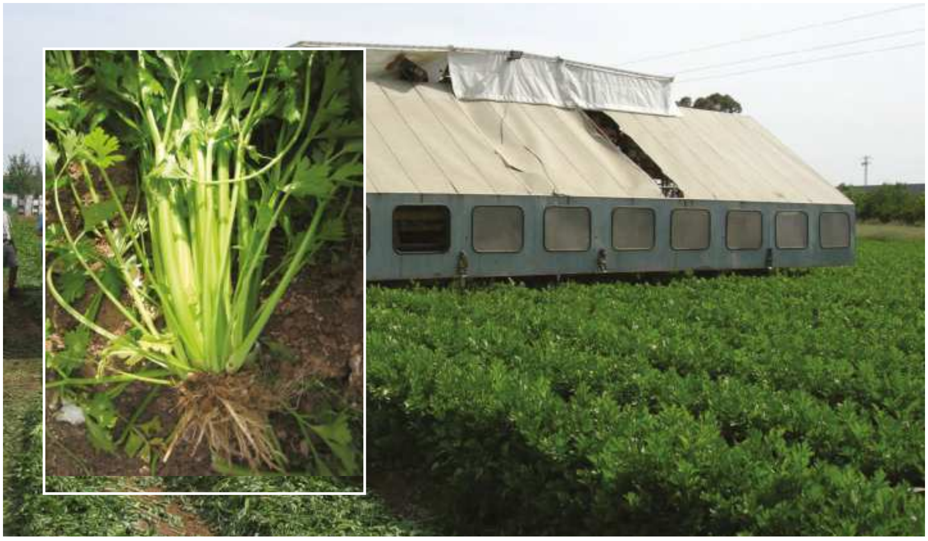
A common practice to counter these effects and utilize readily available portion of the NH_4-N applied, is to use a programme with just 20-30% of the total N as ammonium.

However, in hydroponic systems, ammonium-N use is more restricted. The maximum amount should not exceed 10% of total N, and in practice, growers keep it below 5%.

Figure 29

Ammonia Volatilization in Fertigation

The grey color of the test strip (left) indicates high ammonia volatilization from a soil fertigated with an ammonium-based fertilizer regime. Right, low volatilization from a largely nitrate-based programme.



Celery grown under fertigation has a smaller, denser root system compared to non fertigated crops

Lettuce grown under fertigation has a smaller, but denser root sytstem compared to non fertigated crops

Nitrogen form affects root development of tomatoes. NH_4 (top), NO_3 (bottom). Ammonium produces a deeper, less dense root system than nitrate.

Urea

Urea is very mobile in the soil. As an organic compound with no charge, it is not readily retained on clays or organic matter, moves freely in water and can be leached.

Urea needs to be converted to nitrate to be available to the plant. This is a two stage process, firstly it is converted to ammonium and then through nitrification, to nitrate. This results in an initial alkaline reaction (>pH9), increasing volatilization losses and eventual acidification of the soil.

As a result, it is difficult to accurately confirm the rate of conversion of urea to nitrate nitrogen and hence assess N-supply to the plant. Thus, urea-based fertilizers are not recommended for fertigation plans.

P Phosphorus

Phosphorus is relatively immobile in the soil, and remains concentrated in the zone immediately below the dripper (Figure 21), whatever the soil type (Figure 30).

Because it mainly moves through diffusion, best practice is to use low rates of P, at regular intervals, or even continuously, throughout the fertigation programme.

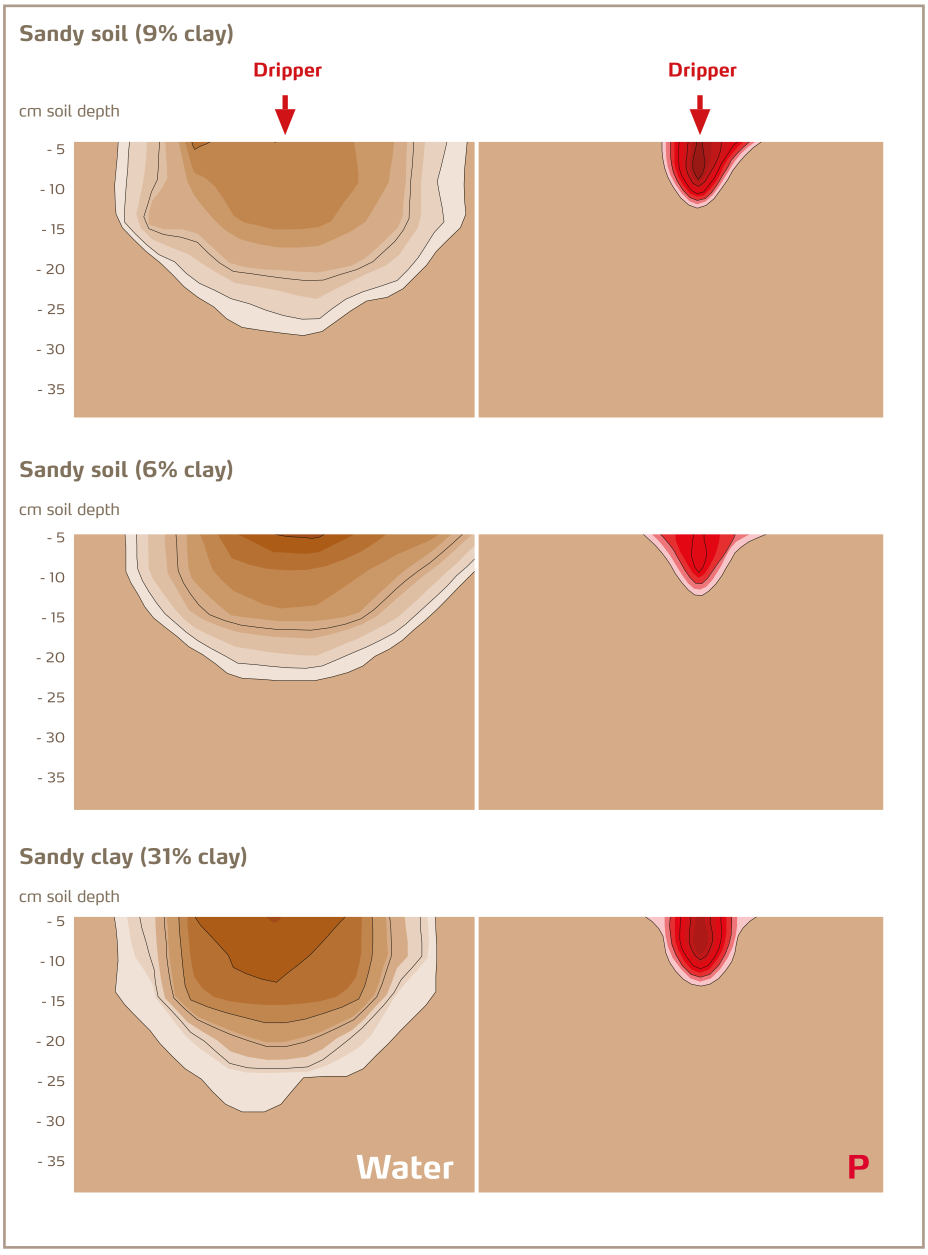
This will ensure phosphorus penetrates deeper into the root zone, improving P nutrition and crop performance.

Phosphorous is quite reactive with other elements in the soil, forming insoluble compounds – notably with calcium, magnesium, aluminum and iron.

Thus, it is important to balance P use with other nutrients, taking into account pH, soil type and P status in the wetted bulb.

Figure 30

Relative Movement of P in Different Soils



Most plants respond well to a constant supply of phosphorus when using fertigation

K Potassium

Potassium moves freely with water when applied in fertigation (Figure 31). It can though be strongly fixed by different clays, resulting in reduced movement by mass flow (Figure 22).

Micaceous clays strongly hold K, however in Kaolinitic clay soils, more K is available.

Over time, micaceous clays will weather, increasing the availability of potassium in soils (Figure 32).

This process can take place very quickly – sometimes within one season – under a fertigation system where there is a constant wetted bulb. Hence it is important to monitor this process to ensure good potassium nutrition.

K source is important. Chlorine (KCl for example), should not be used under saline conditions; nitrates or sulfates are usually more suitable K-sources in fertigation systems.

Figure 31

Relative Movement of K in Different Soils

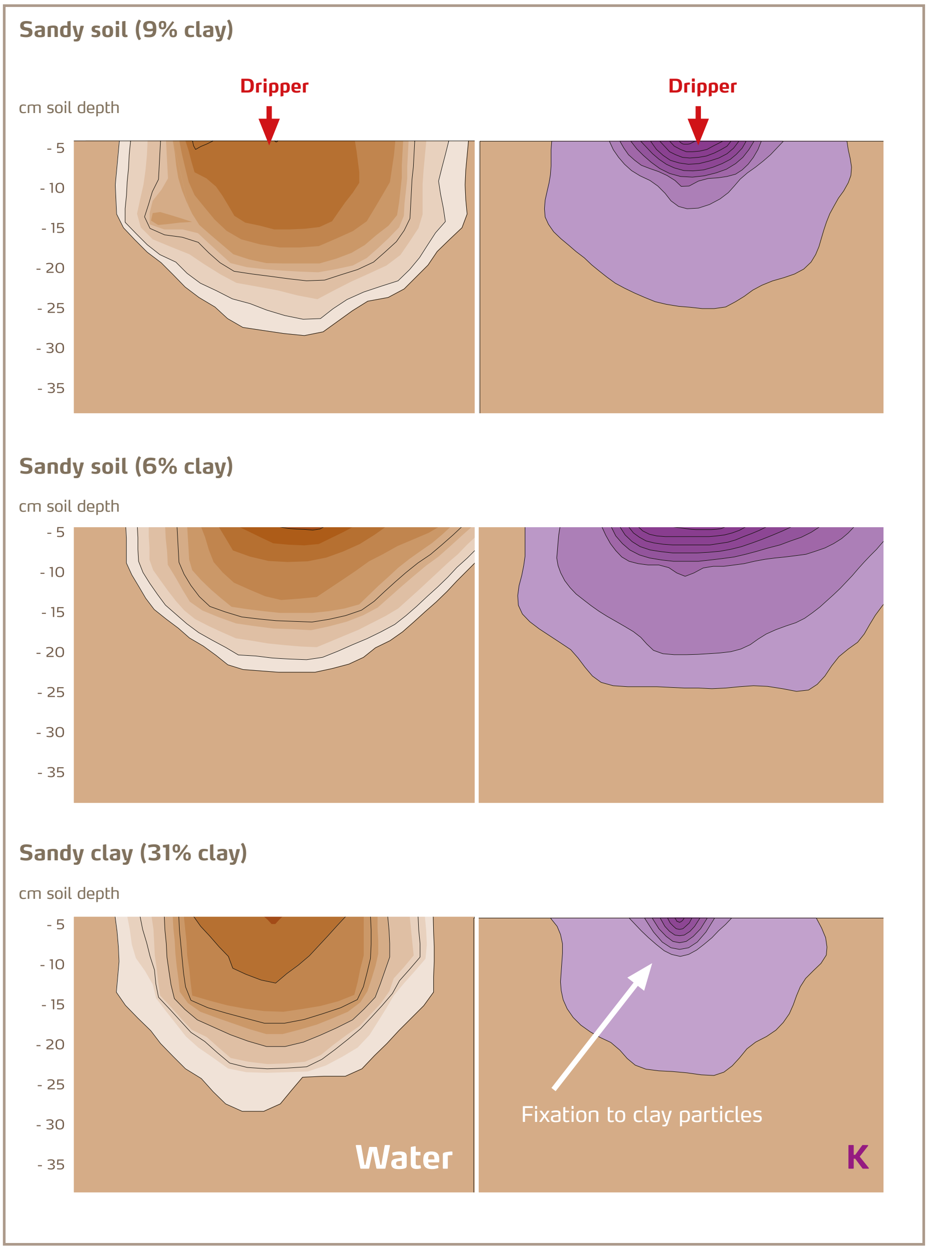
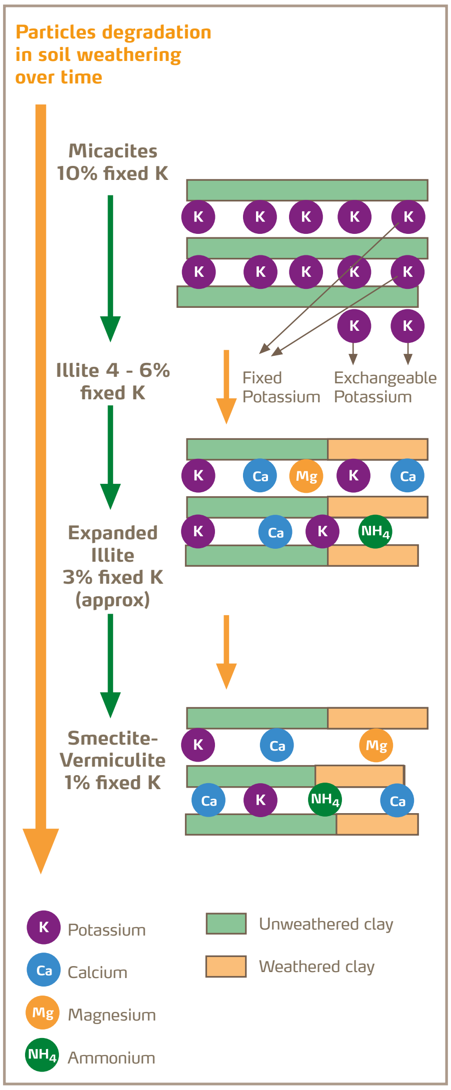


Figure 32

Breakdown of Micaceous Clays



Ca Calcium Mg Magnesium S Sulfur

Figure 33

Relative Movement of Calcium and Magnesium in Different Soils

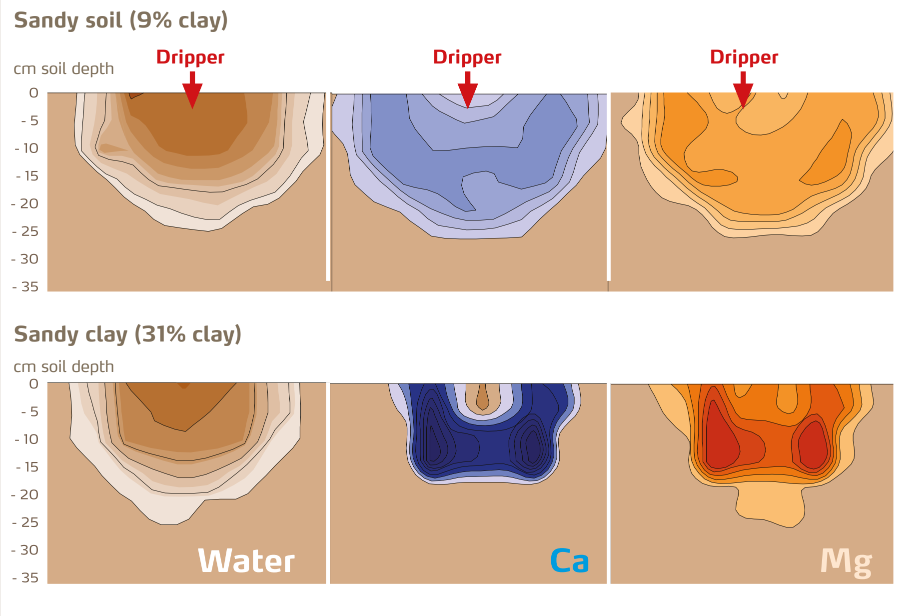
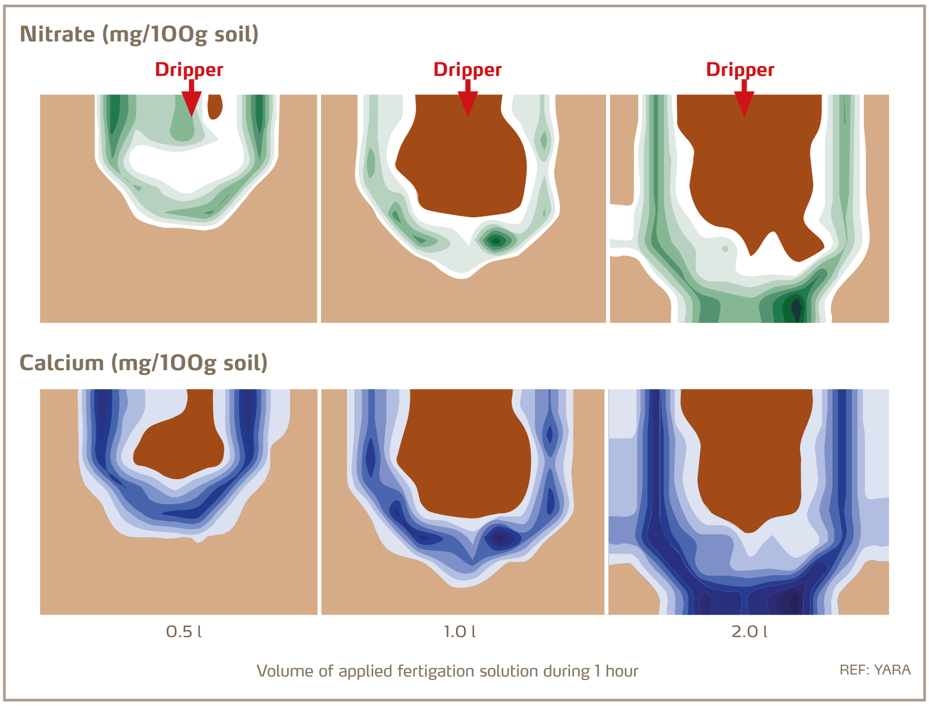


Figure 34

Relative Movement of Calcium and Nitrate in Different Soils



Calcium, Magnesium and **Sulfur** (Figure 21, page 19) are all mobile elements with their concentrations tending to increase at the boundaries of the wetted bulb (Figure 33). Care is needed to prevent these elements from leaching.

There is a very close relationship between calcium and nitrate movement in the soil. Both nutrients have similar distribution patterns in all soils, with the calcium moving with the nitrate (Figure 34).

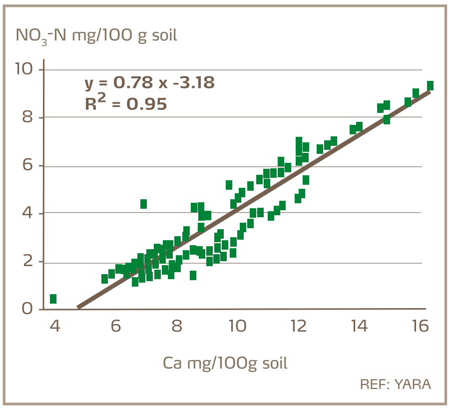
This relationship can be linear in some soils and with a correlation coefficient of 0.95 for calcium nitrate solutions (Figure 35).

It is important to balance Ca, Mg and K applications. If calcium nitrate is used in isolation, then some of the calcium may be absorbed or lost from the soil (Figure 23, page 20). However, when Ca is balanced with K and Mg, then calcium recovery and use is increased.

When a balanced fertigation solution with these nutrients is applied, the availability of the nutrients is not affected by soil type, soil moisture or drip discharge.

Figure 35

Calcium and Nitrate Relationship in the Soil Solution



Micronutrients

B Boron

Cu Copper

Fe Iron

Mo Molybdenum

Mn Manganese

Zn Zinc

Micronutrient availability is directly affected by pH. For this reason, is it important to choose formulations that will be effective in drip systems.

Invariably, because of the many diverse reactions that occur in the wetted bulb, chelates of **copper, iron, manganese** and **zinc** will give the best performance under fertigation.

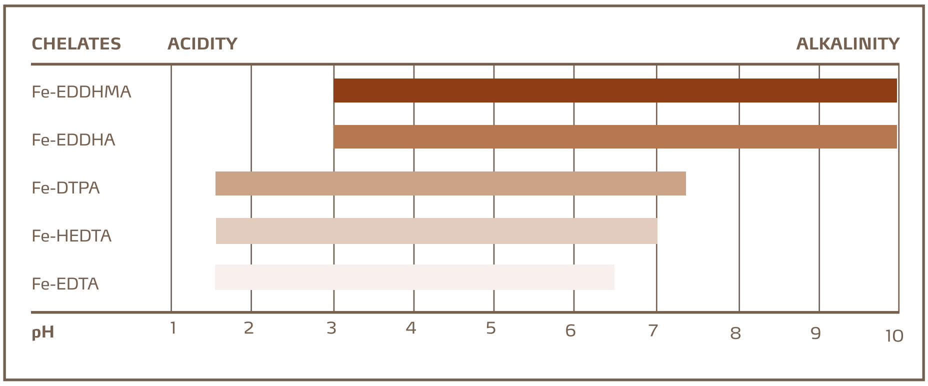
For iron, it is important to choose the correct chelate for the appropriate conditions, for example EDDHMA is less mobile than EDDHA.

Fe-EDDHA and derivates can become bound to organic material and hydroxides in the soil, reducing their mobility.

EDTA chelates are commonly used when fertigating cationic micronutrients on acid soils. Where pH's are alkaline, other iron chelates are more stable and efficient e.g. Fe-EDDHA (Figure 36).

Figure 36

Fe Chelate pH Stability



The stability of chelates in various soil pH conditions is normally stated on the product label. If unsure, contact your local Yara agronomist.

The anionic micronutrients, **boron** and **molybdenum** are normally applied as borate or molybdate salts. Absorption of molybdenum is reduced at lower pHs.

It is important to remember that under fertigation, soil nutrient dynamics occur much more quickly than under rainfed soil conditions. It is essential to monitor the changes in nutrient concentration within the wetted bulb to ensure consistent plant growth.

Fertigation Systems

Based on an understanding of the soil and its properties (see previous section), it is possible to properly plan and install an effective fertigation system (Figure 61, page 73).

The initial selection of the type of fertigation system to be installed is critical. Systems need to be flexible, efficient to run and able to meet crop and producer requirements.

The key components of the system include filters, injection devices, pumps, emitters, and monitoring and controlling devices.

Filters

Filters are needed to remove solid particles from the system to minimize clogging.

The amount of filtration required depends on the size of the emitters, which usually have the smallest cross section diameter of all components in the fertigation system, plus the growing media and the water source.

For example, the filtration requirements for micro sprinklers are less than for drippers as they have a larger diameter discharge area. The effectiveness of a filter can be measured by its pore size (in microns), or the number of holes it comprises per square inch (mesh number).

Note that mesh number is not related to pore size; two filters can have the same mesh number but different pore sizes.

All filters are compared to the mesh size as stipulated for screen filters. So, a disc filter with a 150 mesh will give a similar filtration to a screen filter with a 150 mesh, and will take out particles which are greater than 106 microns in size (Table 17).

Table 17
Mesh Number and Pore Size

Mesh Number	Pore Size (μm)
4	4750
10	1700
20	850
60	250
80	180
100	150
150	106
200	75
250	63

Hydrocyclone filters are well suited for fertigation systems where the water source is high in solids, as they use centrifugal energy to separate the solids (sand) from the water flow.

As water passes into the cone it is forcibly spun, throwing the heavier sand particles to the side of the cone and then into a collection sump at the bottom of the system.

Hydrocyclone filter

Hydrocyclones are normally used when pumping well, or ground water, and are installed immediately after the pump.

Media filters usually use graded sand to intercept particles as the water passes through them. The degree of filtration depends on the size of the sand particles, the flow rate and the depth of the sand layer. They are suitable for filtering organic particles and suspended solids (silt particles).

Media filter

Screen filters are supported by a rigid structure, and are normally stainless steel or plastic. They take out solid material from the irrigation water as it passes through the screen. Screen filters are commonly used as control filters within the head unit.

Screen filter

Screen filter used as control filter

Disc filters are a series of tightly packed, plastic rings with different filter sizes. This system is more effective in filtering smaller sized particles than screen filters, which only filter one surface at a time.

Disc filter

Use Table 18 to select which of the above filter types is most appropriate.

All filters need to be cleaned either by hand or automatically. Contaminant types can be ranked according to their ease of removal and vary according to water source.

Discs in a disc filter

Table 18
Filter Selection

Nature of Problem	Degree of Contam-ination	Quantit-ative Criterion	Type of Filter				Type of Control Filter
			Hydrocyclone	Media	Disc	Auto screen	
Soil particles	Low	<50mg/l	A	B	-	C	Screen
	High	>50mg/l	A	B	-	C	Screen
Suspended solids	Low	<50mg/l	-	A	B	C	Disc
	High	>50mg/l	-	A	B	-	Disc
Algae	Low	-	-	B	A	C	Disc
	High	-	-	A	B	C	Disc
Oxidised iron and magnesium	Low	<0.5mg/l	-	B	A	A	Disc
	High	>0.5mg/l	-	A	B	B	Disc

A = optimum choice - C = least favoured selection

REF: PLASTRO GVAT

Injection Devices

In order to accurately meet a crop's requirements it is important to inject accurate volumes of nutrient solutions into the main water flow.

Selection of injector type depends on a number of factors including the type of fertilizers to be used, available power supply, desired accuracy and cost.

Fertilizers should be injected upstream of the main filters, except in the case of acid injection. Alternatively, a control filter should be installed downstream from the injection point, as well as a non-return valve, to prevent clogging and unwanted injection when the system is closed down.

It is also important to use clean water to flush the injection point and the head unit in order to prevent the accumulation of precipitated solids.

Injectors need to be constructed of a material that is resistant to the product to be injected. They also need to be durable, thereby ensuring a long-life.

All injection systems require accurate calibration using meters installed in the correct position in the system that are also resistant to the materials being injected.

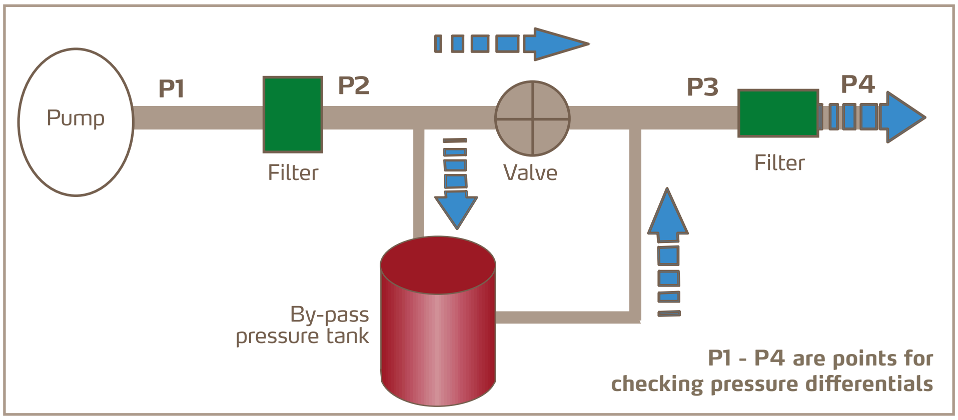
Where water flow meters are used, the system needs to be recalibrated. This is because the scales on these meters are based on the flow of pure water at a given temperature and rates will differ for a fertigation solution.

Recalibration is needed for each nutrient solution that is used; density and sometimes viscosity, as well as temperature, will alter flow rates.

The main types of injection system are:

By-Pass Pressure Tanks where fertilizer is pulled out of the storage tank under the pressure created by mains water flow (Figure 37).

Figure 37
By-Pass Pressure Tank Injection System



Flow meter

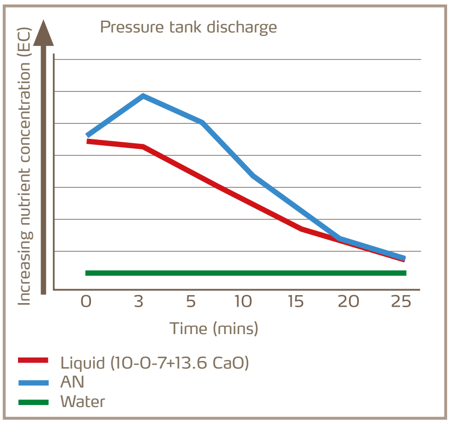
Pressure tanks are the only injection systems that do not need the fertilizer to be diluted before injection.

Construction and maintenance costs are low and the system is easy to operate, as it does not need an external power supply.

The main disadvantage is that there is a fall in pressure across the system and therefore the rate of fertilizer discharge is not uniform over time. More fertilizer is discharged at the start of the injection period (Figure 38) and as a result, salts can build up if irrigation suddenly stops, or towards the end of the fertigation period. Conversely, early fertilizer applications during an irrigation event, can increase leaching of nutrients, particularly mobile nutrients.

In addition, the nutrient tank needs to be filled every time and is difficult to automate.

Figure 38
Discharge Patterns - Pressure Tank Injection Systems



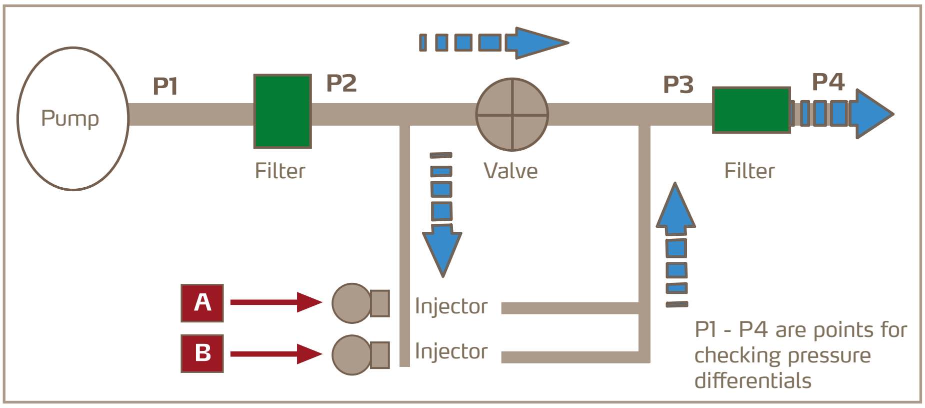
By-pass pressure tank

Venturi injection is where the fertilizer solution is injected into the main flow, as a result of a build up of negative pressure. The system utilizes a pipe with a constricted neck. As the water flows through this pipe, it creates a reduction in pressure that simply sucks the nutrient solution out of the adjoining tank (Figure 39).

Venturi systems are relatively cheap to construct, easy to use, and require little maintenance. In addition, as soon as hydraulic conditions settle down, discharge is relatively constant.

Venturi injection

Figure 39
Venturi Injector System



Venturi injection with booster pump

In order to avoid excessive injection from the feed tank when starting up the system, it is important to run the water pump for a while, so that the system is in a steady state with constant pressure, before the fertilizer tank valve is opened. Alternatively, booster pumps can be installed to feed the venturis with a permanent flow and create a constant pressure gap. However, these will need an external power supply.

Venturi injectors are now the most widely used injection units in fertigation systems. They can be installed in parallel for injection at different points or in continuous connection.

Different densities of nutrient solutions or mother liquids, viscosity, levels in the tank, and pipe length will all affect the injection of fertilizer solutions even when hydraulic conditions are constant. Therefore, calibration of each system is important for accurate fertigation.

Pumps

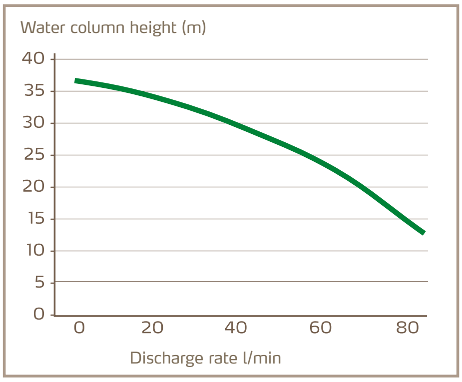
Pumps are electrical, battery, solar, wind, fuel, or hydraulic power operated.

They use a range of injection (hydraulic head) devices; which are either centrifugal, piston or mobile engine, or diaphragm operated.

Most commonly, fuel pumps operate centrifugal heads, while hydraulic pumps utilize a piston or mobile engine. Electrical pumps are used across a wider range of injection heads.

Pump discharge varies according to the outlet pressure needed. Each individual pump has its own pumping curve and it is important to use the specific pumping curve for the appropriate pump. Curves differ according to pump type even those supplied by the same manufacturer (Fig 40).

Figure 40
Example of Pump Discharge Curve



Electrical pumps are the most easily automated and convenient, so are commonly used worldwide where electrical power is available. Maintenance is low, except where power supplies are unstable.

Piston and diaphragm pumps can be calibrated either to provide a specific discharge flow or to deliver a percentage of maximum flow. They can provide a wide range of flow rates, from a few liters per hour to hundreds of liters/hr.

Piston pump

Centrifugal pumps for fertilizer injection have a lower discharge range. These devices are normally fully automated and are operated continuously. Larger centrifugal pumps can be used for direct injection to the pipeline, but injection from larger pumps is usually less accurate.

All pumps provide a constant rate of injection, provided there is no loss in either pressure or water from the system.

To avoid injection when there is no flow in the main line, the injection pump must be linked to, and operated in tandem with, the mainline pump.

Diaphragm pump

There is a smaller range of flow rates available from the various types of diaphragm pumps available on the market, but this type of pump is well suited to provide low, accurate rates of injection.

One engine can drive more than one hydraulic head enabling the user to simultaneously inject more than one fertilizer at any one time.

Piston pump with several heads

Centrifugal pump

Centrifugal pump - small ones

Fuel pumps have similar properties to electrical pumps, but automation is more difficult and costly. They are normally centrifugal in operation and use higher water volumes.

Fuel pumps use suction and include a portable tank for the dilution/product to be injected into the line. These systems require more manpower.

Hydraulic pumps are very convenient in areas where no electrical power is available (or power stability is poor). They are easy to operate and move, and can be adjusted for different flow rates.

Hydraulic pump - Dosatron

Hydraulic pumps are operated using the system's water pressure and invariably suffer from some water loss, which then needs to be disposed of properly.

Hydraulic pumps can be installed in any part of the fertigation system e.g. upstream in a plot hose, either for injection of the nutrient solution or as an additional source of supply for an area of land. Where additional nutrients are supplied upstream, any water lost from the system will also contain fertilizers.

Maintenance and construction of hydraulic pumps is complex. They commonly use either a piston or diaphragm mechanism for injection. Fertilizer injection is proportional and constant to the level of flow, and the pump stops when water flow ceases.

Automated systems

Where two or more injector pumps are used, they can be linked to operate simultaneously. This allows the injection of multiple solutions at any one time.

Automated systems with a number of injectors

Hydraulic pump - Amiad

Automated system with a number of injectors

When solutions are simultaneously injected, the amounts of fertilizer injected from each tank by each pump needs to be varied so as to achieve the desired nutrient solution concentration.

Injection rates are adjusted by volumetric flow meters (cc/l or l/m3) or by the percentage of injection of each tank related to the total injection needed. When using percentage calculations, the desired EC or increase above the water EC is used to quantify the required injection rates.

All injectors have to be calibrated for the same injection rate. Accurate adjustment is essential to avoid compromising fertilizer accuracy.

Properly operated automatic systems will maintain a constant concentration through discontinuous injections. They are most commonly used where the grower needs to frequently alter the nutrient solution for any reason, especially where a range of different species or cultivars are grown across a number of plots or where accuracy is critical (e.g. hydroponics).

Normally, these systems also have specific tanks and pumps to inject acid or base solutions, thereby adjusting solution pH.

Emitters

There are many types of emitter and choice depends on soil type, crop and the required size of the wetted area.

Emitters reduce the system's pressure to almost zero at the outlet, and in order to achieve this the solution needs to be forced to pass through a long network of very thin channels.

These narrow pipes and emitters – usually 0.2-1mm diameter in drippers, and 0.8-1.6mm for micro sprinklers, are the part of the system most at risk of clogging. Thus, it is essential that all upstream filters have a minimum diameter as small as, or smaller than, the minimum diameter of the emitter.

Modern emitters are narrower at the inlet side and wider at the outlet side and are now designed such that water flow is turbulent and of high velocity, rather than low velocity, with a smooth or laminar flow. This reduces clogging risks. To ensure even water distribution across the plot it is important to use accurately manufactured emitters that provide a constant flow with little variation between individual emitters.

Drippers

Many different types of drippers are available. They are grouped according to how they fit into the lines.

Inserted dripper

Microtube dripper

Plug in dripper

Originally, drippers were supplied already inserted into the lines at fixed intervals. However, these types are now rarely used because they tend to 'pop out' as a result of expansion and contraction of the lines.

Now, drippers are supplied separately and can be securely fixed or 'plugged' into the side of the line at the desired spacing. Alternatively, there are tapes with built-in drippers covering a range of discharges and distances between drip points.

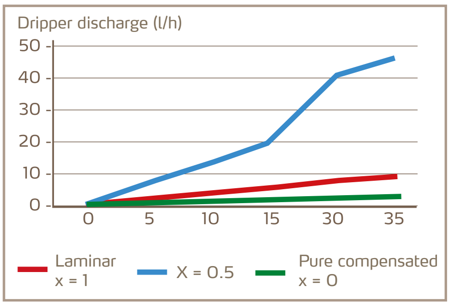
Discharge rates can vary from 0.5 to 16l/hr, although most dripper delivery rates are 2-4l/hr.

Rate of discharge is influenced by pressure and modern drippers can contain an internal diaphragm that ensures they are self-compensating, providing consistent discharge pressures across the fertigation system. It is important that this diaphragm or the dripper is changed when it loses this pressure compensating function.

Components of pressure compensating 'plug in' dripper

Dripper discharge varies according to the formula **$q=Kh^x$**, where **K** is a dripper specific coefficient (supplied by the manufacturer), **h** is the inlet pressure in water column height and **x** is the emitter exponent. These curves are available from the dripper manufacturer (Figure 41).

Figure 41
Typical Dripper Discharge Curve



Micro sprinklers

Micro sprinklers have a greater discharge capacity than drippers, normally >16l/hr. They also apply water to a larger area, making them highly suitable for sandy soils or where higher rates of water are needed.

Micro sprinkler systems also require larger diameter hoses – typically 25-50 mm, compared to 12-20 mm for drippers. Discharge coefficients for micro sprinklers are about 0.5, and the narrowest point in the system is wider than that used in drippers (0.8-1.6 mm), which means reduced problems from clogging.

Micro sprinkler in citrus

Micro sprinkler in papaya

Tapes with built in dripper types (all 4 photos above)

Controlling and Monitoring Devices

In order to maintain effective operation a number of controlling and monitoring devices are incorporated into the fertigation system.

To avoid system malfunction or damage, it is important that all components are constructed of compatible materials.

- **Non-return valves or pressure reducing devices** are used for managing the flow within the system.

Non-return valve

- ll), to maintain an even flow. They are also used to let air into the system, when the system is closing down, and the remaining fertigation water is being discharged, so as to avoid pipe collapse. This type of pressure equalization is essential, especially on farms with sloping land. The suction effect is greatest on larger diameter and longer distance pipes.

On sloping land air or vacuum release valves should be used.

Vaccuum release valve

- Monitoring devices like **flow meters** are used across the system to check main flow rates or discharge from tanks.

Flow meter

Flow meter

- **Pressure gauges** monitor pressure in different parts of the system – e.g. upstream or downstream in drip lines, and upstream of the plots. They are also used to check on filter status by measuring the difference between inlet and outlet pressure - pressure increases as the filter collapses. Some injectors such as venturis require regular measurement of pressure differentials to enable proper calibration.

- **Tanks** should be a convenient size for the amount of fertilizer to be dissolved. Stirrers or air pumps ease this process.

- **Pipes and hoses** need to be compatible with the type of fluid they are to carry – e.g. acids or concentrated solutions at the head unit. Main pipes will need to be able to cope with higher pressures and their pressure tolerance should be checked.

Pressure gauge

Storage tank for liquid fertilizers


Using computer programs to monitor fertigation systems


Tanks for dissolving fertilizers

Pressure controller


Pressure gauge in sprinklers


Air stirrer

Fertilizers for Fertigation

Fertilizers must be fully soluble to prevent clogging of the system. The generally accepted maximum level of insoluble particles is <0.5% on a weight basis, and they must be small in size.

Temperature is a major factor governing solubility. Thus, solubility data always should be related to a given temperature condition.

Fertilizer quality is a real issue to be taken into account. The same chemical composition from one manufacturer is likely to behave differently to that of another, due to variations in the manufacturing process, particle size and shape, the range of additives used, and the type of raw material.

This means that not all fertilizers with the same chemical formula will dissolve or perform in the same way when put through a fertigation system.

When dissolving fertilizers, the pH and EC of the water will change. The expected effects are normally reported for a 1% solution (Table 20 on page 42).

The pH of the solution is an important parameter as it affects the solubility of many salts, and can lead to precipitation and clogging (Tables 20 & 21 on pages 42 & 44).

The pH and EC at different concentrations for selected Yara fertilizers can be seen in Figures 42 to 47.

Figure 42
Fertilizer Concentration and pH

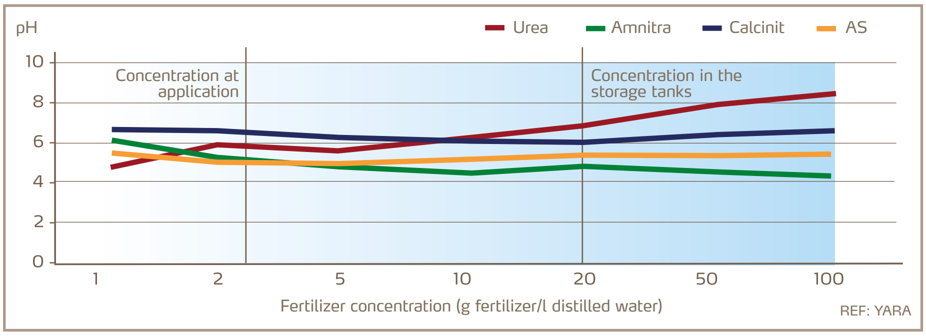


Figure 43
Fertilizer Concentration and pH

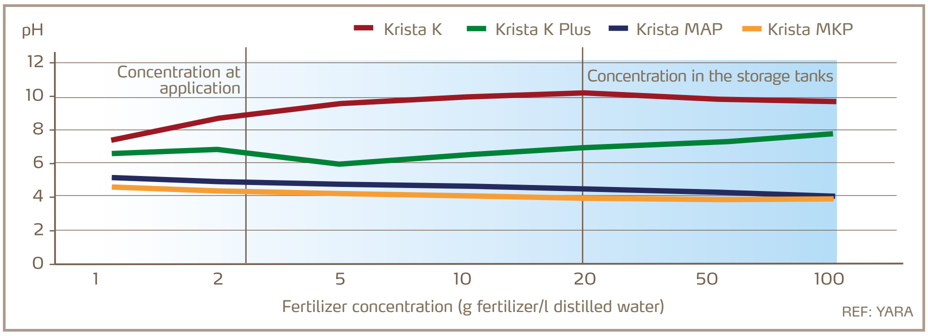


Figure 44
Fertilizer Concentration and pH

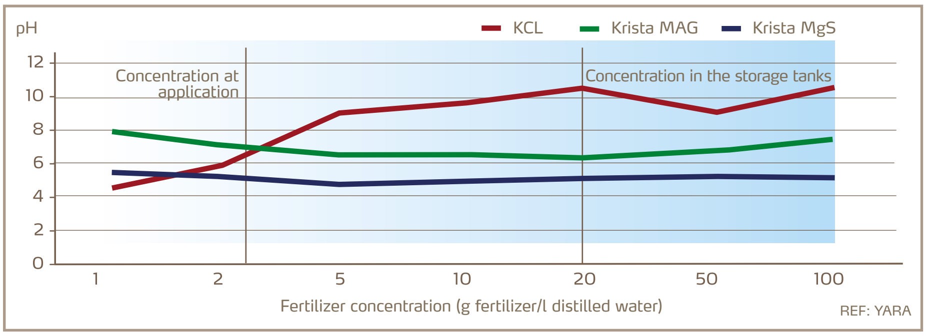


Figure 45
Fertilizer Concentration and EC

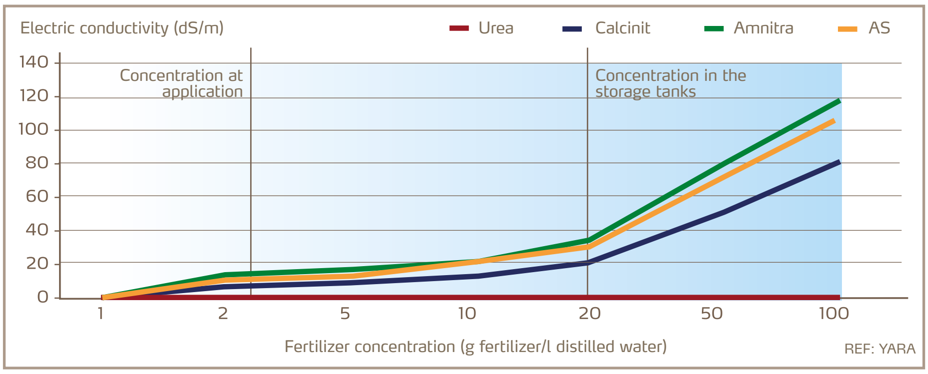


Figure 46
Fertilizer Concentration and EC

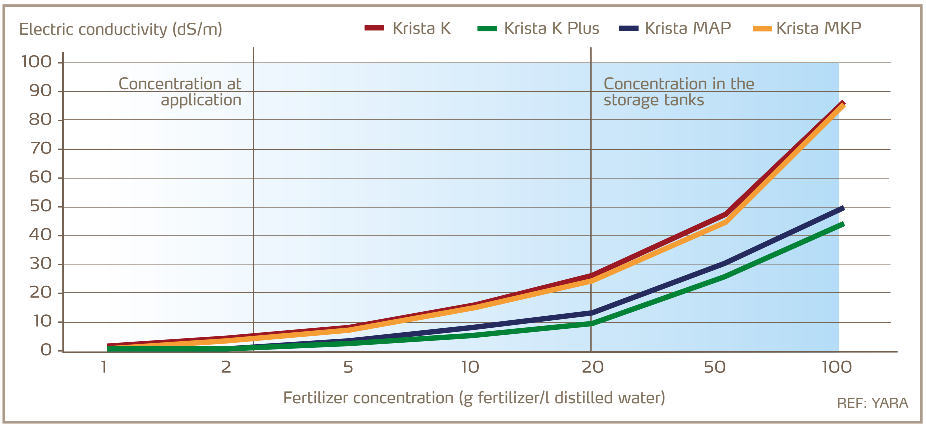
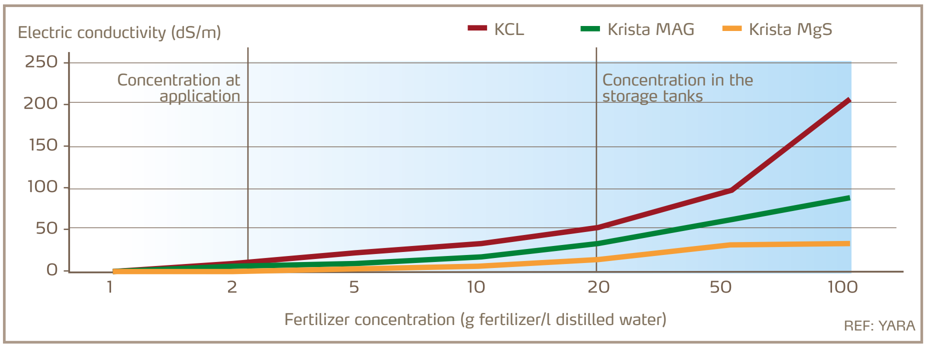


Figure 47
Fertilizer Concentration and EC

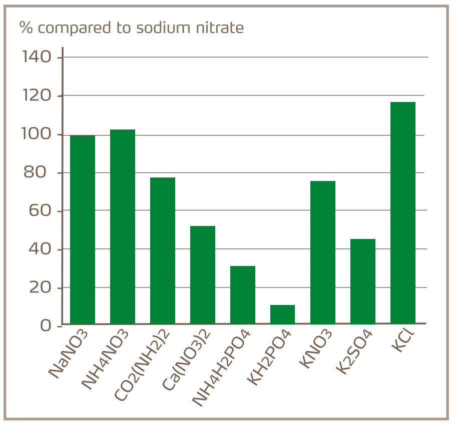


Some fertilizers reduce the temperature when dissolving as a result of an endothermic reaction. This increases the time required for dissolving. It also means that the amount of fertilizer being dissolved in a tank can be reduced in winter, or with colder water, than in summer. Most nitrogen fertilizers, e.g. AN, Urea, KNO_3 and CN have this effect.

In practice, this means that the amount of fertilizer required to make a 10% solution in the summer will possibly only create an 8% solution in the winter, unless the water is heated.

Another index used for fertilizers is the salt index. This relates to the osmotic pressure of a fertilizer when it is in the soil solution. Values are a percentage of the reference fertilizer - sodium nitrate (100%) (Figure 48).

Figure 48
Salt Index



The osmotic potential (bar units) or osmolarity of a fertilizer – the strength or concentration of the solution - is critical and much more important than the EC which relates to the level of dissolved salts in solution. Figures 49 to 51 detail the osmolarity of several Yara fertilizers.

The effect of products with a high osmotic potential – compared to those of a low osmotic potential - is to increase salinity stress, reducing uptake at the root surface.

For the most important fertilizers used in fertigation there is a clear relationship between osmolarity and EC. Urea is an exception to this rule as it is an organic compound which has no effect on EC as it has no ion dissociation when in solution, but has a clear effect on osmolarity.

Figure 49
Fertilizer Concentration and Osmolarity

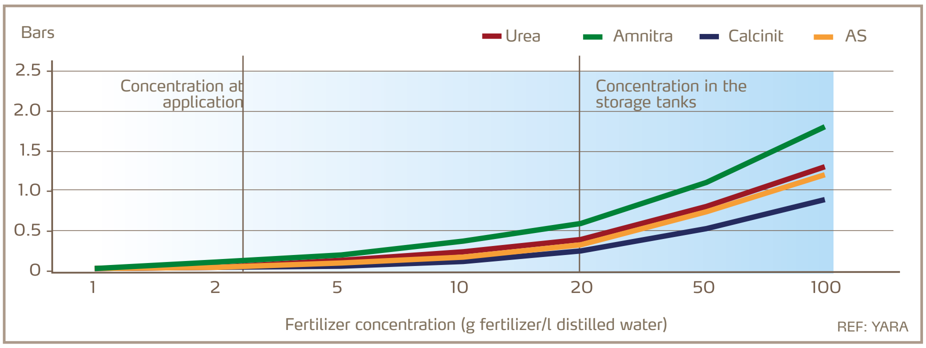


Figure 50
Fertilizer Concentration and Osmolarity

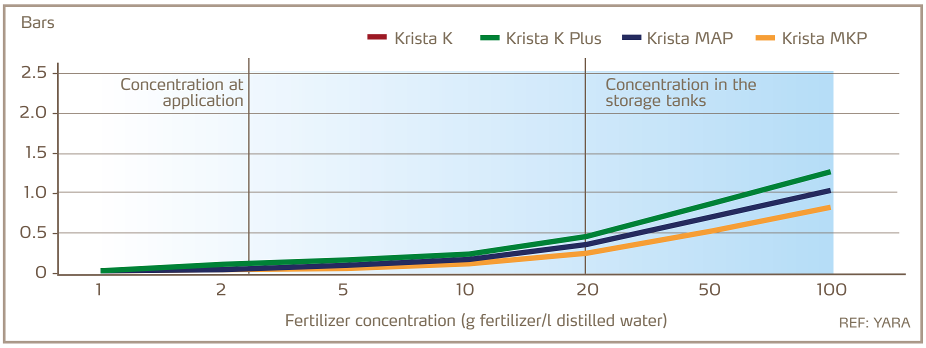
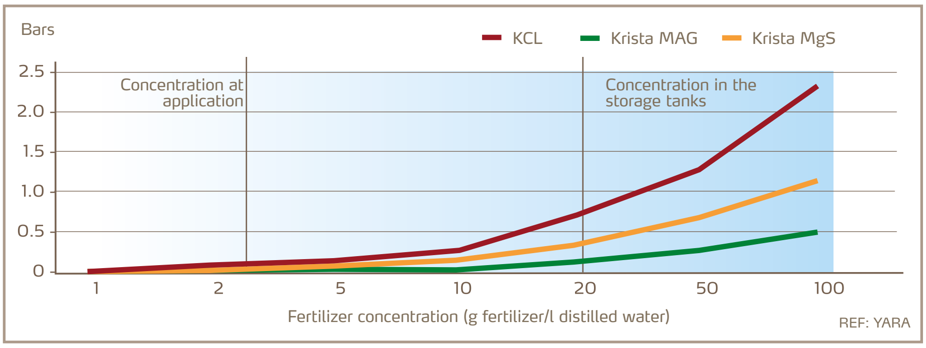


Figure 51
Fertilizer Concentration and Osmolarity



When selecting products for fertigation it is important to consider using those products with a relatively low osmolarity especially in saline situations, so as to ensure good uptake and balanced nutrition. The osmolarity and EC of selected products can be seen in Figures 45 to 47 and 49 to 51. This confirms, for example, that calcium nitrate is a better source of N for use in saline conditions or high nutrient concentration fertigation systems than ammonium nitrate.

Cationic micronutrients for fertigation are usually formulated as chelates. Iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) are normally microgranule formulations.

Boron (B) and molybdenum (Mo) are usually formulated as soluble salts – borate and molybdate.

Iron is the most commonly applied micronutrient by fertigation and it is available in a range of different chelate forms.

The selection of a chelating agent for Fe will depend mainly on the soil or substrate pH (Figure 36, page 27).

- For **soil applications** the most widely used iron chelates are EDDHA and EDDHMA, and they are generally applied as straights.
- For **hydroponics**, DTPA chelates are commonly used. In higher pH conditions EDDHA is an alternative.

In fertigation blends – cocktails of micronutrients - EDTA is the most commonly used chelate form.

Yara offers a complete range of micronutrient products for fertigation. Ask your local agronomist for details of the products available in your region.

Solid Fertilizers

Solid fertilizers used for fertigation are salt based – with the exception of urea – and are usually composed of more than one nutrient.

The water-soluble N-P-K Yara range comprises blends of these salts. There is a wide range of formulations available and micronutrients are often included to provide more complete blends.

Yara is continually adding to its range of products to improve performance in fertigation systems.

Liquid Fertilizers

The main liquid fertilizers available for use in fertigation are nitrogen solutions, e.g. AN or CAN.

However, other liquids are available including one or more elements in solution. These include N-P-K solutions, or clear liquids used as straights.

Acids are used to adjust the pH of the solution. Nitric acid, phosphoric acid (either green or white) and sulfuric acid are the most commonly available acids.

When a more basic solution is required, then hydroxides or carbonates (commonly K-salts) can be used to increase pH. This approach is not appropriate for all installations and requires careful implementation to avoid damage to the crop or fertigation system.

In all cases, care should be taken when handling acid or alkaline solutions, including the use of gloves, safety glasses and proper handling or mixing equipment.

Always add acid to water and never the other way around.

Other products

While Yara specializes in quality fertilizer formulations, other products are commonly used in fertigation, including seaweed extracts and organic compounds.

Safety equipment should always be used

The main specifications for Yara's soluble fertilizers are shown in Tables 19 and 20.
Note that the full range of water soluble N-P-K's is too large to include here.

Table 19

Selected Yara Fertilizers - Nutrient composition (%w/w)

	Amnitra	Calcinit	Krista K	Krista MKP	Krista MAP	Krista MgS	Krista SOP	Krista MAG	Krista UP
	NH_4NO_3	$5\ Ca(NO_3)_2\ .\ NH_4NO_3\ .\ 10\ H_2O$	KNO_3	KH_2PO_4	$NH_4H_2PO_4$	$MgSO_4\ .7\ H_2O$	K_2SO_4	$Mg(NO_3)_2$	$CO(NH_2)_2\ HPO_4$
% N(NO3)	17.1	14.1	13.0					11.0	
% N(NH3)	17.1	1.1			12.0				
% N (Urea)									18
% N total.	34.2	15.5	13.0		12.0				18
% P2O5 / P				52 / 22.7	61 / 26.6		52 / 43		44 / 19.2
% K2O / K			46 / 38	34 / 28.2					
% CaO / Ca		26.6 / 19							
% MgO / Mg						16 / 9.6		15 / 9	
SO3 / S						32.5 / 13	45 / 18		
% Cl									

Table 20

Selected Yara Fertilizers - Solubility, pH and EC

	°C	Amnitra	Calcinit	Krista K	Krista MKP	Krista MAP	Krista MgS	Krista SOP	Krista MAG	Krista UP
Solubility at °C (g/l)	0	1183	956			227		70		
	5			133	110	255		80	680	
	10		1000	170	180	295		90		790
	15		1055						700	
	20	1065	1100	315	230	374	750	124	710	960
	25		1170		250	410			720	
Effect in solution (1% w/w)	pH	5.6	6	8 - 9	4.5	5.6	6.6	5.6	6.5	1.8
	EC (dS/m 20°C)	0.9	1.2	1.3	0.7	0.7	0.7	1.54	0.88	1.5

For more information on local products contact your local Yara agronomist.

Mixing fertilizers

When mixing fertilizers of unknown compatibility, it is important to check for compatibility using a jar test; always using the same strength of solution that will be used in the fertigation system mixing tanks.

When mixing fertilizers:

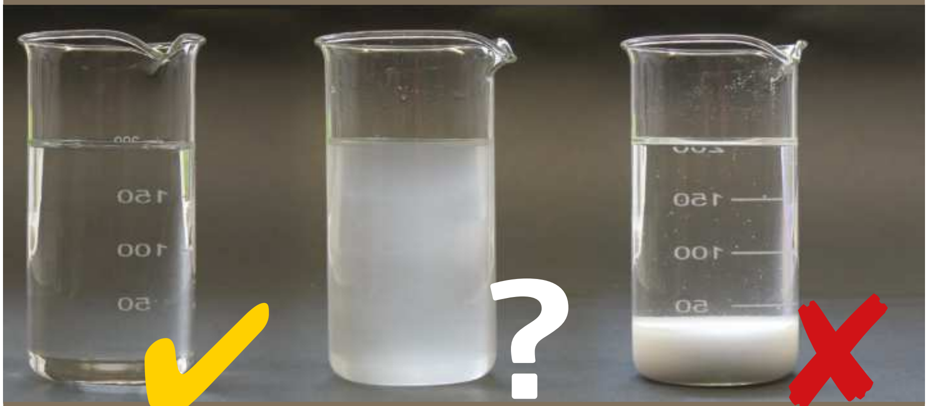
- Never mix sulfate or phosphate containing fertilizers with calcium.
- Only add phosphorus fertilizers with magnesium when the pH of the solution is below 7.5.
- Don't mix iron with phosphorus.
- Add acids first and never mix acid and alkaline products directly, as this will result in a strong, hot chemical reaction.
- Don't mix chelates and organic matter based products in the same tank as acids.
- When a colored product is part of the mix, the color of the solution is likely to change or remain the same (see photo at bottom of page).
- Remember that water with high levels of Ca, Mg, SO4, Fe, or Mn can affect some mixtures.
- Take into consideration other compounds that are to be added, e.g. pesticides.
- When mixing products the solubility can be lower than expected for a single product due to some reactions. For example, if magnesium sulfate is mixed with potassium nitrate the reaction may form potassium sulfate, which has a lower solubility and can precipitate out.
- Wear proper safety equipment.

1. Fill the jar with water - one liter should be sufficient

2. Slowly add the appropriate quantity of the first fertilizer or compound.

3. Ensure it is dissolved by constantly stirring. Add the next fertilizer, or fertilizers, one by one, continuing to stir the solution.

Once the last fertilizer has been dissolved, allow the solution to sit for 30 minutes to 2 hours and periodically check for precipitates.



The mixture is compatible. Replicate the process in the field, always mixing the same fertilizers in the same order and the same relative concentrations used in the jar test.

Continue to check the jar, and providing that the turbidity does not increase and there are no precipitates at the bottom of the jar, then the mixture is unlikely to cause any problem when used. The turbidity is probably a result of some insoluble components within one of the fertilizers.

The mixture is incompatible and cannot be used.

Always remember to add acid first into the jar – again use the same proportion that will be used in the tank. IF IN DOUBT......... DO NOT MIX IT, DO NOT APPLY IT

When mixing colored fertilizers the final solution may or may not be colored

Table 21
Compatibility of Selected Yara Fertilizers

- Incompatible
- Solubility as SOP solubility
- Solubility as MOP solubility

	Krista MGS	Krista MAG	Calcinit	Krista K	Krista SOP	Krista MOP	Krista MKP	Krista MAP	Phosyn Acid	AS	Amnitra	Urea
Urea												
Amnitra												Yes
AS											Yes	Yes
Phosyn Acid										Yes	Yes	Yes
Krista MAP									Yes	Yes	Yes	Yes
Krista MKP								Yes	Yes	Yes	Yes	Yes
Krista MOP							Yes	Yes	Yes	Yes	Yes	Yes
Krista SOP						Yes	Yes	Yes	Yes	Yes	Yes	Yes
Krista K					Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Calcinit				Yes	No	Yes	No	No	No	No	Yes	Yes
Krista MAG			Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
Krista MGS		Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes

The compatibility for most common fertilizers is shown in Table 21. If mixing products not shown in the table then always carry out a jar test first.

Under some circumstances it may be possible to make solutions of the incompatible products shown in Table 21, by manipulating the solution pH.

Ask your local Yara Agronomist for details.

Mixing incompatible fertilizers causes problems

FAST

Fertigation Assistant Software

Yara has developed a practical, quick and easy to use software program to help devise fertigation programmes.

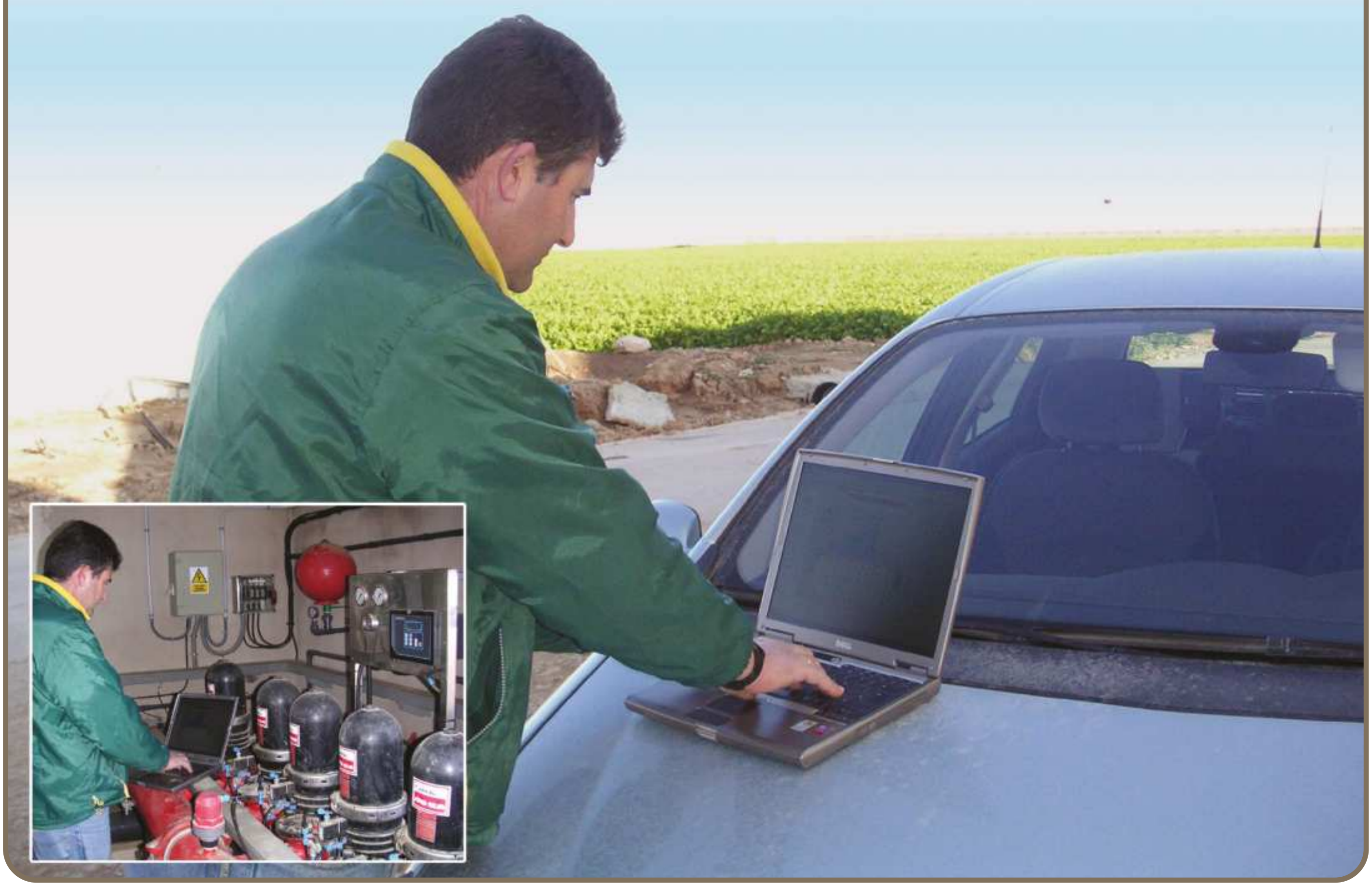
FAST - Fertigation ***A***ssistant ***S***of***T***ware- establishes the nutrient requirements for each individual crop and then converts them into a precise fertigation recommendation.

The system allows the end user to adjust these programmes to suit specific conditions based on their own analyses.

Every calculation is compiled and adjusted for the specific head unit at the farm level, providing a comprehensive report for daily use.

FAST also provides an easily accessible record of fertilizer use on every fertigation plot, allowing the grower to compare data between plots, crops and seasons.

FAST......Monitoring fertigation programme performance has never been easier.



Fertigation Management

When preparing a fertigation plan it is important to follow the steps below:-

1) Calculate crop water requirements, taking into account the expected yield and growing season and any inefficiency in application.

PAGE 46

2) Calculate the nutrient needs of the crop.

PAGE 49

3) Convert nutrient needs into fertilizer requirements.

PAGE 53

4) Schedule fertigation according to the plant needs, soil conditions and climatic factors.

PAGE 56

5) Calculate the nutrient concentrations needed, their rate of application, and how best to manage nutrients in tanks and at the point of injection.

PAGE 62

Once the fertigation plan is made, it is important to regularly monitor performance and fine-tune where needed.

1) Calculating Crop Water Requirements

In order to calculate water needs, it is necessary to establish the maximum evapotranspiration, i.e. the total losses due to transpiration from the plant and evaporation from the soil.

Evapotranspiration is calculated using climatic data and a knowledge of crop water needs. It provides an indication of the total water requirement for a given crop.

Locally, advisors often use '**reference evapotranspiration**', ETo, which is calculated from the evapotranspiration of a healthy growing lawn, supplied with sufficient water and nutrient for maximum growth. (Doorembos and Pruit. 1977).

Summary
Assess the maximum evapotranspiration.

This can be done manually, or by utilizing local services.

Adjust according to crop type, crop development and soil evaporation.

From this, assess the net irrigation need in order to meet a crop's requirements over a period of time.

On-farm meteorological station (above and right)

ETo can be calculated using locally adapted mathematical models including Penman-Montheith (FAO recommended); Hargraves; Blaney-Criddle; Priestly-Taylor or Radiación. All use climatic data to obtain the local ETo value.

Alternatively, ETo can be calculated by using a standard piece of apparatus (a Class A pan) placed on the turf and filled to a certain height with water (Figure 52 and photographs below).

Stilling well

Class A pan

The ETo is the amount of water in mm evaporating from the pan, over a given period, modified by a value, Kp, that depends on the pan location and local wind and site location conditions (Table 22). The value obtained is the ETo in mm for the period.

Table 23 provides some useful conversion factors.

Figure 52
Evapotranspiration Assessment using a Class A Pan

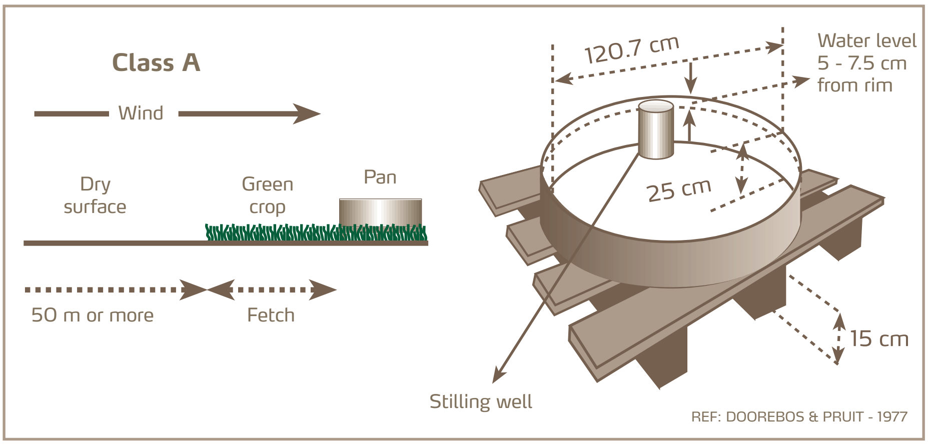


Table 22
Kp Coefficient

Class A pan	Case A: Pan placed in short green cropped area			
RH mean (%)		Low <40	Medium 40 - 70	High >70
Wind speed (m/sec)	Windward side distance of green crop (m)			
Light	1	0.55	0.65	0.75
< 2	10 100 1000	0.65 0.7 0.75	0.75 0.8 0.85	0.85 0.85 0.85
Moderate	1	0.5	0.6	0.65
2 - 5	10 100 1000	0.6 0.65 0.7	0.7 0.75 0.8	0.75 0.8 0.8
Strong	1	0.45	0.5	0.6
5 - 8	10 100 1000	0.55 0.6 0.65	0.6 0.65 0.7	0.65 0.7 0.75
Very Strong	1	0.4	0.45	0.5
> 8	10 100 1000	0.45 0.5 0.55	0.55 0.6 0.6	0.6 0.65 0.65

REF: FAO

Table 23
Evapotranspiration Conversion Factors

	Depth	Volume per unit area		Energy per unit area
	mm day^{-1}	m^3 ha^{-1} day^{-1}	l s^{-2} ha^{-1}	MJ m^{-2} day^{-1}
1 mm/ day	1	10	0.116	2.45
1 m^3 /ha/day	0.1	1	0.012	0.245
1 l/s/ha	8.640	86.40	1	21.17
1 MJ/m^2/day	0.408	4.082	0.047	1

REF: FAO

In addition there are a range of computer programs available to calculate ET_0, e.g. CROPWATT from the FAO using a series of climatic data. In many countries, the ET_0 can be obtained from the local meteorological or agricultural extension services.

The ET_0 value is a reference value and is not related to a specific crop. Each crop has its own specific needs (ETc) and thus the ET_0 value needs to be adjusted by a crop coefficient Kc (Table 24).

The Kc coefficient varies according to crop stage, crop height, reflectance, leaf surface and crop surface coverage. Thus, while Table 24 provides a good guide to calculate the ETc, it needs adjustment to suit local irrigation scheduling and local growing conditions.

Table 24
Kc Coefficient for Specific Crops

Crop	Kc initial	Kc mid	Kc end	Max Crop Height (m)
A) Small Vegetables	**0.7**	**1.05**	**0.95**	
Broccoli		1.05	0.95	0.3
Brussels Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Onions - Dry		1.05	0.75	0.4
Onions - Green		1.00	1.00	0.3
Onions - Seed		1.05	0.80	0.5
Spinach		1.00	0.95	0.3
Radish		0.90	0.85	0.3
B) Vegetables - Solanum Family *(Solanaceae)*	**0.5**	**1.15**	**0.80**	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05	0.90	0.7
Tomato		1.15	0.7-0.9	0.6
C) Vegetables - Cucumber Family *(Cucurbitaceae)*	**0.5**	**1.00**	**0.80**	
Cantaloupe	0.5	0.85	0.60	0.3
Cucumber - Fresh Market	0.6	1.00	0.75	0.3
Cucumber - Machine Harvest	0.5	1.00	0.90	0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Squash, Zucchini		0.95	0.75	0.3
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
D) Roots and Tubers	0.5	**1.10**	**0.95**	
Beets, table		1.05	0.95	0.4
Potato		1.15	0.75	0.6
E) Legumes *(Leguminosae)*	**0.4**	**1.15**	**0.55**	
Beans, green	0.5	1.05	0.90	0.4
Beans, dry and Pulses	0.4	1.15	0.35	0.4
Chick pea		1.00	0.35	0.4
Soybeans		1.15	0.50	0.5-1.0
F) Perennial Vegetables (winter dormancy & initially bare or mulched soil)	**0.5**	**1.00**	**0.80**	
Artichokes	0.5	1.00	0.95	0.7
Asparagus	0.5	0.95	0.30	0-.2-0.8
Mint	0.60	1.15	1.10	0.6-0.8
Strawberries	0.40	0.85	0.75	0.2
G) Fibre Crops	**0.35**			
Cotton		1.15-1.2	0.7-0.5	1.2-1.5
Turf Grass - Cool Season	0.90	0.95	0.95	0.10
Turf Grass - Warm Season	0.80	0.85	0.85	0.10
K) Sugar Cane	**0.40**	**1.25**	**0.75**	**3**
L) Tropical Fruits and Trees				
Banana - 1st Year	0.50	1.10	1.00	3
Banana - 2nd Year	1.00	1.20	1.10	4
Cacao	1.00	1.05	1.05	3
Coffee - Bare Ground Cover	0.90	0.95	0.95	2-3
Coffee - With Weeds	1.05	1.10	1.10	2-3
Date Palms	0.90	0.95	0.95	8
Palm Trees	0.95	1.00	1.00	8
Pineapple - Bare Soil	0.50	0.30	0.30	0.6-1.2
Pineapple - With Grass Cover	0.50	0.50	0.50	0.6-1.2
Rubber Trees	0.95	1.00	1.00	10
Tea - Non-Shaded	0.95	1.00	1.00	1.5
Tea - Shaded	1.10	1.15	1.15	2
M) Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes - Table or Raisen	0.30	0.85	0.45	2
Grapes - Wine	0.30	0.70	0.45	1.5-2
Hops	0.30	1.05	0.85	5
N) Fruit Trees				
Almonds - no ground cover	0.40	0.90	0.65	5
Apples, Cherries & Pears:				
- no ground cover, killing frosts	0.45	0.95	0.70	4
- no ground cover, no frosts	0.60	0.95	0.75	4
- active ground cover, killing frosts	0.50	1.20	0.95	4
- active ground cover, no frosts	0.80	1.20	0.85	4
Apricots, Peaches, Stone Fruit:				
- no ground cover, killing frost	0.45	0.90	0.65	3
- no ground cover, no frosts	0.55	0.90	0.65	3
- active ground cover, killing frosts	0.50	1.15	0.90	3
- active ground cover, no frosts	0.80	1.15	0.85	3
Advocado, no ground cover	0.60	0.85	0.75	3
Citrus, no ground cover:				
- 70% canopy	0.70	0.65	0.70	4
- 50% canopy	0.65	0.60	0.65	3
- 20% canopy	0.50	0.45	0.55	2
Citrus, active ground cover or weeds:				
- 70% canopy	0.75	0.70	0.75	4
- 50% canopy	0.80	0.80	0.80	3
- 20% canopy	0.85	0.85	0.85	2
Conifer Trees	1.00	1.00	1.00	10
Kiwi	0.40	1.05	1.05	3
Olives - 40-50% canopy	0.65	0.70	0.70	3-5
Pistachios - no ground cover	0.40	1.10	0.45	3-5
Walnut	0.50	1.10	0.65	4-5

REF: FAO

Locally adapted Kc values may be available for the different crops in your area. Check with your local Yara agronomist.

As stressed above, K_c, is a single crop coefficient. When a more precise measurement is needed, the crop coefficient is split in two:

1) Crop transpiration (K_{cb}).
2) Evaporation from the soil (K_e).

Total evapotranspiration $K_c = K_{cb} + K_e$.

For tree crops and some vegetables at certain stage of growth, the Kc is modified by a factor based on canopy cover, measured as the soil area shaded by the crop at midday.

The shaded area will have lower evaporation than the unshaded area. This correction factor is called the **shaded area coefficient** (K_r), and has a maximum value of 1 for a crop with a complete canopy cover.

The amount of water needed is then calculated as $ET_o \times K_c \times K_r$ (trees). Values are in mm/day or over a given time period. This value is called the **net irrigation need** (Ni), and needs to be adjusted according to the following factors to get the total irrigation amount:

A) The amount of effective rainfall.
B) The need for leaching-out of salts or toxic elements.
C) The relative inefficiencies of the fertigation system.

It is important to carry out this calculation before growing each different crop. Glasshouse production requires a similar approach to calculate net irrigation need.

Table 25
P Supply Correction for Garlic

	P Level in the soil (ppm)					
Bray P1 (pH<7.4)	0-10	11-20	21-30	31-40	41-50	>51
Olsen P (pH>7.4)	0-7	8-15	16-25	26-33	34-41	>42
Kg/ha P_2O_5	200	150	100	75	50	25

REF: UNIVERSITY OF MINNESOTA - EXTENSION SERVICE

Ask your Yara agronomist for more information on absorption curves or specific nutrient demands for crops in your region.

2) Calculating Nutrient Needs

Uptake Curves

An estimation of a crop's total nutrient needs can be obtained from wide variety of sources. Textbooks are one possibility; especially if the work quoted is based on trials in the region you are working.

However, it is also possible to calculate nutrient needs from crop absorption curves, most of which are based on fundamental research.

These charts show the uptake of each nutrient over a growing period for a given production level. ***Yara's Plantmaster™ Manuals are a good source of uptake curves for a variety of crops.*** Examples for potato and citrus are given in Figures 53 and 54.

When making assumptions based upon nutrient absorption or uptake curves it is important to differentiate between varieties/cultivars and to adjust nutrient levels according to anticipated yields.

To achieve the best results in a fertigation programme, it is important to use the correct proportion and amounts of different nutrients to match crop needs, while still ensuring a balanced nutrient supply without any adverse competition for uptake.

Absorption curves are related to the specific crop and sometimes variety, and may also need adaptation when implementing at a local level. This will be due to the local soil conditions and nutritive status. For example, Table 25 can be used to adjust P requirements for garlic based upon soil analyses.

Nutrient uptake curves are ideal as guides for nutrient needs under a fertigation system because the system is usually more efficient than solid field-based fertilizer programmes and so less correction for fertilizer inefficiencies need to be made.

Summary
Based on uptake curves, decide what nutrients the crop needs across the season. Use soil, tissue, sap and soil water analyses to modify nutrient needs for each crop or production unit.

Decide what is the best plan to meet these crop requirements, taking into account the limitations of the fertigation system.

Figure 53
Typical Uptake Curve - Daily Rate of Macronutrient Uptake - Whole Potato Plant

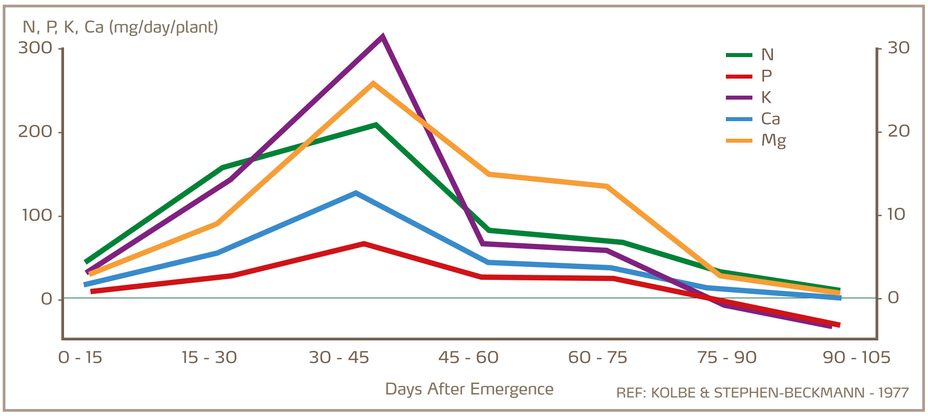
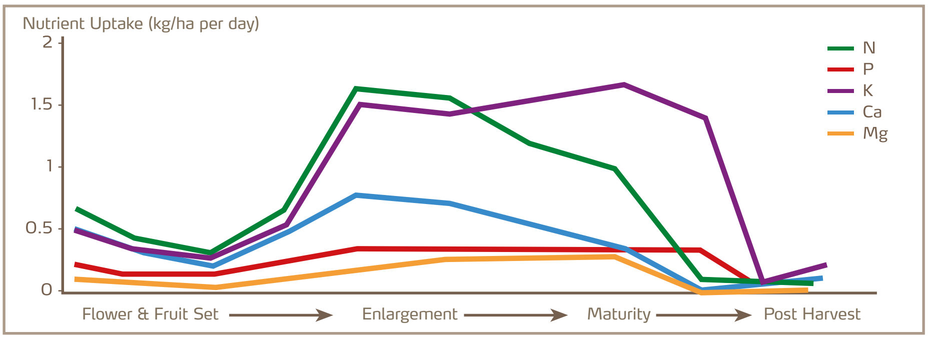


Figure 54
Typical Uptake Curve - Citrus



Nutrient Analysis

Soil analysis data can also be used for calculating the fertilizer requirements for nutrients such as P, K or Mg. Remember, in fertigation, the soil profile is only that zone within the wetted bulb. Therefore, nutrient calculations should be related to the average wetted bulb volume and the soil bulk density.

The bulk density is usually around 1.4g/cm^3 in most soils, but lower where organic matter is higher. Agronomic practices such as tillage will also affect bulk density.

Adjustment of soil nutrient levels is most commonly carried out:

- For vegetable crops.
- For perennial crops - calculations need to take into account recycling from crop residues, e.g. leaves and prunings.
- Where manure has been used.

Under fertigation, the aim is to maintain soil fertility in its original state, and only provide the nutrients needed for the crop within the wetted bulb. This will maintain the long-term fertility status of the soil, even under intensive, high yielding crop systems.

Tissue analysis is an important monitoring tool in fertigation. It identifies the plant's nutrient status, confirming a deficiency or excess of any nutrient at critical growth stages of the crop.

Most commonly, tissue analysis is used to compare the crop's nutritional status with a standard reference for that crop. ***These are available from your Yara agronomist or in the Yara Plantmaster™ Manuals.*** Some examples for glasshouse tomatoes and pome fruit are given in Tables 26 and 27.

In perennial crops, tissue analysis is normally used to check the current season's nutritional status and to make adjustments for the next crop (Table 28).

Table 26

Adequate Nutrient Range - Glasshouse Tomato

USA

Leaf samples: most recently matured leaf

Stage		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Mo	Zn
		%						ppm					
Most Recently Matured Leaf	Adequate	3.5	0.3-0.65	3.5-4.5	1.0-3.0	0.35-1.0	0.2-1.0	5-35	30-75	50-300	25-1000	0.1-1.0	18-80

REF: PLANK - 1989

Table 27

Macronutrients Leaf Analysis at Mid Fruit Development - Pome Fruit

- all dry matter, fully expanded leaves from midpoint of new shoots

Nutrient (%)	Deficient	Marginal	Adequate	High	Excessive
N	<2.00	2.00 - 2.25	2.25 - 2.70	2.70 - 2.85	>2.85
P	<0.14	0.14 - 0.16	0.16 - 0.28	0.28 - 0.30	>0.30
K	<1.00	1.00 - 1.20	1.20 - 1.85	1.85 - 2.00	>2.00
Ca	<1.04	1.04 - 1.20	1.20 - 2.00	2.00 - 2.20	>2.20
Mg	<0.15	0.15 - 0.19	0.19 - 0.36	0.36 - 0.39	>0.39
S	<0.10	0.10 - 0.14	0.14 - 0.18	0.18 - 0.22	>0.22

REF: BERGMANN ET AL., WINTER ET AL., IFA

Table 28

Factors for Fertilizer Programme Correction based on Foliar Analysis - Oranges

	Content in leaves (%)				
Nutrient	Very low	Low	Normal	High	Too high
N	1.5	1.5-1.1	1	0.8-0.6	0.5
P_2O_5	2	1.6-1.2	1	0.5-0	
K_2O	2	1.8-1.3	1	0.6	

REF: IVIA-VALENCIA

Thus, if leaf tissue analysis in citrus groves suggests that levels of N in the leaves are low, then adjust the nutrient amount to be applied by multiplying the recommended nutrient need by a factor of 1.1-1.5.

Sap analysis can be used to monitor the nutritional status of the crop at a specific time or growth stage. However, guidelines for the interpretation of sap analysis are not readily available.

Analysis of water supply allows corrections to be made to the fertigation plan to ensure the nutritional programme remains balanced.

Analyses usually assess nitrate, cation content - especially magnesium – and toxicities, such as boron or sodium.

It is also used to provide an indication of salinity problems in water. Here, calcium applications are particularly valuable to minimize toxicity effects and to leach sodium from the wetted bulb.

Increasing the proportion of nitrate based fertilizers in the fertigation solution will also minimize the effects of high chlorides and boron in the soil solution (Figures 18 & 19 on page 14).

Seasonal Nutrient Needs

Nutrient requirements vary throughout the growing season and it is critical that the nutrient supply from fertigation closely matches the needs of the crop.

This not only improves nutrient efficiency, but also reduces the risks of contamination of the produce, or the environment. ***More details are provided in the Plantmaster™ Manuals.***

For tree crops, most of the nutrients used early in the season, are remobilized from the tree reserves. At this time, there is very little evapotranspiration (low irrigation need), and therefore little root uptake of nutrients.

Research in Spain shows that as much as 32% of the total N needed for a productive orange tree is remobilized from reserves and that 17% of the tree's P, 29% of K, and 30% of Mg, can also come from this source (Table 29). Later in the season, nutrients are mainly supplied from applied fertilizers.

Root activity – and hence supply of nutrients from the soil - depends on soil temperatures and other growing conditions. Thus, in warmer climates, with good active root growth, the role of recycled nutrients within the tree is less important.

Not all nutrients can be remobilized. Immobile nutrients like Ca or Fe need to be taken up from soil reserves or applied fertilizers.

When designing a fertigation plan in fruit trees it is important to supply nutrients late in the season, so that these can be transferred and stored in the trunk, branches and roots, ready for remobilization in the following spring.

Specific programmes will also be needed to influence the quality requirements of the harvested crop e.g. in table grapes, and to meet the high nutrient demands of a short season crop such as lettuce. Balanced nutrition and correct nutrient timing will increase both nutrient and water efficiency, and will achieve the best results as shown, for example in tomatoes (Table 30).

Table 29
Nutrient Recycling in Citrus

	Yield (kg/tree)	Nutrient	Needed (kg/tree)	Supply by plant (% of total need)
New plant		N P K Mg	6.8 0.8 3.6 1.4	25 12 22 24
Young plant (6 years)	28	N P K Mg	210 18 121 46	32 16 28 30
Mature tree	120	N P K Mg	667 53 347 135	32 17 29 30

REF: F. LEGAZ, E PRIMO-MILLO-IVIA-SPAIN - 2003

Table 30
Tomato Yield - Irrigation Method and Nutrient Supply

	1984 (N)		1985 (N-P)		1986 (N-P-K)	
Treatments	Yield (t/ha)	WUE	Yield (t/ha)	WUE	Yield (t/ha)	WUE
Sub-surface - high frequency - drip irrigation	121a	18a	168a	22a	220a	31a
Surface - high-frequency - drip irrigation	126a	19a	152b	20b	201b	29b
Surface - low-frequency	114a	16a	130c	18c	187c	26c
Water Use Efficiency (WUE): fresh yield/crop evapotranspiration (kg/m^3)						

REF: PHENE - 1995

These trials confirm that:-

- Annual use of balanced nutrition increases yield, independent of application method and timing.
- The greater the number of applications, the higher the yield.
- Subsurface irrigation ensures better water utilization and higher crop productivity than other irrigation methods.

While high rates of fertilizer are needed for optimum yields, care has to be taken to ensure that crop quality is not adversely affected. High rates of late season N can lead to fruit and vegetable crop breakdown in store.

In addition, in-season or late applied nutrients such as calcium – often used to counteract salinity problems - may not affect yield, but can have a significant beneficial affect on quality by improving skin quality and cell integrity across a range of crops.

Luxury consumption of the major elements will normally increase yield but quality can suffer.

However, increasing applications beyond the plant's yield potential is wasteful, and uneconomic.

Where crops are already near to their maximum yield potential, increasing application rates will usually reduce nutrient efficiency (Table 31).

Table 31
% Nutrient Recovery and Yield in Greenhouse, Short Season Tomatoes

	%					(kg/m²)
Nutrient application	**N**	**P**	**K**	**Ca**	**Mg**	**Yield**
50%	108	154	124	38	25	9.1
Optimum (100%)	72	106	86	52	38	12.3
200%	56	69	58	65	59	13.3

REF: YARA - CIFA ALMERIA - SPAIN

While highest yields in these trials were secured when fertilizer rates were double that of normal (200%), the efficiency of the applied nutrients and cost-effectiveness were significantly reduced.

Fertigation is a highly efficient means of supplying nutrients as soon as they are required by the crop and on a continuous basis to a specific part of the plant.

For example:

- Directly targeting the potato stolon with calcium through fertigation into the ridge or hill, improves tuber Ca levels and provides better quality potatoes.
- Ca and Fe are often needed in large quantities when a new flush of growth is occurring. In certain situations this is best met by adopting a concentrated fertigation programme with high levels of these nutrients.

It is important to start early and maintain fertigation programmes over a long period of time to supply specific immobile nutrients such as calcium, thereby ensuring as high a concentration as possible in the end produce.

However, where specific transient leaf deficiencies or fruit needs are indicated, then foliar or fruit sprays with properly formulated products may provide a fast, immediate response.

For macronutrients and also where iron is in short supply, then fertigation is needed. Foliar application will not meet season-long requirements for these nutrients.

The key is to have the required nutrient available at the right time, in the correct quantity, where it is needed.

Monitoring Fertigation Solutions

Fertigation solutions should be checked regularly.

Analyse the solution as it leaves the system head unit to assess how the system is operating. Checking the soil/growing media solution provides an indication of what is really available to the plant.

In hydroponic systems in Holland, the nutrient solution is commonly sampled every fortnight and checked for EC, pH and complete nutrient content.

Because the growing media and distribution of nutrients through the system vary, it is important to obtain an accurate analysis by collecting as many samples as possible.

Every sample analyzed should be a composite sample of 500ml from at least 40 different points, of which half are between plants, and the other half are from under plants. One composite sample is taken per ha and samples are taken usually in the morning, after two-three fertigation events.

Fertigation systems in open field situations need similar sampling care. It is recommended to collect 25 to 30 samples over a larger area (one hectare) to ensure the sample represents the soil type.

Monitoring the soil solution

Analyze soil on farm

Two of the most common methods for sampling the nutrient status of the soil in fertigated crops are the Porous Cup and Funnel System:

(1) Porous Cup
Soil solution extracts can be collected via a porous ceramic cup placed into the root zone connected to the soil surface by a tube. This tube is capped and the soil solution collected by using a vacuum system.

(2) Funnel System
Soil solutions can also be collected from a funnel placed at the desired depth in, or below, the wetted bulb, which is connected by a pipe to the surface.

The solutions should be analyzed for pH, EC and all nutrients.

Monitoring wells

Suction pump

3) Matching Fertilizer to Crop Need

The photos above show the funnel system for collecting soil solutions in South Africa

Once crop nutrient requirements have been established, fertilizer selection and rates need to be confirmed. These are calculated either by weight or by concentration:

Fertilizer Calculation by Nutrient Weight

This approach calculates the total fertilizer need for a given period (or growing season) and then apportions this out over that period.

The distribution of the desired nutrients can be continuous with each irrigation, or applied with a more limited number of irrigation events increasing the concentration each time.

In similar fashion, each selected fertilizer can be applied with every irrigation or more periodically.

The period between each fertigation or product application can vary from every day, or alternate days, to several days.

While there is a wide range of options available, the use of all the selected fertilizers needed for that period of growth, during every irrigation, ensures that all nutrients are in balance and generally gives the best results.

For convenience, some nutrients or fertilizers may be split due to limitations in the system e.g:

- When there is likely to be incompatibility between nutrients and only one feed tank.
- The fertilizer programme may include a base dressing of solid fertilizer with fertigation of nutrients during the growing season.

The concentration of the nutrient in the feed solution is calculated after you have decided on the desired irrigation schedule. The total amount of nutrient needed is split and applied over this complete irrigation period. The calculation of nutrient concentration is only used as additional information to check salinity status, because the concentration varies over the irrigation period.

This approach, based on weight of nutrients, is widely used, especially where rainfall can modify the irrigation plan.

An alternative approach is to apply all or some of the nutrients required at the same time, but to vary the concentration of the nutrients across irrigation events.

Fertilizer Calculation Based on Nutrient Concentration

The nutrient concentration can be expressed as:-

- Parts per million (ppm) or mg/l
- Millimol per liter (mmol/l)
- Milliequivalent per liter (meq/l)

These units can be also be referred to in oxide or elemental forms (ppm of NO_3-N, P_2O_5 etc.) or more commonly in hydroponics, as ions (NO_3^-, H_2PO_4, K^+ etc.).

Calculation based on concentrations is used worldwide in greenhouses and glasshouses, with many commonly comparable nutrient solutions being used across most crops.

The concentrations used have been devised following many trials using nutrient solutions adjusted to suit a crop's demand across the whole season.

In comparison, in open field situations, where periods of rainfall restrict irrigation demand, it is more difficult to devise a system using nutrient concentrations. In drier climates, with less rainfall, minimal adjustment is needed.

In all situations the concentration can be calculated based on the amount of water required in a given period and using all required nutrients during every irrigation.

Summary

Select an appropriate fertilizer formulation and type – liquid or solid - that most closely meets the crop's nutrient needs.

Decide whether you intend to fertigated with one solution throughout the season or will vary nutrient concentrations to match specific seasonal growth needs.

Calculate fertilizer application rates and timings based upon nutrient weight or concentration ensuring you supply the required balanced mix of nutrients across the season.

Calculating Fertilizer Needs

1

The basic calculations needed to convert nutrient needs into fertilizers are given below:

Fertilizer terminology - the content of N, P and K is always written from left to right and expressed as pure nitrogen (N), phosphorus oxide (P_2O_5) and potassium oxide (K_2O) on a percentage weight basis.

Conversions - elemental to oxides and vice versa.

Note, in many countries the nutrients are shown in their oxide form but in others the nutrients are always shown in their elemental form. Nitrogen (N) is the only nutrient shown in elemental form at all times. The conversion factors are shown in Table 32.

Table 32
Nutrient Conversions
Elements to oxides and vice versa

To convert	To	Multiply by
P	P_2O_5	2.29
P_2O_5	P	0.44
K	K_2O	1.21
K_2O	K	0.83

2a

Solid Fertilizers

Solid fertilizers are shown on a weight basis. In order to calculate the amount of nutrient in a solid fertilizer you multiply the weight of the fertilizer e.g. one kilogram, by the percentage of nutrient in the fertilizer.

Example: A 15-5-30 fertilizer contains 15% nitrogen, 5% phosphorus oxide and 30% potassium oxide.

In weight, 1 kg of this fertilizer contains 150 grams N, 50 grams P_2O_5 and 300 grams K_2O (Table 33).

Table 33
Solid Fertilizer Nutrient Content
Oxides

	N	P_2O_5	K_2O
1 kilo of fertilizer 15-5-30 Nutrient content (%)	15	5	30
To convert to grams (1000/100) multipy by 10 Nutrient content (g)	150	50	300

When converted to elemental form, 1kg of 15-5-30 fertilizer contains 150 grams N, 22 grams P and 249 grams of K (Table 34).

Table 34
Converting this fertilizer from Oxide to Elemental form

	N	P_2O_5	K_2O
1 kilo of fertilizer 15-5-30 Nutrient content (%)	15	5	30
Oxide to Elemental	x 1	x 0.44	x 0.83
To convert to grams (1000/100) multipy by 10 Elemental nutrient content (g)	150	22 P	249 K

2b

Liquid Fertilizers

Liquid fertilizers, for convenience, are often shown on a volume basis. In order to calculate the amount of any nutrient in a given volume of fertilizer, multiply the percentage weight by the specific weight of the fertilizer (the weight of one unit volume e.g. weight per liter [kg/l]).

Example: One liter of 2-0-10, with a specific weight of 1.15kg per liter, contains 23 gram N and 115 gram K_2O (Table 35).

Table 35
Nutrient Content in Liquid Fertilizer

	N	P_2O_5	K_2O
1 kilo of fertilizer 2-0-10 Nutrient content (%)	2	0	10
Multiply by specific weight of fertilizer. To convert to grams (1000/100) multipy by 10 Nutrient content (g)	23	0	115

3 Calculating Nutrient Requirements.

Calculating Nutrient Requirements. When the amount of nutrient required is known, it is necessary to calculate the amount of fertilizer needed to meet this nutrient requirement:

3a For Solid Fertilizers

Nutrient in kg is divided by the nutrient percentage in the fertilizer.

Example: to apply 20kg of N using a 15-5-30 fertilizer you need an application of 133kg.

Note this will also apply 6.7kg P_2O_5 and 40kg K2O (Table 36).

Table 36
Weight of Solid Fertilizer Required to meet Nutrient Demand

	N	P_2O_5	K_2O
Nutrient weight (kg)	20	= 6.7	40
Nutrient content (%)	/15	x 5	x 30
Conversion factors for %	x 100	/ 100	/ 100
Fertilizer weight (kg)	= 133	133	133

***Note:** the first conversion is made with the desired nutrient, in this case nitrogen, and then the other nutrients also in the fertilizer are then also calculated as indicated by the arrows in the table.*

3b For Liquid Fertilizers

Nutrient weight (kg) is divided by nutrient percentage of the fertilizer and then divided by the specific weight of the fertilizer.

Example: To apply 20kg of N using a 2-0-10 fertilizer (specific weight 1.15kg/l) 870 liters will need to be applied. Note: This will also apply 100kg of K2O (Table 37).

Table 37
Volume of Liquid Fertilizer Required to Meet Nutrient Demand

	N	P_2O_5	K_2O
Nutrient weight (kg)	20	= 0	= 100
Nutrient content (%)	/ 2	x 0	x 10
Specific weight (kg/l)	/ 1.15	x 1.15	x 1.15
Conversion factors for %	x 100	/ 100	/ 100
Fertilizer volume (litre)	= 870	870	870

4 Nutrient Concentration Calculations.

Nutrient Concentration Calculations. When using the concentration of a nutrient in the irrigation water, instead of a quantity (weight or volume) application, calculation should be as those for solid fertilizers and then dividing the desired concentration by the actual concentration of the fertilizer.

4a Solid Fertilizer Example:

In order to apply 100ppm of N using a 15-5-30 fertilizer, it will be necessary to apply 0.67kg of this fertilizer per cubic meter of water. This application will also provide 33ppm P_2O_5 and 200ppm K_2O (Table 38).

Table 38
Weight of Solid Fertilizer Required to Apply a Given Nutrient Concentration

	N	P_2O_5	K_2O
Nutrient concentration (ppm)	100	= 33	= 200
Nutrient content (%)	/ 15	x 5	x 30
Conversion factor	/ 10	x 10	x 10
Fertilizer weight (kg)	= 0.67	0.67	0.67

***Note:** the first conversion is made with the desired nutrient, in this case nitrogen, and then the other nutrients also in the fertilizer are then calculated.*

4b Liquid Fertilizer Example:

In order to apply 100ppm of N using a 2-0-10 liquid fertilizer which has a specific gravity of 1.15kg/l - apply 4.3 liters of this fertilizer per cubic meter of water. This application will also give 500ppm K_2O (Table 39).

Table 39
Volume of Liquid Fertilizer Required to Apply a Given Nutrient Concentration

	N	P_2O_5	K_2O
Nutrient concentration (ppm)	100	= 0	= 500
Nutrient content (%)	/ 2	x 0	x 10
Specific weight (kg/l)	/ 1.15	x 1.15	x 1.15
Conversion factor	/ 10	x 10	x 10
Fertilizer concentration (litre)	= 4.3	4.3	4.3

4) Fertigation Scheduling

Growers can soon build up a simple knowledge of best practice irrigation through trial and error. For example:-

- If water penetration is too deep, it means they are applying too much water and the soil's infiltration rate is higher than expected.

  Solution: Split apply irrigation over the same period. If coverage is still not sufficient, then the wrong emitters are being used.

- If there is run off or the soil is waterlogged, the infiltration rate is lower than expected (Table 2, page 9).

  Solution: Check the depth of penetration of the wetted bulb to see if there are any soil restrictions. If soil conditions are fine, then split timing irrigation should solve the problem. If the wetted bulb depth is not sufficient, then the rate of discharge is probably too great and growers either need to change the emitter, or use pulsed irrigation, applying small doses at frequent time intervals.

The interval between irrigation events will depend on how the moisture moves in the soil. This needs to be evaluated locally.

At all times it is important to avoid either waterlogging or water deficits. Should they occur, the system needs to be checked to correct the problem. This could also happen in some specific areas within a single production plot.

Growers will also soon learn from experience that the frequency of irrigation they need to use, in order to maintain the same wetted bulb, will vary according to different soil texture and type.

It is also fairly easy to assess the maximum amount of water that can be supplied to a soil by a given set of emitters before field capacity is reached.

However, in order to properly schedule irrigation to coincide with a crop's needs, growers also need to assess:

- **Evapotranspiration** losses (see page 46).
- The amount of **system discharge** and infiltration losses.
- The level of plant **available water** in the soil.

Calculating System Discharge

System discharge can be estimated based on the number of emitters in the plot and the amount of water they supply (see box opposite).

Localized water run off

Values should be adjusted based on a uniformity coefficient - the absolute difference between the emitters with the biggest discharge and those with the lowest discharge - see section on monitoring on page 35.

System discharge
= Number of drippers x drip discharge
*= **litre / hour** for the area of the plot = Pd*

***Time needed** for a given volume of water needed (irrigation)*
*= Pd/ (volume in m3 *1000)*
= hours

Calculating Available Soil Water

Knowledge of the soil's plant available water is critical for scheduling, as system discharge (e.g. dripper type and number) and infiltration rate cannot be easily changed. There are many ways of monitoring soil moisture:

Tensiometers, gypsum blocks etc., measure potential (matrix potential). Tensiometers are the most commonly used device worldwide.

Volumetric methods include **Capacitance probes, neutron probes and lysimeters,** etc. They measure either soil moisture content or a percentage of total water content capacity.

On farm the devices most commonly used are tensiometers and capacitance probes. For every soil, there is a relationship between water content and matrix potential (Table 1, page 9), and from measurements taken from these devices a curved graph can be produced that is specific to each soil.

Summary
Adjust irrigation events such that there is a consistent nutrient and water supply to the roots in the wetted bulb.

Monitor and modify fertigation practice based on changes in soil water availability due to evapotranspiration and plot discharge/drainage.

Regularly check performance at the head unit, adjusting nutrient concentrations and rates to mirror crop needs.

Tensiometers

A tensiometer is a water-filled tube with a vacuum gauge and filling port at the upper end, and a ceramic cup at the lower end. When it is placed in the soil, the water in the instrument comes to equilibrium with the water in the soil by flowing through the ceramic cup. At equilibrium, the water tension in the instrument is equal to the water tension in the soil. A vacuum gauge then measures the soil water tension. Tensiometers assess soil water potential or tension - a measure of the amount of energy required for a plant to overcome capillary and gravitational forces to extract water from a soil. Thus, tensiometers can be used to schedule irrigation when the soil water tension is low - that is, before plant water stress occurs.

While tensiometers measure the hydraulic potential in a soil, they do not assess the osmotic potential in the soil solution. This needs to be taken into account in saline soils or when irrigating with saline water, as the tensiometer pressure gauge will present a reading that is higher than expected.

Common practice is to use 2 or 3 tensiometers installed at different depths in the soil. This allows the monitoring of water at a range of depths in the wetted bulb. Positioning needs to match the rooting depth of the crop – normally 30, 60 and 90cm in trees.

Water movement is always from the point of highest pressure potential to that of the lowest and the potential in the soil is a negative value. Thus, with a tensiometer reading of –30cbar at 30cm depth and –60cbar at 90cm, there is a lower hydraulic potential deeper in the soil, so water will move down through the soil profile.

When calculating the matrix potential, readings should deduct one cbar for each 10cm depth from the reference point (pressure potential).

Therefore to calculate matrix potential at each depth (30 and 90cm), the matrix potential pressure potential of each (30cm mean -3cbar and 90 mean -9cbar), so, the matrix potential for each depth will be -27 and -81cbar respectively, giving a matrix gradient of -54cbar, using the soil surface as a reference point.

A soil at full field capacity has a potential around -10cbar or less. Ranges for crops vary from -10cbar to -200cbar (Table 40). For intensive horticultural production the upper limit is around –50 cbar.

Air starts to penetrate into the ceramic cup at -80cbar, however care should be taken when interpreting readings in very fine soils, as air inside the soil can provide readings that are higher than reality.

Tensiometer

Tensiometer

Tensiometer

Table 40
Common Tensiometer ranges across irrigated crops in a well drained soil

	cbar range	
Crop	**From**	**To**
Alfalfa	-150	-80
Banana	-150	-30
Beans	-200	-75
Broccoli	-70	-45
Carrot	-65	-55
Cauliflower	-70	-60
Celery	-30	-20
Cotton	-100	-30
Cucumber	-100	-30
Deciduous fruit trees	-80	-50
Flower	-50	-10
Grass	-100	-30
Lemon	-40	-20
Lettuce	-60	-40
Melon	-40	-30
Onion	-65	-45
Orange	-100	-20
Potato	-50	-30
Strawberry	-30	-20
Sugar cane	-50	-15
Tobacco	-80	-30
Tomato	-150	-80
Turf grass	-36	-24
Vineyard	-100	-40

Monitoring soil moisture with a capacitance probe

Capacitance
Capacitance is a measure of the amount of electrical charge stored within the soil.

It can be used to provide an indication of the depletion of water within the soil profile. Different soil moisture states have different capacitance readings and once a defined capacitance level is reached at a given depth, irrigation should commence.

Capacitance devices are usually placed at different depths in the wetted bulb and are suitable for continuous monitoring of soil moisture content as it changes.

Capacitance measurement and tensiometers can be highly automated with remote controllers and different interfaces.

As with all monitoring systems, sample points need to be representative of the whole plot.

Other methods available for soil moisture monitoring include; **neutron probes, dielectric methods** (which include capacitance), and also **impedance** and **time domain reflectometry**. Some systems use blocks of gypsum or quartz as sensors.

There are also some plant based systems that make a correlation between plant growth and irrigation need. These include dendrometers.

Dendrometers are metallic or plastic bands placed around a tree's trunk or branches that measure the small changes in diameter in response to environmental conditions.

The magnitude of the change is normally very small from less than one mm up to several mm in some trunks, but provides an indication of a response to and need for water.

Capacitance probe in lettuce field (in operation)

With all methods of assessment of water status, it is important to take into account and test local standards, adaptations and principles.

Capacitance probe in lettuce field (open)

Dendrometer
Photo courtesy: W. Conejaro, CEBAS-CESIC, Murcia, Spain

Head Units

Having decided on the nutrient needs, the fertilizers to be used and, the amount of water to be applied across the growing season, growers need to bring it all together at the plot head unit (Figure 61, page 73).

This is where fertilizers are dissolved and injected into the irrigation system, and one head unit can service several plots.

Location of the head unit is not fixed. Usually it is positioned upstream, before any plot discharge.

There is a vast range of potential settings for head units. Some important considerations include:

- Location should not be very far from the plots. A long distance (e.g. >1km) between a head unit (injection) and a plot complicates management and can result in unexpected reactions between components in the fertigation solution across a long run of pipes.
- Selection of injection devices is critical. Any compromise in quality and number will restrict fertigation practice and accuracy.
- The capacity of the head unit is the key for the performance of the whole system.
- The relative sophistication of the head unit will influence fertilizer application, and can limit the number of fertilizers (and nutrients) that can be used at any time.
- Filtration systems must match the water source, as any problems will greatly affect the system's performance.

Head unit at pumping station

Plot head unit

Installation options
Head units can be categorized according to the number of injection points available, taking into account injection system, tank size and number:

a) Head units with one tank and one injection device:
These are not particularly flexible as it is not possible to apply all fertilizers simultaneously.

Also, where there are many different plots within the same crop, the head unit frequently needs refilling, unless growers compromise and accept an average rate of nutrition across all the plots.

Some flexibility can be achieved by adding extra tanks, but unless injection is also independent, this system will not be fully flexible.

Care is needed with tanks that have the same injection devices, as incompatibility problems can occur when mixing solutions in the inlet injector pipe - a cleaning system is needed to prevent this.

Head unit one injection and multiple tanks

Head unit one injection

b) Head units with two injectors.
This unit allows simultaneous injection from tanks that are normally labeled A & B.

If just one tank is to be used at any one time then operation is similar to a) above.

When both A & B tanks are to be used, a more comprehensive nutrient solution can be applied, mixing fertilizers from the two separate tanks and avoiding incompatibility problems between different nutrients and products.

The injection rate needs to be calculated for each tank, or the concentration of each tank should be adjusted for the same desired injection rate.

The above photos show head units with two injections

Head unit with typical A + B tank, large scale

c) Multiple injection with more than two injectors:
With this type of head unit, it is possible to simultaneously apply a multitude of different solutions.

This can be achieved by simple adjustment of each injector discharge, or the proportion discharged between them all.

Head unit with multiple and independent tanks and injectors

The above photos show head unit with different injector types

Operating Options
Each head unit will operate in three main ways:

a) Head units where the fertigation solution is pumped directly into a separate tank prior to pumping out into the pipe system:

Head operating typical A + B tanks + specifics tanks for micronutrient and acid solutions, small scale

This head unit system is used where there are many small plots and where greater accuracy is needed.

It is suitable for nurseries, research centers or small farms.

In larger units, production and storage of the appropriate feed solution is more difficult.

All fertilizers needed for each specific irrigation event are dissolved directly in the irrigation water before application.

b) Tanks that are filled each time.
These include pressure tanks and those that are commonly used for a small number of plots, or where different plots are being supplied by just one injector. Here, the calculation will be one of the following:

Figure 55
A Typical Fertigation System

a) injection rate, when the tank dilution is standard (fertilizer max. solubility).

b) dilution (water in tank), when the injection is fixed and cannot be changed.

c) Time of injection, if the injection and tank concentration are standard.

c) Those that operate with the solution already formulated at the head unit. In this situation, the tank or tanks, have a given concentration, and the mixture is the one that will be injected.

This can be one tank for use in different plots with the same needs (where the injection is adjusted to suit plot size), or a group of tanks, to supply different needs to a range of plots, or to meet different nutrient demands. Here, the calculation needed will be:

a) Injection rate.

b) Length of time of injection, if the injection rate is fixed.

c) When using multiple tanks, and the percentage between tanks is used for injection proportions – use the percentage of each tank related to the total injection rate. If the EC is used to quantify this, it will also be required for the calculation.

For calculation purposes, the type of injector and its operation is taken into account. Thus, either the injection rate or tank concentration will need to be adjusted.

Depending upon make and model, injection rates can be assessed as follows:-

Quantitative: discharge is measured over time, measured as liters per hour of operation.

Proportional: based on injection rate for a certain system volume. This can be:

- liters of solution injected per m3 of irrigation water - l/m3- (same as cc solution per liters irrigation – cc/l).
- % of the injection related to the irrigation water, i.e. the volume of water divided by the volume injected, multiplied by 100 (volume in l or m3, for all - l/hr – m3/hr can also used for the purposes of calculation). When the injection rate is fixed, then time or tank concentration can be adjusted.

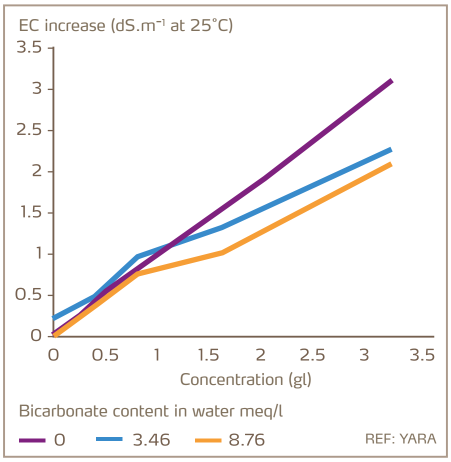
Fertilizer EC

To estimate fertilizer EC, use the tables and figures shown on pages 39 and 42.

Note: A small increase in EC can slightly alter the pH if the fertilizer solution is acidic. Water quality – notably bicarbonate content – can also cause some small variation (Figure 56), especially with acid products due to neutralization processes. Tables are normally produced using distilled water.

Figure 56

EC Variation of Acid Products in Water with Varying Carbonate Levels
(mmol/l bicarbonates) acid solution - P acid 72%



PUMPING → SELECTING → FERTIGATING →

Example Calculations:-

Note that, where more than one head unit is available, the calculation will be the same for each one.

Example 1:
Injection adjustment when the tank concentration is given

Data for Example:
- Volume needed for each irrigation time: 100m³
- Plot discharge: 200m³/h
- Fertilizer needs for irrigation time: 5kg
- Tank size: 1000l
- Fertilizer used for solution: 100kg
- Water dilution at tank: 1000l

Concentration at tank = kg fertilizer/ water in the tank
= 100/1000
= 0.1kg/l tank solution x 100
= 10% concentration.

Calculation process:

1 - Proportional Calculation:
a) Injection adjustment (l/m3)
= amount of fertilizer / concentration at tank / volume needed
= 5/0.1/100 = 0.5l/m³.

b) Injection adjustment (%)
First the total volume of the tank to inject must be calculated.

Total volume tank to inject
= fertilizer need / tank concentration (kg/l)
= 5/0.1= 50l

Injection adjustment
= total volume tank/total irrigation multiplied by 100
= 50/100/1000 x 100 - (conversion l to m³ and %)
= 0.05%

% X 10 = l/m³

2 - Discharge:

Time of irrigation = water needed/ system discharge
Time = 100/200 = 0.5 hours
Injection adjustment = the total volume the tank is to inject (see previous)/irrigation time
Injection adjustment = 50/0.5
=100l/hr

Example 2:
Where a multiple injection unit is in use, calculate the percentage to be supplied by each unit and the sum of each individual discharge will be the total discharge needed *(note - maintain same units across all calculations).*

Total discharge (TD)
= discharge tank 1 + discharge tank 2 +... + discharge
tank n.

The % of each tank will then be:

Discharge tank 1 / TD x 100
= DT1%,

and the same for other tanks.

The total of all the percentages for each individual tank should be 100%.

Example 3:
When injection rates are fixed and there is a need to calculate tank concentration.

Calculate injection rates as above, and the tank concentration for the application (l/tank).

Using the same data set from the previous example:

1 - Proportional Calculation:
Injection Rate (IR)
= 0.5l/m³
= 0.05%
= IR (l/m³) x irrigation water (m³)
= 0.5 x 100
= 50l for each application

In order to check this concentration:

Fertilizer concentration in the tank
= fertilizer need (kg)/ water need at the tank (l).
= 5/50
= 0.1kg/l

Concentration in %
= 0.1kg/l x 100 (% factor)
= 10% solution

Check that this concentration is not too high at the tank for the specific fertilizer.

2 - Discharge:

Injection rate (IR)
= 100l/hr Water need at tank
= IR x hours of irrigation
= 100 x 0.5
= 50l.

Again, check the concentration of the nutritive solution.

Fertigation Practice

Dissolving Fertilizers

It is important to follow the guidelines laid down on page 43 when dissolving fertilizers.

In addition, tanks and connecting lines should be clean and free from any remaining solution from the previous irrigation.

When preparing fertilizer solutions:-

- Check that products to be used in the same tank are compatible.
- Fill the tank at least 3/4 with water and start to add small quantities of fertilizer, stirring continuously. Adding large quantities at one time will slow the dissolving process, especially those fertilizers that cause an endothermic reaction. This reduction in temperature may cause previously added fertilizer to precipitate.
- Once complete, top-up the tank with water and maintain agitation to complete the solution.

Always add fertilizer in the correct order, adding any acids or base products first. Make sure that the correct safety equipment is used.

When liquid fertilizers are used, take into account the increase in volume they will add to the tank and adjust the amount of water accordingly.

Tanks need to be cleaned before use as dirty tanks will result in problems

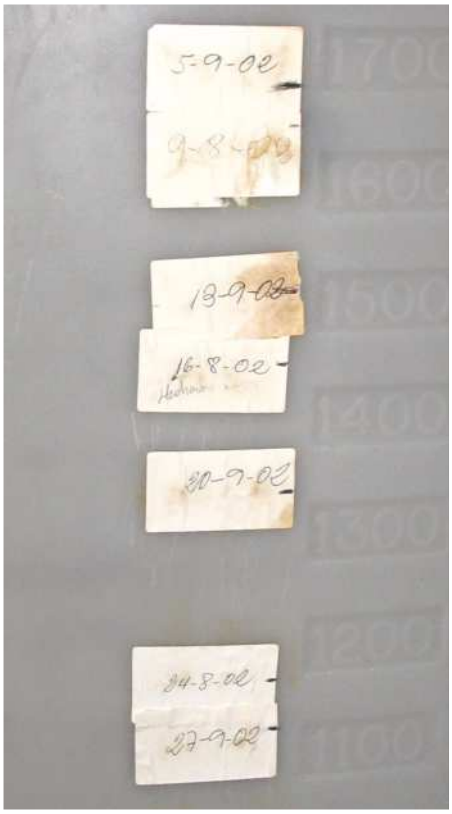
Adding fertilizer to a tank

Strirring until complete dissolution is important

Monitoring Injection

Adjust injection rates as needed and check for injection accuracy. This can be carried out by comparing levels in the tank, before and after application.

Leaks should be repaired, and all devices need to be checked to ensure they work properly.



Tanks with labels monitoring application levels

Pre and Post Irrigation

It is important to run the system without fertilizer for a period prior to starting fertigation.

In this way, pressure, flow rates and the area of the wetted bulb can be stabilized.

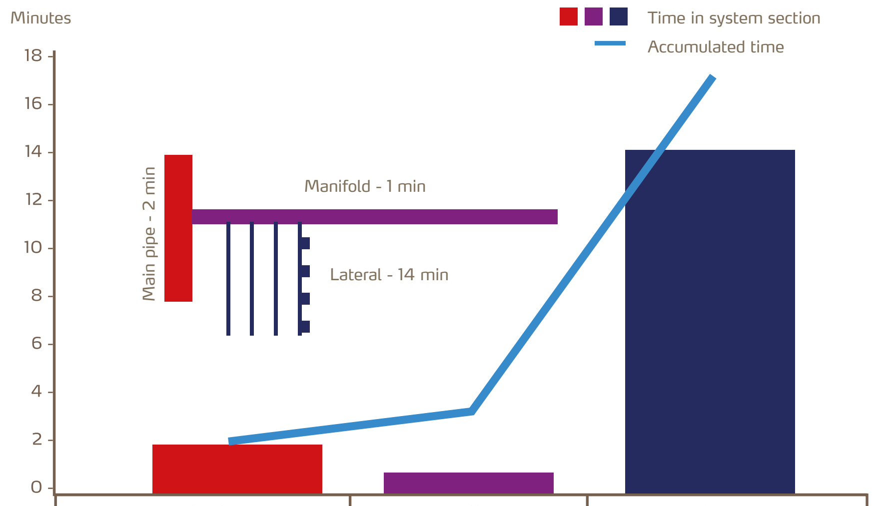
The time needed to stabilize the system largely depends on its design capabilities (Figure 57). This can be monitored by regular observation of pressure gauges.

Post fertigation management is even more critical. Get it wrong and over-flush the system and mobile nutrients such as nitrate and calcium can be leached out of the wetted bulb (Figure 58).

Again, the time needed depends only on system layout. A simple way to calculate this is to measure how long it takes for the water and the injected solution to reach the plot furthest away from the pump by assessing changes in EC of the solution from the last dripper in the line.

Figure 57

Example of Time Needed to Flush a System

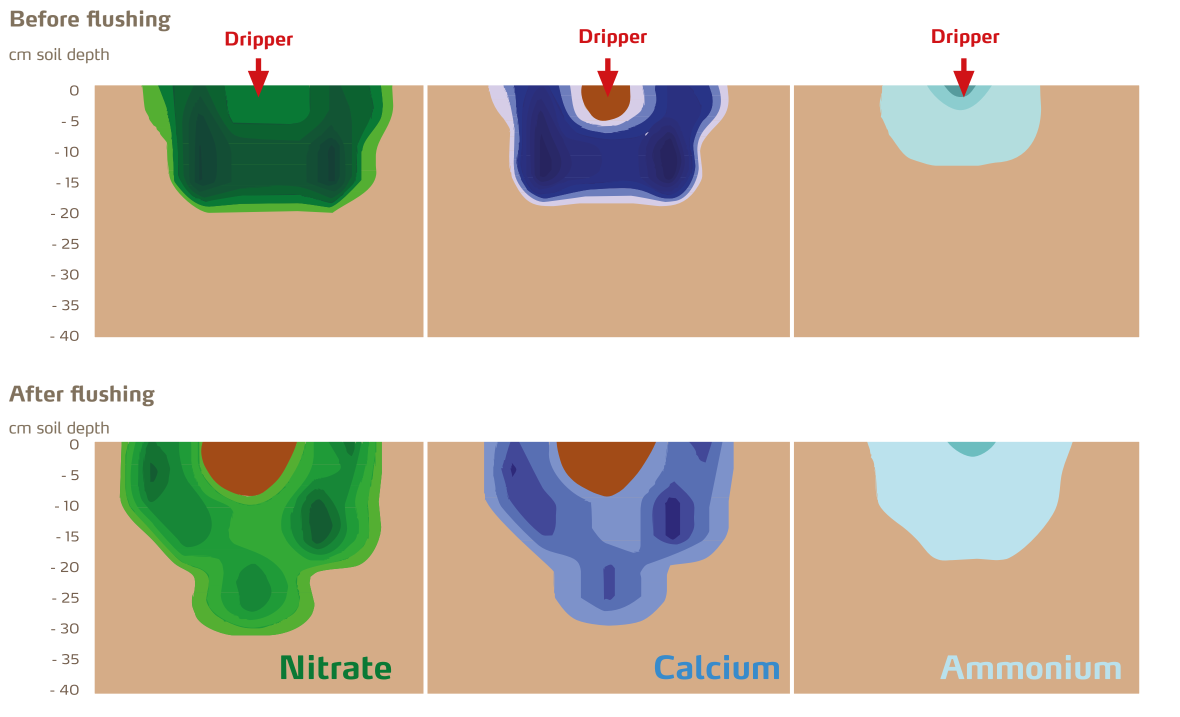


Main Pipe	Manifold	Lateral
Diameter 75 mm **Length** 100 m	**Spacing** 1.8 m **Diameter** 50 mm **Length** 50m	**Discharge** 4 l h^{-1} **Spacing** 0.5 m **Diameter** 20 mm **Length** 100 m

It is important that this is accurately assessed in order to avoid leaving nutrient solution in the pipe and drippers after irrigation, which can lead to clogging.

Figure 58

Potential Nutrient Losses from Post Irrigation Management



Dry clay loam 1 litre NPK fertigation solution + 250 ml clear water to clean pipes after fertilizer

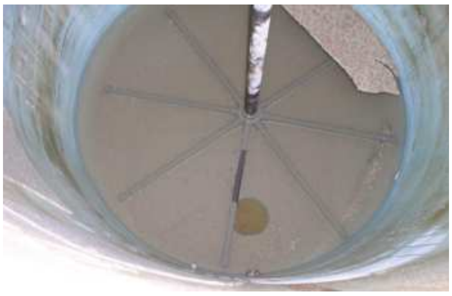
Cleaning the System and Acidification

Growers should instigate a regular maintenance program to clean the whole system.

This is particularly important for filters, injection devices, tanks, pipes and manifolds.

The system will fail to operate effectively if filtration is poor. Filters are likely to collapse when their surfaces become completely clogged, resulting in a corresponding fall in water pressure. So, it important to make regular checks.

It is also important to clean the whole system if it has been closed down for some time. Filters can become cemented with fine particles, again resulting in collapse.



Deposit from incompatible fertilizer

Precipitation from long term addition of micronutrients

To clean tanks, flush out and then dry to remove final deposits

Dirty filter

Always clean the tank before closing down the system, especially when you are going to use different fertilizer products when next fertigating.

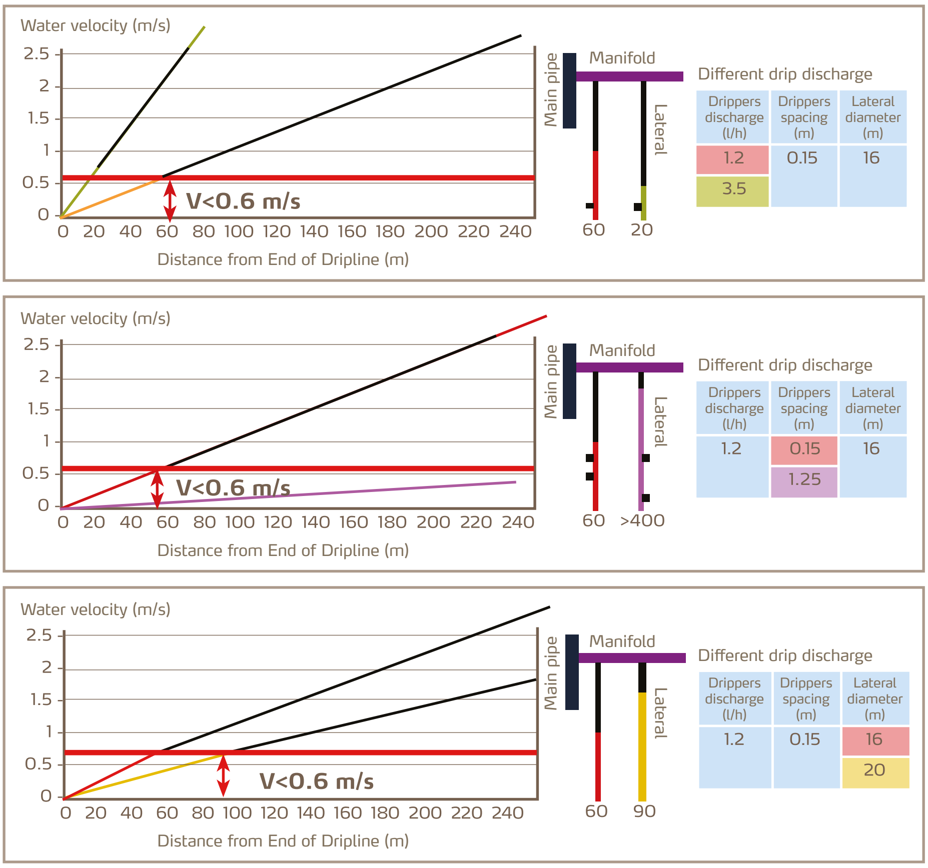
Pipes and hoses are also likely to collect a range of different sediments during operation and can collapse. The main problems are caused by small particles of clay and chemical precipitates, which are fine enough to pass through the filter mesh.

These materials tend to accumulate at the end of the pipes as the flow velocity slows (Figure 59). If this fine material reaches the dripper, it is liable to clog. Critical velocity is 0.6m/second.

Figure 59

Factors Affecting Water Velocity Inside a Lateral (Dripper Line)
Distance from the lateral end - under constant flow 0.6<V<3.0 m/s and pressure (1.5atm)

Critical velocity (0.6 m/sec) particles start settle down — No sedimentation problem



Occasionally, objects such as seeds and small animals can also be found inside broken pipework.

Once pipework has been repaired, the system needs to be flushed, using an increased operating pressure if possible

When flushing:

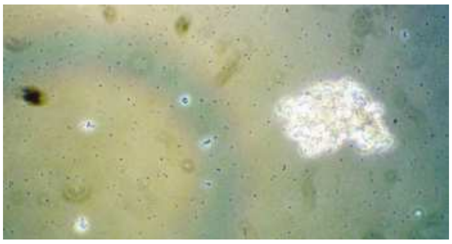
- Firstly, open the system and let water run through the complete system.
- Then, start to close each separate section, commencing with the upstream part when clean water is seen running through each section.

Flushing a lateral is particularly important after the use of acids or antiblock

The source of water may create different contamination issues. Surface sourced water (rivers, reservoirs) commonly contain more organic material whereas ground sourced water may have high mineral content. Correction measures will vary according to the source of contamination.

Bacteria and algae can flourish inside and also outside pipework, particularly where iron or manganese based fertilizers have been used. Algae can also be abundant where large open reservoirs are the water source.

Where these microbes are a problem, use products such as Antiblock O™, chlorine, or hydrogen peroxide to prevent build-up in the system. However, take care as some of these products can be oxidized and, either fail to work, or will damage plant roots. Also, the rubber diaphragm in some pressure compensated drippers can also be damaged by these products.

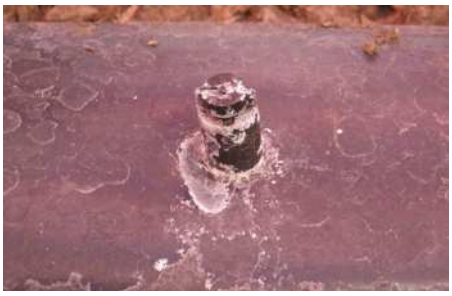


Treatment with Antiblock O™ will clean organic growths

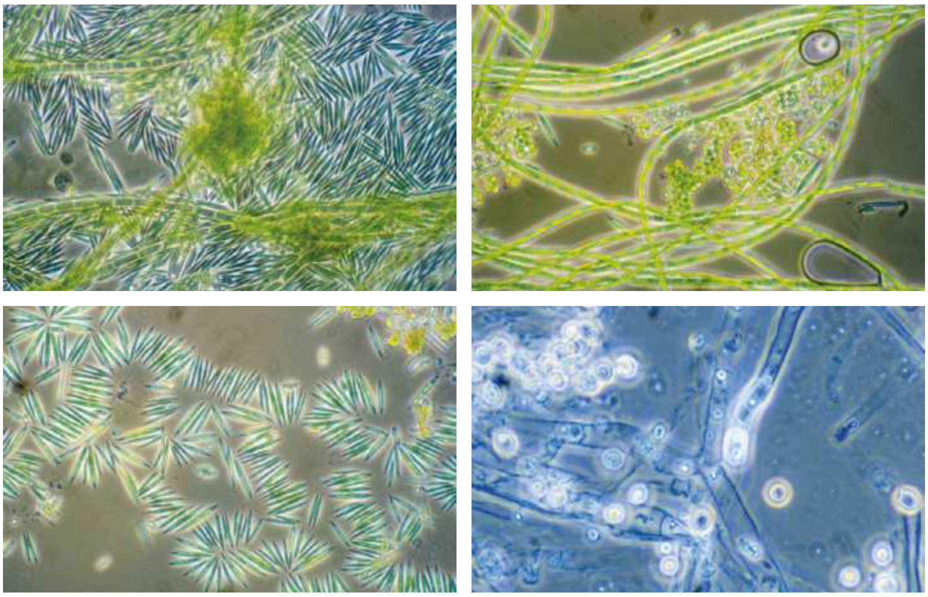
Algae can grow even outside the dripper under favorable conditions

Accurate rates of application are essential in these types of application.

Again, ensure the system is properly flushed after using this type of product.



All types of drippers are liable to clogging



Microscopic growth (algal or bacterial) will cause clogging

Remove contamination from tanks

Some water sources and, more commonly, nutrient solutions will leave precipitates in the system. For example, regular use of water with a high Fe and Mn content will result in scaling.

Some of the ways round these problems are to oxidize iron by aerating the system (see photo below).

In addition, high pH water, with a heavy carbonate and bicarbonate loading will react with Ca or Mg compounds leading to some precipitation.

Scales in pipe before and after usage of Antiblock O™

Solubility of most fertilizer compounds is best in low pH waters. Gypsum is an exception to this as it already has a low solubility rating - pH has no effect on this.

pH and EC meters at the head unit

Aeration tower for irrigation water

The acidity of the nutrient solution can also be lowered to pH 5.5 – 6.5, by using acids, minimizing precipitation. The Langelier Index helps provide an indication of the tendency of water to form Ca or Mg scales (see page 17).

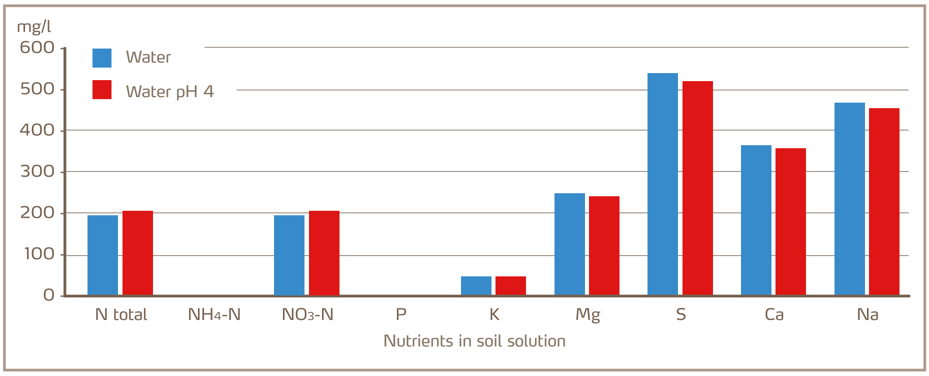
Acidification is purely a maintenance operation for the system, and has a minimal effect on nutrient availability (Figure 60), and no effect on soil pH.

Acidification can be achieved by selecting more acidic fertilizer products eg. Krista UP (see page 42, table 20). Alternatively, nitric, phosphoric and sulphuric acids can be used.

Measuring pH and EC in the field

Figure 60

Nutrient Availability and Fertigation Solution



The amount of acid to use will depend on the type of acid selected (the strength of an acid is expressed in mol of H^+ per kg of product, acid equivalent) and the water.

The rate of acid needed to overcome a specific water problem can be established using a laboratory titration curve.

As a practical rule of thumb, in order to reduce pH to 6-6.5, the amount of acid to be used in mmol/l will equate to the amount of bicarbonates and carbonates in the water (mmol/l) less a factor of 0.6.

To calculate the amount of acid, use the acid equivalent (Table 41) to calculate the kg/l need for the type of acid used. Adjustments due to the acid concentration may be required.

Volume can be calculated from a knowledge of the acid's specific gravity (Table 41). Sometimes, acid equivalent is given directly in base volumes.

Remember, all acids are dangerous and should be managed and handled properly using the right protective materials.

There are other products available, such as Antiblock M™ from Yara, which act as a retardant and minimize the likelihood of any precipitative reactions occurring within the fertigation system.

Best practice is to use these products continually, or regularly apply maintenance rates of acids.

Where acids are not used as a matter of routine, periodic cleaning should be carried out, using high concentrations of acids.

The recommended concentration of acid is 0.6% (6l acid per m^3 of water) and the process should start when the system is stable, with injection lasting for around 15 minutes (or that time needed for the acid to reach the furthest lateral).

In cases where clogging is relatively severe, acid solution can be left in pipes for a few hours providing plenty of time to dissolve the precipitate or scale. The system will then need flushing with clean water for around an hour.

Such an operation will not work where the system is fully clogged. Acids will not dissolve and remove all of the precipitate inside a dripper. No curative product is available to clear blocked systems, thus it is important to establish a maintenance programme using acids on a regular basis.

Table 41

Acid and Base Product Properties

% in w/w Mol/kg	N-total	NO_3-N NO_3^-	Urea N	P_2O_5 $H_2PO_4^-$	K_2O K+	SO_4 SO_4^{2-}	Acid input Mol H^+/kg	Density g/l
Nitric acid (56-59%)	12	12						1.35
		8.9					8.9	
Phosphoric acid (72-74%)				5.3				1.61
				7.4			7.4	
Sulphuric acid (97%)						93		1.84
						10.01	20.0	
KOH (34%)					28.2			1.33
					6		-6	
Krista UP			18	4.4				
			12.9	6.3			6.3	

Example: Continuous acidification

1) Water with 2.6mmol/l Bicarconate and zero carbonates

2) Nitric acid, (56%) with 8.9mol/kg H^+ and density of 1.35g/cc

The amount of bicarbonate needed to be neutralized: 2.6 – 0.6 = 2mmol/l of Acid

Amount of acid needed for neutralization
= 2/1000 (mmol/l to mol/l) x 1000
(kg to g)/8.9 (acid equivalent)
= 0.225g/l

Or in volume terms... 0.225/1.35 (specific gravity for nitric acid)
= 0.166cc acid/l water
= 0.166l acid/m^3 of water
This neutralization with nitric acid (N content = 12%) will also supply 0.027g N/l or kg N/m3 or 27kg N in 1000m^3 of irrigation.

Monitoring the System

Growers need to regularly check irrigation systems to ensure all plants receive the water and nutrients they need.

The two main checks carried out for this purpose are a pressure check and dripper discharge.

Pressure tests should be carried out when every dripper is functioning properly. The main aim is to identify any unexpected falls in pressure within the system, such as broken pipes or poor connections.

Drippers need a minimum pressure to operate effectively and discharge accurate amounts of water and nutrient. Normal operating pressures range between 1 to 4 bars.

Do not mix dripper types

Pressure Gauge for monitoring pressure in different parts of the system

Collecting water from drippers

Sampling drip discharge

Any variance between **dripper discharges** within a system will result in uneven growth and yield.

In this respect it is important not to mix dripper types within a plot, as this will invariably lead to poor nutrient and water distribution.

Discharge uniformity, (Table 42) should be evaluated as a part of a normal maintenance programme, using the calculation illustrated in the text below.

The following guidelines have been established for uniformity.

Table 42
Guidelines for Showing Uniformity Coefficients for Variances in Discharge ASAE Category

60% or less	unacceptable
60-70%	poor
70-80%	fair
80-90%	good
>90%	excellent

Table 43
Example of Uniformity Coefficient (UC) Calculation for the drippers on one lateral

Drippers	Lateral A Seconds/100cc
1	72
2	75
3	67
4	67
5	69
6	69
7	67
8	62
9	70
10	69
11	63
12	70
13	70
14	67
15	67
16	61
17	71
18	67
STD	3.5
AVG	67.9
UC	0.9
ASAE Category	95%
Category	Excellent

Drip suppliers provide a manufacturing coefficient of variation for each model as a result of variances in the material and production process. This varies according to each dripper model.

Clogging will also significantly affect uniformity coefficients by reducing discharge. Changes in pressure can also be a problem; where pressure drops, discharge rates fall, with the result that there are even greater differences between drippers across the system (see example Table 43).

Assessing Uniformity Coefficient

The process will take some time when carried out properly.

The main parameter to measure is the time taken to discharge 100cm3 or the volume filled in a given time.

1) Select and test three laterals. One should be upstream and close to the head unit, another at the furthest extent of the system, the other somewhere in between.

2) If you suspect clogging, select laterals that are furthest down-slope in the plot, as solids particles tend to accumulate in these sections.

3) Mark and number 18 drippers in each of the selected laterals.

4) Run the system at normal pressure, and, when pressure is stable, record the amount of time needed to discharge $100cm^3$ from each dripper.

5) At the same time, check on the system's pressure at various points. This can help when it comes to analyzing the results.

6) Once all results are collected, calculate the standard deviation (STD) of the discharges from each lateral. Then calculate the average (AVG) value of the series. The relationship of the STD/AVG is the coefficient of variation (CV) for the drippers. Uniformity is 1-CV= 1-(STD/AVG) and multiply by 100 to get the %.

Troubleshooting

This section aims to help the reader to identify some of the most common causes of malfunction in the fertigation system. It is not a complete list of all possible scenarios and eventualities, but does cover most commonly occurring problems, even if they seem obvious.

Hydraulic or system operations

Pressure is too low

Possible causes:

- Pressure gauge is not functioning.
- Pressure gauge is located incorrectly in the system.
- Valves in the system are not open.
- Main pump has failed.
- Upstream main valve is closed or partially closed.
- Pressure regulators in the line have failed.
- Major leak in the system.
- Other plots are irrigating simultaneously or the valves in these other plots are malfunctioning.

Pressure too high

Possible causes:

- Check pressure gauge and connections -the outlet valve could be closed.
- Check all valves in the system including one-way and plot valves.
- Automatic plot valve system has failed - check electrical wires or hydraulic micro hoses.
- Filter system is clogged.
- Irrigation plot is too small for the system.
- Check devices for main pump - frequency variator malfunctioning.
- If pressure is increasing in the same plot every time - check the emitter to see if it is clogged.

System discharge too low

Possible causes:

- Check main pump.
- Check flow meter is functioning.
- Main plot valve is closed or partially closed.
- Air is in the system.
- Possible leak in the system.
- Emitters are clogged.
- Filters have collapsed.

By-pass tank still contains fertilizer at the end of the irrigation

Possible causes:

- Pressure differences across the pressure tank are too small – adjust valves if needed.
- Increase the flow into the tank. If it is already at its maximum setting - increase size of connection pipes, and inlet-outlet fittings.
- Irrigation time is too short to empty the by-pass tank.
- Fertilizer quantity is too high for the current system.

Injectors do not perform as planned

Possible causes:

- Check hydraulic conditions (pressure and water volume) in the injectors.
- For Venturi injectors, adjust either the pressure or system discharge changes at each operation - for each different plot.
- Check injection rate is properly adjusted.
- Valves of feeding tanks are closed or partially closed.
- Control filter for feeding tank is clogged.
- Injector has failed.
- Check that the discharge point at the head unit is not clogged.
- When working with high density solutions, injection rates should be adjusted accordingly compared to using straight liquid fertilizers.

Excessive or increased clogging problems at the emitters or inside the system

Possible causes:

- Check filtration equipment is functioning and not partially clogged, or broken.
- Filtration system is not suitable for the specific conditions.
- Check filter back-flush procedure (cleaning process).
- Check fertigation plan
  - Compatibility of fertilizer used.
  - Water quality.
  - Nutrient concentrations.
  - Interactions.
- Dissolving process for fertilizers used.
- Check for changes in fertilizer or water quality.
- Post-irrigation scheduling is not adequate or not carried out.
- Water treatment is needed due to changes or variations in water quality.
- Changes in the hydraulic properties of the system – e.g. irrigated area is larger than that originally planned for the system. This will reduce the velocity of water in the system leading to an increased settling of particles, which then accumulate and cause blockages.
- Leaks in the system can lead to soil or other material being introduced into the system – e.g. (suction of air and other material inside pipeline while working).

Head unit maintenance is essential

Poor Plant Performance

Don't rule out the effects of other operations on the farm. However, some common problems due to fertigation system malfunction include:-

Wilting

Possible causes:

- Insufficient water supply - check fertigation plan and/or system performance.
- Insufficient leaching resulting in salt stress.
- The water moves too fast through the soil or media. Adjust the fertigation scheduling or the system layout – check the irrigation times and quantities.

Yellowing

Possible causes:

- Too much water is applied.
- Lack of iron or N (see pages 22 & 27).
- Poor emitter placement – insufficient emitter numbers, or discharge rates are too high.
- Fertigation scheduling is insufficient -adjust to ensure sufficient nutrient is
- reaching the plants.
- Incorrect fertigation plan - adjust to correct nutrient balance.
- Soil condition (mainly pH) needs correction, or proper maintenance.
- Too much acid applied during cleaning operations.
- Climatic conditions – e.g. too cloudy and so too much water supplied.

Scorching

Possible causes:

- Damage due to salt accumulation
  - Over application of fertilizer.
  - Insufficient leaching for the specific crop.
  - Water quality changes – e.g. an increase in total or single salt content.
- Check nitrogen form and potassium source. Relative sensitivity is specific to each crop.
- Crop is especially sensitive to use of fertigation through sprinklers or center pivots.

Plant growth is stunted or too vigorous

Possible causes:

- Check the nutritional plan for shortages, imbalances or excess nutrient applications.
- Check the timing of fertigation.
- Water quality does not suit the crop or needs to be neutralized.
- Salt content and crop tolerance
  - Water quality is unsuited to crop.
  - Fertilizers concentrations are too high or too low.
- Climatic conditions have varied (usually cloud cover) - adjust fertigation programme accordingly.
- Check soil and water analysis for nutrient status and interactions.
- Excessive post irrigation time can lead to leaching of mobile nutrients.

Uneven crop

Possible causes:

- Check the system for uniformity of distribution
  - In the same plot.
  - Between plots irrigated at the same time.
- Due to soil type variations or micro climatic conditions – modify system layout, insert correction injectors at plots, or use foliar application to compensate.
- Irrigation scheduling is inadequate - irrigation time is too short and head units are too far from the plot. This may lead to fertigation plans between plots being mixed during normal operation.

Uneven distribution of water creates problems

Glossary

Acidification (of the fertigation system): The reduction of the fertigation solution pH by the addition of acids.

Alkali Index: See page 16.

Anoxia: See page 11.

Bulk Density: The weight of soil particles in a given volume of soil. It is affected by particle type, size, porosity, carbon and organic matter content. It varies from 1 to 2.1g/cm^3.

Chelates: Organic compounds that protect cations from precipitation in the soil.

Chemigation: Application of pesticides, fungicides, disinfectant or any needed crop chemicals through the irrigation system.

Crop Coefficient: See table 24, page 48.

Diffusion: The movement of chemical in the soil due to thermodynamic forces. See page 18.

Dispersion: See page 18.

Dripper: See page 34.

Electrical conductivity (EC): Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water by measuring the electrical current across the solution. Pure water has an EC of 0. (ECex, ECn, ESP) See pages 15 to 17 & 39.

Emitter discharge: The volume of water in a given time that any emitter supplies. Usually measured in l/hr.

Evapotranspiration: See pages 46 to 49.

Fertigation: The supply of nutrients within irrigation water as a nutritive or feed solution.

Field Capacity: See page 8.

Head unit: That part of the fertigation system where chemical (chemigation) or fertilizer (fertigation) is added to the irrigation water.

Hydraulic Potential: See page 8.

Infiltration: The process of penetration or movement of water and nutrient with the soil or growing media.

Kc Coefficient: See page 48.

Langelier Index (pHc): See page 17.

Lateral: The last pipe or hose within the fertigation system, where the emitters are located.

Manifold: The pipes that feed the laterals. One manifold will feed all the laterals in one irrigation unit - All the manifolds combined, comprise an irrigation or fertigation plot.

Mass Flow: The movement of chemical (nutrient) into a soil profile with water. It is the main transport mechanism for plant nutrition. See pages 18 to 26.

Matric Potential: See page 8.

Mesh: The unit used to measure the degree of filtration for a given filter. Defined as the number of pores (holes) in one inch.

Micro irrigation: Irrigation techniques based on applying small volumes of water over a given time using pressurised systems.

Micro sprinkler: The emitter used in micro irrigation with a high-medium discharge rate.

Net Irrigation Need (Ni): See page 49.

Osmotic Potential/Osmolarity: See pages 8 and 16.

Pressure Potential: See page 8.

Pre and Post Irrigation: The period of time used to stabilize pressures within an irrigation system when commencing fertigation. Post irrigation is the time needed to flush the system with water after fertigation has ceased.

Salinity/Saline soil: The presence of salts in a solution or a soil. When related to fertigation, it refers to the unwanted salts in the water, or in the soil, which can adversely influence crop production or soil management. Depending on the type of salts, the salinity is described as sodic (Na), or saline sulfate (S), etc.

SAR: See page 16.

Saturation Point: See page 8.

Scott Index: See pages 16 and 17.

Shaded Area Coefficient (Kr): See page 49.

Sodium Carbonate Residual (SCR): See page 16.

Soil Potentials (Hydraulic, Osmotic, Matrix, Gravity): Forces in the soil solution that influence water uptake. See pages 8 to 9.

Uniformity Coefficient (UC): The difference in absolute terms between the emitters with the bigger and the smallest discharges in any give area. See page 69.

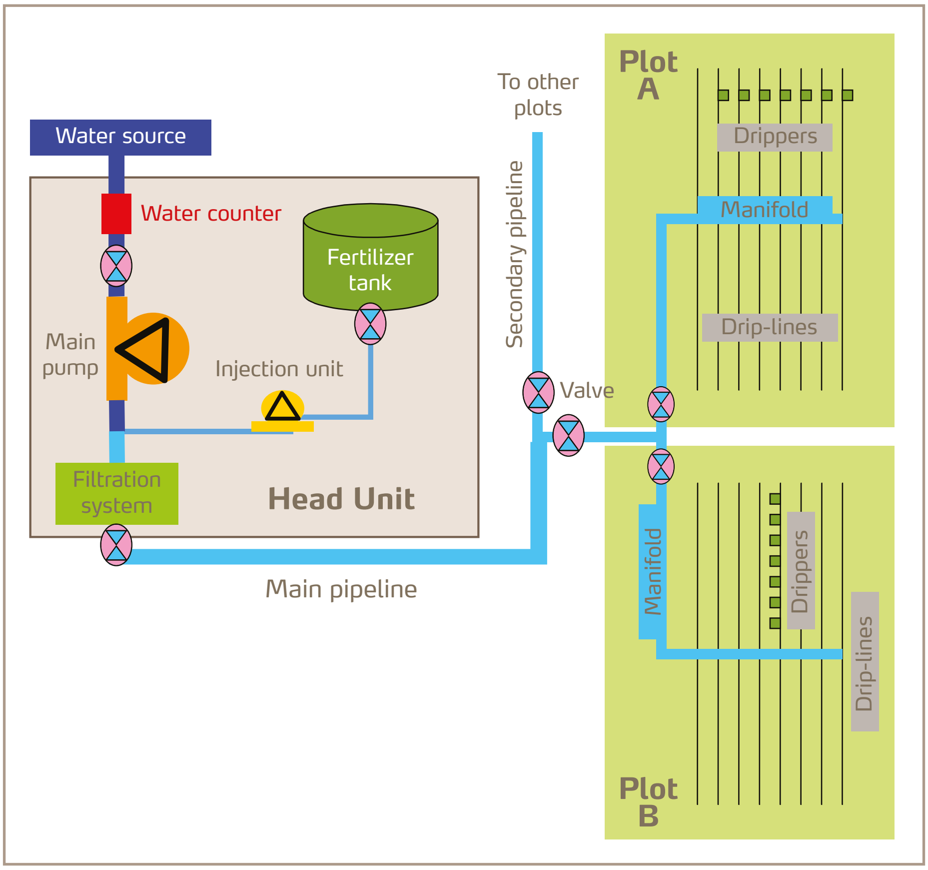
Wetted bulb: The area of the soil where water and nutrient are concentrated.

Wilting Point: See page 8.

Figure 61

Basic Plan for a Fertigation System

Upstream head unit



This reference diagram illustrates the basic components of a fertigation system. It can be referred to when reading the text.

Units

The units used within this manual are largely those used and quoted by the authors or the source in their country of origin. Where applicable, metric equivalents have been used.

Nutrient uptake figures are quoted in the elemental form. Within the main nutrient chapters, particularly where dealing with fertilizer rates, oxide forms are more commonly used.

Converting oxides to elemental form

P_2O_5 to P	**multiply by 0.437**
K_2O to K	**multiply by 0.83**
SO_3 to S	**multiply by 0.4**
CaO to Ca	**multiply by 0.715**
MgO to Mg	**multiply by 0.603**

Some equivalents

- 1% nutrient content = 10kg per tonne OR = 10 gram per kg
- 1ppm = 1 gram/m^3 of water when the specific weight of the water is 1kg/l.
- One l/m^3 = cc/l

Yara staff took all photos in this manual unless otherwise stated.

Unless otherwise stated, all tables and figures are based on Yara's own research programmes, trials or field experience.

For further information contact:
Yara International ASA
Postboks 343, Skøyen
0213 Oslo
Norway
www.yara.com

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