HYDROPONIC NUTRIENTS

Easy Ways to Make Your Own

A CULTURAL HANDBOOK by M. Edward Muckle

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3RD Edition

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by

M. Edward Muckle

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Foreward

This is the third printing of a book which growers of all levels of expertise have found useful. The revisions and expansions contained in this edition are extensive. Over 100 pages have been added. The information will be useful to a wider range of growers and is the most current published anywhere.

For those of you who are nervously considering making your own plant foods for the first time, relax. If you can read and use a calculator you have all the expertise you need to get started. Much has been published in the "popular press" about the topic of organic versus chemical fertilizers. The best I can do for those who are confused about the conflicting information is provide a short explanation of how plants feed.

Unlike us humans, plants can only take up minerals which have been dissolved in water. They have no teeth so whether the calcium is contained in a 'chemical' fertilizer or cow manure is of no concern to the plants. The calcium must be removed from the source and dissolved in water before it is available to the plant.

For the organic approach to plant nutrition a lot of organisms are involved in releasing the plant nutrients (minerals) from the cow manure so water can dissolve them. If you waited that long in a hydroponic garden, your plants would starve to death. We can create 'manure teas' to use in a hydroponic garden. What you have to go through to do this will clearly demonstrate that there are easier ways of feeding your plants.

There is no such thing as an "organic" mineral. Calcium is calcium no matter how many times it has been through the cow. It is exactly the same calcium as you will obtain by dissolving a fertilizer which has been made by combining calcium and nitrogen into a stable salt called calcium nitrate. By embarking on creating your own nutrient solutions for your plants you are directly addressing the nutritional requirements of your plants with no intermediaries. Hydroponics is, very simply, feeding plants instead of feeding dirt. The organic method is really just feeding dirt and hoping a huge colony of bacteria, micro-organisms and other critters such as worms finally make those essential minerals available to the plants.

Learning to create your own nutrient solutions and formulations is the first step on the road to vastly improving the productivity of your garden. As time goes by and you experiment further you will find that a properly formulated nutrient will boost production in any type of garden, no matter where it is. I know wheat farmers on the prairies who boost yields by applying a full formulation nutrient solution as a foliar spray two or three times a year.

All the information you need to get started is in this book. I have tried to present the information in a simple, easy to follow format. There are times when you will run into new words, instead of just skipping over them, grab a dictionary and you will get a lot more out of this book.

Since 1939 when Arnon and Stout published "the criteria for essentiality" growers have followed the advice of researchers who have looked at only part of the picture of plant nutrition. Here are the criteria which have governed their work;

"1. Omission of the element in question must result in abnormal growth, failure to complete the life cycle, or premature death of the plant.
2. The element must be specific and not replaceable by another.
3. The element must exert its effect directly on growth or metabolism and not by some indirect effect such as by antagonizing another element present at a toxic level."

I find this type of restriction *"If it doesn't kill or maim by being missing"* just a bit limiting. I prefer to follow another broader rule of investigation,

"If it causes a beneficial effect, it bears investigation."

Plants evolved on a planet which is composed of all the elements in the periodic table. Some are toxic in even tiny quantities, all are toxic in excessive quantities and some the plants seem to be able to ignore even if they absorb them. Gold is routinely found in tissue analysis, yet no one knows why it is there and lettuce is a great arsenic accumulator, and again no one seems to know why.

The fact is that there are more questions than answers and everything in this book can only act as a guide to what has been discovered to date and what has worked successfully. With this in mind you will forgive me if I classify the plant nutrients in a slightly different fashion than what you may have read in other texts or articles. Instead of the Macro, Secondary and Trace division of nutrients, I have found it more beneficial to work with :

FREE

Those elements we can enhance but which are generally provided by the air and water.

MACRO

Those elements which are historically soil sourced and which can comprise up to 1% of the dry weight of plant tissue.

TRACE

Those elements which are historically soil sourced and are found only in parts per million of the dry weight of plant tissue.

Traditional thinking dictates that there are 16 elements essential to plant growth. My viewpoint is that there are at least 18 elements we can manipulate to advantage now, and probably another half dozen we will learn to beneficially manipulate in controlled environments as knowledge is increased.

I hope that you will, when finished first reading of this book, come to the realization that all elements discussed are essential to plant growth and that no one single element can be called the 'most important'. Nutrient formulation is the technology of arriving at the optimum balance of elements and compounds which provides plants with everything they need for maximum productivity.

I will emphasize again that this is an introductory text. All of the answers about manipulating plant nutrition and formulation are not in this book. I am preparing a more advanced text at the time of this printing and if you will to pursue the topic further, drop me a line care of Growers Press and I will let you know when it is available.

Chapter One

Hydroponic Nutrients

Fully Formulated Plant Food

An Introduction to Plant Nutrition

The first step toward being able to create your own hydroponic nutrients is understanding the difference between those bags of soil-amendment fertilizers you are used to and, the reality of actual fertilizer composition. In addition, you need a guideline against which to measure the completeness of any fertilizer intended for hydroponic applications.

Hydroponics gives the gardener a control over the feeding of plants which is not available in any other type of garden. For the purposes of this discussion we are defining hydroponics as any system of growing in which we are feeding the plant not soil or some other substrate. In other words the nutrients are dissolved in water and as such are immediately available to the plant.

To accomplish this it is necessary to use nutrients which are in fact complete nutrients;

NOT soil supplement fertilizers.

There is no soil supplement fertilizer which is in fact a complete nutritional package for a plant. In addition soil supplement fertilizers are generally made from a lower grade of ingredients than hydroponic nutrients. This means an unwanted level of contamination in soil fertilizers.

Most gardeners are familiar with the N P K numbers which are listed on every fertilizer of any type manufactured to-day. Very few gardeners actually know what these numbers mean.

FOR EXAMPLE:
What does 20-20-20 really mean?
Is it as most gardeners think?

20% Nitrogen	(N)
20% Phosphorus	(P)
20% Potassium	(K)

NO IT IS NOT!
WHAT IT REALLY IS, IS

20% Nitrogen	(N)
20% Phosphorus Pentoxide	(P_2O_5)
20% Di-Potassium Oxide	(K_2O)

WHICH TRANSLATES IN ACTUAL % OF N P K TO:

20% Nitrogen	(N)
8.8% Phosphorus	(P)
16.6% Potassium	(K)

A good **HYDROPONIC PLANT NUTRIENT** will contain all of the elements necessary for plant growth

IN THE PROPER RATIO TO EACH OTHER.

Many novice hydroponic gardeners are misled by reading the labels on plant foods without understanding the ratios which should be present. They assume that because all of the symbols are shown that all of the necessary elements are present in the proper quantities when nothing could be further from the truth.

The elements which must be in the nutrient formulation are commonly divided into two groups; The **MACRO-ELEMENTS** & The **TRACE ELEMENTS.**

The **MACRO-ELEMENTS** ARE:		% ratio
Nitrogen	(N)	21.287345%
Phosphorus	(P)	6.244288%
Potassium	(K)	28.383127%
Calcium	(Ca)	21.287345%
Magnesium	(Mg)	5.960456%
Sulphur	(S)	11.353250%
The **TRACE ELEMENTS** ARE:		
Iron	(Fe)	4.825131%
Manganese	(Mn)	0.454130%
Zinc	(Z)	0.045413%
Copper	(Cu)	0.011352%
Boron	(B)	0.141915%
Molybdenum	(Mo)	0.005676%
Sodium	(Na)	0.000283%
Chlorine	(Cl)	0.000283%

You will note the ratios do not add up to exactly 100% but then I could have gone a lot more decimal places too! There will be a change in the grouping of these elements later in the book for reasons which will make complete sense, I hope. Here thery are grouped simply by the concentration generally provided in the formulation.

The ratios shown above are a general guideline only for a multi-crop hydroponic nutrient mix. The above balance of minerals will grow just about anything. There are additional elements which may have impacts on plant growth and physiology. At this time we simply do not have enough information to identify them. Ensuring that you make all of the potentially unknown elements available in the naturally minute quantities needed for growth is as simple as adding a teaspoon of seawater per gallon of nutrient solution.

Growth and yield of any plant species can be optimized by creating a formulation specifically designed for the variety being grown and the specific environment and cultural technique. The ability to manipulate the ratio's between the elements for various stages of growth is a precision tool available only to the hydroponic gardener.

Considerations in Choosing formulas and concentrations

The second method of nutrient manipulation available to us is the concentration of nutrient solution that we use. The general guidelines that we follow are quite simple since they correspond to the different stages of growth of the plant. Common sense tells us that a small seedling is not going to require the same strength of solution, frequency of feeding, or formulation, as a ten foot tomato plant carrying 10 trusses of fruit. The same common sense tells us a lettuce plant does not need as much food as that big tomato plant.

So how do we categorize the plants, the formulations and the concentration of nutrient solution required?

---

1. The age of the plant.

2. The stage of growth - seedling
- vegetative
- fruiting
- flowering

3. The type of plant - tropical
- vegetable
    - green
    - fruiting
    - root
- flowers
- cacti & succulents
- trees & shrubs

4. What we want the plant to do.

Lets take the example of a pepper plant grown from seed then transplanted into a hydroponic recycling system with an aggregate in the pots.

For the sake of this example we will consider the strongest solution to be 100%. The specific methods of measuring concentration are covered in a later chapter. For the moment we will stick to simplicity.

STAGE OF GROWTH	**CONCENTRATION**	**TYPE OF SOLTN**
seedling	75%	rooting
transplant	100%	rooting
vegetative	100%	vegetative
flowers	100%	flowering
pepper growth	100%	flowering
ripening	75%	flowering
new flowers	100%	flowering

and so on.

You will notice in the example that I have combined both the solution strength and the manipulation of the element ratio at the various stages. In practice in small hydroponic systems, especially those with a number of different types of crops we would simply use a single solution such as the one outlined in the above chart on the elements. The above example does however give you an idea of the type of manipulation available.

The solution strength and frequency of feeding is also affected by the type of hydroponic system you are using. No two systems are handled exactly the same in irrigation so never make the assumption that what you are going to do is the same as your friend who has a garden unless your garden is in fact identical to his. There are a wide variety of garden systems and types as the following list shows.

LIST OF GARDENS USING NUTRIENTS

Classified according to feeding techniques and medium.

SUPPLEMENTARY FEEDING

SOIL

Outside garden
Soil in containers
Soil & manure mixes w/lime in containers
Soil & manure mixes w/o lime in containers

COMPLETE FORMULA FEEDING

SOIL-LESS MIXES

Potting soil in containers
Soil-less mixes in containers handwatered
Soil-less mixes in containers Beta watering
Soil-less mixes in containers drip from tank
Soil-less mixes in containers injector systems
Soil-less mixes in Tropical planters (wick)
Vegie Patches w/ soil-less mixes
Poly planter systems
Tank recycling systems
    ; drip return
    ; flood and drain
    ; spaghetti
Gericke Systems

ROCKWOOL SYSTEMS;

propagation
recycling
one-way drip

AGGREGATES

Luwasa systems w/ hydro-stones
Vegie Patch w/ hydro-stones
City Green Gardens
    (Air pump powered)
Tank recycling systems ; drip return
    ; flood and drain
    ; spaghetti hose

WATER CULTURE SYSTEMS

Ebb & Flow
NFT ; trough
    ; layflat
    ; hypertonic feeding
    ; bifutricated root
      w/ hypertonic feed

AEROPONIC systems

; propagation
; growing

The foregoing list is by no means complete as to the number of specific types of gardens in use to-day. It does cover all of the technologies in common use. In the normal commercial greenhouse you will find only one of four or five systems in use. It is the hobby growers who tend to experiment with every system they ever hear about.

Add to this list the incredible variety of plants available to grow plus all of the environmental factors and you begin to see that there are reasons why nutrient formulas are different.

We have always had the plants going for us. Their incredible survival instinct and ability has enabled them to grow and adapt in very non-optimum situations. The most common cause of these non-optimum situations is a nutrient diet which is completely unbalanced. Plants growing under adverse conditions will genetically adapt to those conditions within a very few generations. They grow, they survive; but they do not produce anywhere near their optimum genetic potential.

Comparing the results achieved with poorly formulated fertilizers in minimal environments to outside results in adverse environments usually shows an improvement in production. Unfortunately many people take these results as being good when they are in fact terrible. The potential for plant growth and productivity under optimum genetic conditions is unknown to the majority of gardeners and most of the so-called experts. The only way of achieving the truly potential results is knowledge. Knowledge of every aspect of plant growth.

Nutrients are only one factor affecting plant growth, there are others equally important and all are directly inter-related. In this book we will deal only with basic nutrient formulation so you can get started in making your own nutrient formulas. It is up to you to apply this knowledge to best advantage and to balance this knowledge with study in all other areas so you can achieve the full potential of your hydroponic garden.

The real aspect of optimum production in any hydroponic system is being able to provide your plants with the precise combination of nutrients they require. Doing this is actually quite easy. You will not be an expert overnight but you will be able to immediately cut your nutrient costs and provide a better balance of nutrients to your plants. As you work with your garden your plants will tell you what you are doing right and what needs correcting.

The easy way to start is with the tried and proven formulas and then adjust from there. For a complete book on nutrient formulation, complete the pre-order blank for the book "The Magic of Nutrient Formulation", to be published by Growers Press Inc. This book is designed to get you started on making your own plant nutrients as thousands of other hobbyists have been doing for years.

NOTES

Chapter Two

The Ingredients of Nutrient Formulation

As with any other process the quality of the ingredients determines the quality of the end product. The cost of the best quality ingredients for your formulas is actually very cheap. You use so little that most hobby growers will want to purchase the ingredients by the pound rather than the sack.

When creating formulas for a hydroponic nutrient we are determining what will be fed directly to the plant. Imagine your horror if you saw your mother baking a cake using contaminated ingredients. We have the control potential in hydroponics to ensure your plants are never exposed to such a disaster. That is a lot more than organic gardeners can say.

Along with this goes the caution that you must forget the old adage; "If some is good more is better". A formulation that works well will simply kill your plants if you attempt to double or triple the dosage to make things go faster.

The first thing you need to do is get a water analysis of the water you will be using in your hydroponic garden.

I cannot stress enough how important this is.

Most people are totally unaware of what the water they drink actually contains. Never use water that has been run through any sort of a water softener. These units put sodium into the water in quantities which are toxic to plants and frankly are not very good for people either.

The cost of a simple water analysis is generally under $50.00. Once you receive the results of the analysis you have several options for getting advice. The store where you buy your nutrient salts, your local extension agent, the local university, area commercial growers, are just a few of the potentials. If all else fails you can write to me: c/o Growers Press Inc. P.O. Box 189, Princeton, B.C., Canada V0X 1W0 for advice if you are unsure of how the analysis will affect your nutrients. Water analysis can be obtained from local health departments, private labs, extension agents or your local water company.

You need to know the exact content of the salts you are using to create your nutrients in order to be able to do a proper formulation. Just any old salt will not do. Listed in this booklet are the analysis of the salts most commonly available and used by commercial growers. All salts are not the same and if your local supplier cannot provide you with equivalent information on their products save your money and your plants; buy from someone who can provide you with the exact information you require. Some fertilizer salts that are quite acceptable for the field grower are close to useless in your garden, in fact they can be dangerous.

On the following pages we have included some quick calculation information on each of the commonly used salts to make your calculations easier. At this point you may not understand these calculations. That is OK. As you get into the later information it will make more sense. This just saves me printing it a number of times. For the moment I will explain the quick calculation charts.

SALT	**1 gm/l = PPM**	**ELEMENT/ COMPOUND**	**Required PPM X multiplier = gm/l of salt needed**
Under this heading is the common name of the fertilizer salt, purity, and the chemical formulation.	In this column are the list of the elements, and or compounds, which are provided if you dissolve one gram of the salt in one liter of water.	The chemical symbol of the element or compound which is listed in the PPM column and the Required PPM Multiplier column on the same line.	This is the number you would use to find out how many grams of the salt you need to provide a specific PPM of an element. To do this you take the PPM required, multiply by the number and the result is the number of grams you will need for every liter of solution.

The multiple uses for this information will become evident as you proceed through the following chapters. Just about now I can hear some readers beginning to scream, "What happened to ounces and gallons?" Well the fact is they have never been anywhere near the serious grower.

One of the problems is the fact there are two different gallons in common use. When you get a formula from someone in Canada (Imperial measure common; sometimes) who borrowed it from someone in the US (US gallons; mostly) the only way you can be sure of the amounts is if it is in grams and liters. The other problem is the insane calculations required to work with fractions of ounces.

Do yourself a favour and simply work in metric, that's the grams and liters system. If you absolutely have to, use the conversion chart in the Appendix to convert the results to ounces and your own particular brand of gallons. Eventually you will give up on such foolishness, especially if you start to get formulations from around the world.

Read through the information on the salts and then have a look at the tried and proven formulas. Once you have done that we will go through the basic procedure for creating and making up a nutrient formula from scratch. The same process can be used to adjust an existing formula.

GREENHOUSE GRADE CALCIUM NITRATE

15.5-0-0

Description; The product is a refined, prilled, highly soluble material consisting of calcium nitrate - Ca $(NO_3)_2$ - with 5.7 - 6.5% ammonium nitrate (NH_4NO_3) and approximately 15% water of crystallization.

Typical Analysis;

Total Nitrogen (N)		15.5% min.
Nitrate Nitrogen (NO_3)	14.5%	
Ammonium Nitrogen (NH_4)	1.0%	
Calcium (Ca)		18.8% min.
Water Insolubles**		0.2% max.

**(Calcium phosphate, fluoride, sulphate and SiO_2)

Soluble Impurities;

Copper (Cu)	<0.0001%
Magnesium (Mg)	0.002%
Lead (Pb)	<0.0001%
Aluminum (Al)	<0.005%
Manganese (Mn)	<0.001%
Potassium (K)	0.005%
Chloride (Cl)	0.001%
Sodium (Na)	0.01%
Iron (Fe)	0.0015%
Sulphate (SO_4)	<0.02%

NOTE: This product is uncoated.

SALT	1 gm/l =PPM	ELEMENT/ COMPOUND	Required PPM x factor = gm/l salt
$Ca(NO_3)_2 * 4H_2O$	155	N	6.4516
NORSK refined	188	Ca	5.319

GREENHOUSE GRADE POTASSIUM NITRATE

Chemical Analysis by %	**Typical**	**Guarantee**
KNO_3	99.0	-
K_2O	46.2	46.0
N	13.8	13.5
Na	0.2	-
Cl	0.001	0.02
S	0.01	-
H_2O (moisture)	0.1	-
H_2O Insoluble	0.03	-

Solubility ; 31 gm/100gm H_2O @ 68 deg F

SALT	**1 gm/l = PPM**	**ELEMENT/ COMPOUND**	**Required PPM x factor = gm/l salt**
POTASSIUM NITRATE	460	K_2O	2.1739
HC - KNO_3	382	K	2.6178
	134	N	7.4626

SULFATE OF POTASH

Product Specifications; Granular

Chemical Composition	**Typical % Analysis**	**Range %**
K_2O	50.5	50.0 - 52.0
Cl	0.20	0.05 - 0.25
H_2O	0.15	0.05 - 0.20
S	17.4	17.0 - 17.7
K	42.3	41.5 - 43.2
SO4	52.0	51.0 - 53.0

Solubility .... 1 lb./gallon @ 77 deg F.

SALT	**1 gm/l = PPM**	**ELEMENT/ COMPOUND**	**Required PPM x factor = gm/l salt**
SULFATE OF POTASH	505	K_2O	1.9802
G/L K_2SO_4	423	K	2.3641
	174	S	5.7471
	2	Cl	500.00

MONOPOTASSIUM PHOSPHATE (MPK)

General Description; Clean white crystalline product

Formula - KH_2PO_4 **Molecular Weight:** 136.1

Specifications:

Assay % KH_2PO_4	98.0 min
pH 1% Solution	4.2-4.7
% moisture @ 105 deg C	1 max
Arsenic, ppm	3 max
Fluoride, ppm	10 max
Heavy Metals (as Pb) ppm	20 max
Lead, ppm	5 max
% water insoluble	0.2 Maxi
Sizing, USSS % R on 20	10 Max

Typical Sample Analysis:

Assay % KH_2PO_4	99.7
Arsenic, ppm	< 1
% P_2O_5	52.0
Fluoride, ppm	< 1
% K_2O	34.3
Heavy Metals, ppm	<10
% Loss on Ignition	13.5
Lead, ppm	< 5
% Moisture	0.15
pH, 1 % Solution	4.5
% Water Insoluble	0.05
Bulk Density lbs/cu ft	80
Sizing, USSS % R on 20	1
%CR on 100	9

Solubility: g/ 100g H_2O

0 deg C	14.8
25 deg C	25.0
50 deg C	40.8
90 deg C	83.5

SALT	**1 gm/l =PPM**	**ELEMENT/ COMPOUND**	**Required PPM x factor = gm/l salt**
MONOPOTASSIUM PHOSPHATE 98%- KH_2PO_4	520	P_2O_5	1.923
	226.98	P	4.4248
	343	K_20	2.9155
	284.76	K	7.024

MAGNESIUM SULFATE

Epsom Salts

Nature: Bright rhombic salt crystals of white colour.

Formula: $MgSO_4 * 7H_2O$

Contents: Pure Technical

$MgSO_4 * 7H_2O$	99.9%
$MgSO_4$	49%
MgO	16%
Mg	10%
SO_3	33%
SO_2	26%
S	13%

Long term storage at 20 deg C within 45 to 90% relative humidity;
Below these values gradual decay,
Above these values slow deliquescence.

SALT	**1 gm/l = PPM**	**ELEMENT COMPOUND**	**Required PPM x factor = gm/l salt**
MAGNESIUM SULPHATE EPSOM	100	Mg	10.000
K&S $MgSO_4 * 7H_20$ 99.9%	130	S	7.6923
	160	MgO	6.25

Chelated Trace Element Mix

MANUFACTURER; Plant Products

GUARANTEED ANALYSIS;

Iron	(Fe)	7.00 %
Manganese	(Mn)	2.00 %
Zinc	(Zn)	0.40 %
Copper	(Cu)	0.10 %
Boron	(B)	1.30 %
Molybdenum	(Mo)	0.06 %

Note: do not use this product in areas having excess Boron in the water supply or with Boron presence in the growing media.

CHELATED TRACE ELEMENTS SOURCE; A chelated metal complex of tetrasodium and hydroxethyl ethylenediamine tetra-acetate.

EDTA Content (minimum) 48%

FERTILIZERS ACT REG# 790687B

SALT	**I gm/l = PPM**	**ELEMENT/ COMPOUND**	**Required PPM x factor = gm/l salt**
CHELATED TRACE ELEMENTS 7% Fe PP	20	Mn	50.00
	70	Fe	14.287
	13	B	76.923
	1	Cu	1000.00
	4	Zn	250.00
	0.6	Mo	16,666.67

The preceding information is from sources which I believe to be accurate and reliable. It is presented as an example of the variety of information which fertilizer manufacturers do provide and as such applies only to the specific products. This information cannot be taken as applying to all salts or fertilizers bearing the same NPK identification or a similar salt name.

Close review should be tempered by the understanding that, in the greenhouse business, this is the 'good stuff'. Just imagine what an accurate analysis would tell you about the fertilizers destined for use in the fields. Absolutely pure salts are available. The cost is beyond even the enhanced returns available from a properly operated hydroponic system. Also keep in mind that the contamination of any of the salts is expressed as a percentage or PPM concentration of the dry salt, not as a factor of the final use solution. After these salts have been diluted, the results are a purer mixture than you will find in your backyard or an organic garden.

Chapter Three

The Basics of Making Nutrient Solutions from Existing Formulas

There are many sources of information which can provide you with formulations you may want to try. Other growers, books, magazines, research reports, and extension agents, are just a few of the likely candidates for that special recipe. The method used to describe the solution may not be in the units of measure you commonly use for other purposes. Most formulas from growers, consultants, and extension agents, are provided in units of weight per volume of solution; generally metric (that's right, those grams and liters again). This is the international working standard and metric is the easiest system to work with. What you can get from researchers is something else which is covered in another text. The advantage is that if you get a formula from a grower, he/she at least speaks your language.

The following three formulas are ones which have been used successfully by thousands of hobby growers for several decades. I originally developed these formulas to answer the demand for easy to mix solutions which could be created from commonly available materials. At the same time they had to grow just about anything. The original trial gardens were a sight. Corn with daisies, grapes, cucumbers, geraniums and another 30 species of plants.

They are very simple in that they require only 6 source salt ingredients. They just happen to be the same salts covered in the previous chapter. Quite a coincidence. Working with a limited number of ingredients also made it much easier to teach growers the basics. Some progressive retail stores have made it a practice to make the salts available in small quantities to hobby growers who want control of their gardens.

The charts show both the elemental yield of the final solution and a simple mixing chart for a ready-to-use solution. When checking formulas you receive from other sources make sure you know what the parameters are or you could wind up mixing an injector strength formula in your feed tank and losing your plants.

LEAFY & PREFLOWER FORMULA

9.5 - 5.67 - 11.3

ELEMENTAL PPM RESULTS

N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
304	79	349	282	60	99	7	2	.4	.1	1.3	.06

MIXING CHART

SALT	GM/L	X	# LITERS	=	WT REQUIRED
$Ca(NO_3)_2$	1.5			=	
KNO_3	0.522			=	
K_2SO_4	0.115			=	
KH_2PO_4	0.348			=	
$MgSO_4{*}7H_20$	0.606			=	
TRACE 7% Fe	0.100			=	

FRUIT FORMULA

8.2 - 5.9 - 13.6

ELEMENTAL PPM RESULTS

N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
316	99	435	383	60	205	6.3	1.8	.36	.09	1.17	.054

MIXING CHART

SALT	GM/L	X	# LITERS	=	WT REQUIRED
$Ca(NO_3)_2$	2.04			=	
K_2SO_4	0.695			=	
KH_2PO_4	0.435			=	
$MgSO_4{*}7H_20$	0.606			=	
TRACE 7% Fe	0.090			=	

FLOWER FORMULA

5.5 - 7.97 - 18.4

ELEMENTAL PPM RESULTS

N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
158	99	435	191	60	205	6.3	1.8	.36	.09	1.17	.054

MIXING CHART

SALT	GM/L	X	# LITERS =	WT REQUIRED
$Ca(NO_3)_2$	1.02		____________=	____________________
K_2SO_4	0.695		____________=	____________________
KH_2PO_4	0.435		____________=	____________________
$MgSO_4 \cdot 7H_2O$	0.606		____________=	____________________
TRACE 7% Fe	0.090		____________=	____________________

NUTRIENT MIXING PROCEDURE

For this procedure you will an accurate scale. The best is a triple beam scale. I prefer the model with the "Dial-a-gram" feature but the lower cost straight triple beam is just as accurate. For the beginner who really doesn't want to invest in a scale there is another way if you are purchasing your salts from a service oriented retailer. They can weigh the salts out in the quantities necessary to create stock solutions.

Another alternative is to buy your salts in bulk and borrow a scale to weigh them out in the necessary amounts for the stock solutions. The weights are as follows and are based on the salts being identical to those described in previous chapters:

Calcium nitrate (Norsk Hydro)	500 gm
Potassium nitrate (Haifa)	500 gm
Sulfate of potash (Great Lakes)	500 gm
Monopotassium phosphate (Haifa)	500 gm
Magnesium sulfate (Epsom salts)	500 gm
Chelated Trace Element Mix (Plant Prod)	100 gm

All you have to do is dissolve 1 package of each of the different nutrient salts into a separate container holding 10 liters of water. Once you have done this simply multiply the weight of salt required from the charts by 20. This gives you the volume in milliliters of stock solution required for each salt.

Let's go over that once more. If you are buying the salts in pre-weighed packs (or doing the pre-weighing yourself) there are 6 different nutrient salts. These are the salts necessary to create the preceding formulas. There are multiple packages of some of the salts. To create a stock solution you need 6 containers with lids which contain 10 liters of water. The best containers are plastic pails with lids. A good 1 liter measuring cup with 10 milliliter markings is also an excellent tool. Take one package of each of the different nutrient salts from the salt pack and dissolve each into a separate container. The extra packages should be left sealed and stored in a dry place. Make sure you mark each container so you know which container holds each different salt.

Here is a sample of how you change the **dry salt chart** into a **STOCK SOLUTION CHART.**

LEAFY & PREFLOWER FORMULA

9.5 - 5.67 - 11.3

ELEMENTAL PPM RESULTS

N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
304	79	299	282	60	99	7	2	.4	.1	1.3	.06

MIXING CHART

SALT	GM/L X	# LITERS =	WT REQD	X 20 = STK SLTN	
$Ca(NO_3)_2$	1.5	______ =	______	**X 20** = ______	ML
KNO_3	0.522	______ =	______	**X 20** = ______	ML
K_2SO_4	0.115	______ =	______	**X 20** = ______	ML
KH_2PO_4	0.348	______ =	______	**X 20** = ______	ML
$MgSO_4*7H_20$	0.606	______ =	______	**X 20** = ______	ML
TRACE 7% Fe	0.100	______ =	______	**X 20** = ______	ML

For those who are buying salts in bulk of identical quality and analysis to the salt packs, simply weigh out 500 grams of each salt except the trace element mix. Only 100 grams of this are required to create the stock solution. Make sure you are using accurate scales. Kitchen scales tend to be a joke. It's tough to laugh when your plants are dying.

Okay at this point you either have nutrient salts and a scale that is accurate or 6 buckets of stock solutions. It is time to make up the nutrient solution. The procedure for both ways of doing it follows.

FOR SALTS AND A TRIPLE BEAM

1. Fill your reservoir to the 3/4 mark with water.

2. Check the pH of the water

3. Adjust the pH as required:

soil	7
Soilless	6.5
Rockwool	6.5
Water Culture	6.0

4. Complete the mixing chart to determine the quantity of each salt required for your reservoir.

5. Weigh out each salt.

6. Dissolve each salt in 1 liter of **HOT WATER**
and mix into the nutrient reservoir.
Mix thoroughly after adding each salt.

7. Top the reservoir up with clear water to the full mark.

8. Check the pH and adjust as required:

Soil	6.5
Soilless	6.0
Rockwool	6.0
Water Culture	5.8

9. Turn on your air injection system.

10. Set your timer & turn on your irrigation system.

FOR STOCK SOLUTIONS & A MEASURING CUP

1. Fill your reservoir to the 3/4 mark with water.

2. Check the pH of the water.

3. Adjust the pH as required;

Soil	7
Soilless	6.5
Rockwool	6.5
Water Culture	6.0

4. Complete the mixing chart to determine the quantity of each stock solution required for your reservoir

5. Measure out the stock solution required using your liter measuring cup.

6. Mix each stock solution into the nutrient reservoir. Mix thoroughly after adding each.

7. Top the reservoir up with clear water to the full mark.

8. Check the pH and adjust to 6.5.

Soil	6.5
Soilless	6.0
Rockwool	6.0
Water Culture	5.8

9. Turn on your air injection system.

10. Set your timer & turn on your irrigation system.

CONGRATULATIONS!

You have just completed the first step in mixing your own nutrients. The solution that is now feeding your plants you created yourself. The next step is to create the formula itself. No more relying on someone else's cookbook without understanding why the ingredients are used. The prospect may seem daunting but the fact is that if you have made a mistake up to now or failed to allow for water, climate, or cultural considerations, your plants are making it plain through an exotic display of undesired colours and shapes. All your next step really involves is learning what that display means in simple English instead of complicated plant language.

To create your own formulas you have to understand how the plant uses each nutrient. Let's take a look at how each element is used and how they all inter-relate. You will of course also have to take into consideration the environmental factors and the crop being grown. Those are the subjects of another couple of books. At this point I have a news flash for you, no matter how much you learn and I have been at this for several decades very successfully, there is always something more to learn. If you really want to enjoy getting the most out of your garden, stop looking at it as a challenge or some 'big deal education' and start having an adventure. It is a lot more fun that way.

Chapter Four

What the Minerals Do and Their Role in Plant Growth

Here is an analysis of each nutrient and the role it plays in plant growth. This will help you decide what you want to do with the nutrient formula you want to create. At this point it would be a good idea to go back and review the chart (pg. 6) covering the various elements a plant uses as food and the relationships they hold to each other in a general formula.

Let's take a look at the elements found in all plants on analysis and the concentrations in which they are present as a range. This will give us a picture of all the elements required for healthy plant growth.

ELEMENT ANALYSIS OF PLANTS SHOWN AS A RANGE

Based on Dry Weight

THE FREE ELEMENTS

Carbon (C) = 30 - 45 %
Hydrogen (H) = - 6 %
Oxygen (O) = 30 - 50 %

THE MACRO ELEMENTS

Nitrogen (N) = 0.2 - 4%
Phosphorus (P) = 0.3 - 3%
Potassium (K) = 0.3 - 3.5%
Calcium (Ca) = 0.1 - 10%
Magnesium (Mg) = 0.05 - 1.0%
Sulphur (S) = 0.2 - 2.0% (high 7%)
Chlorine (Cl) = 0.2 - 1.0%
Sodium (Na) = 0.1 - 1.0% (high 15%)

THE TRACE ELEMENTS

Iron (Fe) = 20 - 100 ppm (high 1500 ppm)
Boron (B) = 10 - 100 ppm (high 600 ppm)
Zinc (Zn) = 5 - 75 ppm (high 600 ppm)
Copper (Cu) = 1 - 25 ppm
Manganese (Mn) = 5 - 50 ppm
Fluoride (F) = 0 - 1.0 ppm (high 800 ppm)
Molybdenum (Mo) = 0.3 ppm

The above chart is based on a dry weight analysis of a variety of plants. Plants are like people in that they are on the average 90% water before being dried to provide the above analysis. If we start by considering that a plant before drying is 100% weight and we then lose 90% of that weight by drying, we begin to get the relative value of the elements that we put into a nutrient solution into perspective.

Even if we assume the lowest values for the carbon, hydrogen and oxygen; and the high side of the range for those elements we add to water to make a nutrient solution we find that through our expertise in nutrient formulation we are only directly adding the components which compose an absolute maximum of 3% of the plant. To achieve this value we would be discussing a plant like I have never encountered. The actual average composition of these elements in a plant is 1% or less!

I bring out this point not to belittle our efforts to create the perfect plant nutrient, but rather to emphasis that we are working in a range that will not tolerate the old concept that if a little bit works then more is a lot better. In formulating nutrients we walk a fine line that has nothing to do with the tons per acre of chemical fertilizers, that destroyed our farmland. We work in the actual reality of how many grams of balanced nutrient diet a particular plant will require over its life span and the adjustment of that balance during that life span.

Ideally if we do our job well, there will be nothing left over and no plant in our gardens will hunger for a single molecule of a single element. Ideals are great to shoot for but then the reality of our own ability and experience, the available equipment and the economics of the value of production decide how far we will actually go.

You can see from the above analysis chart that our range of plant nutrient elements is broken into three definite catagories. Before we go any further with discussions we had better take a look at each one of the elements we can provide in the nutrient solution and become familiar not only with it but also with what a plant uses it for. So that is what is next.

THE FREE ELEMENTS

I call these elements the free elements because they are not the result of our nutrient formulations to a major extent. They are rather in the major part either obtained from the air or the water we use in creating the nutrient solutions. A plant is 90% water (H2O). All of the carbon, for example, is absorbed through the leaves from the air, not from our efforts at creating an ideal nutrient solution for our special crop or plant. In fact waste carbon is exuded by the roots.

CARBON

Carbon forms up to 50% of the dry weight of a plant. It is not however an element which we include in our calculations for the creation of a nutrient solution. Its importance to us in nutrient solutions lies in the carbonates (CO_3). This compound is the most stable buffer we have available to control pH fluctuation in the nutrient solution.

It is introduced in two ways. First by pumping air into the nutrient solution on a continuous basis so there is a constant creation of carbonates in the nutrient solution. Second through the use of such compounds as potassium carbonate to change the pH to a higher level than the water starts at. Caution must be exercised if carbonates are sourced from a bicarbonate salt. Excess levels will affect nutrient uptake and the plant metabolism. The best source of carbonates is potassium carbonate or bicarbonate.

We are not only concerned with the creation of nutrient solutions. It must also be delivered to the roots of the plants in such a manner as to allow it to be assimilated by the roots. Here we run into carbon again. One of the by-products of the process of respiration is the emission of CO_2 by the roots of the plants along with other gaseous by-products. Failure to create a root zone environment which allows for the easy dissipation of these gases will severely inhibit the plants ability to take up your so carefully created nutrient solution.

These effluent gases dissipate 10,000 times faster in air than they do in fluids. Ensuring there is a constant percolation of air through the root zone is critical to the rapid dissipation of these gases. Also percolating air through the nutrient solution in the reservoir helps stabilize pH and removes a fair portion of the effluent gases picked up by the solution.

INTRODUCTION

The role of carbon is probably the most unusual of all the elements which are required for plant life. The quantity of it which exists in gaseous and solid forms is about 12 - 100ths of 1% of all of the elements which make up the Earth and atmosphere. In spite of this carbon comprises almost one half of the dry weight of most plants.

HISTORY

The importance of carbon in plant growth was not recognized until the mid 1800's. It was an astounding discovery for scientists that the plants they were growing yielded a harvest 10 times greater than the fertilizer they employed and required an expenditure of energy over 500 times greater than what they had invested. This realization and the attempts to quantify the processes involved had a great impact on the understanding of carbon assimilation.

An interesting historical note is that such research was not taken as important until the United States began its first grain shipments to Europe. Faced with cheaper imports European scientists scrambled to find ways of increasing the local production and reducing costs. This of course required a better understanding of plant growth processes so previously unexplained mysteries needed to be defined.

COMMON SOURCES

Carbon exists in both solid and gaseous forms. The solid forms are the result of assimilation into plants of the gaseous form. We are all familiar with the solid storage of carbon in the form of diamonds, coal, oil, charcoal, wood and other plant and animal tissue at various stages of decomposition or transition. Estimating the quantity of carbon stored in solid form is something which cannot be done accurately but research indicates it is about 0.080% of the earth's crust.

For untold centuries the life and death cycle of plants has continuously been the controlling factor of the quantity of carbon in the atmosphere. Without intervention from human processes, the concentrations actually decreased over time as the plants grew faster than they decomposed after they died. The evidence of this is the extensive deposits of coal and oil around the world today. Man's activities in releasing this stored carbon has reversed the declining trend of carbon availability in the atmosphere.

It is interesting to note that our own breathing cycle is critically related to the atmospheric availability of carbon. The amount of carbon dioxide in our lungs is a key regulator in our breathing process. Perhaps plants were in their own way responsible for man being able to evolve. They removed excess carbon dioxide from the atmosphere until a level was reached at which our evolution was possible.

It is easy to measure the amount of carbon in the atmosphere and track the changes which occur in this concentration over time. The concentration of carbon in the atmosphere has increased by almost 100% in the past 500 years. Currently the atmospheric concentration of carbon as carbon dioxide is about 350 ppm or 95.45 ppm of pure carbon. This is almost nothing as compared to other components such as oxygen at 209,800 ppm.

ROLES IN PLANT GROWTH

The low concentration of carbon is directly in opposition to its importance to life in general and plant life specifically. This can be perhaps most graphically illustrated by using the example of corn being grown to yield 100 bushels per acre. The attainment of such yields requires about 6,800 pounds of oxygen. The carbon required is 5,200 pounds.

Therefore the plants must draw 5,200 pounds of carbon from a source which contains little more than 1/10th of 1% of the concentration of oxygen in the same source. How this situation evolved is something for others to explain, we must simply deal with the fact that it is.

Plants as we know, have no teeth, so carbon in its solid forms is unavailable to most green plant life. The main source of carbon for plants is carbon dioxide which is itself an unusually stable gas. Once created through any number of naturally occurring processes it is remarkably stable. Few naturally occurring phenomenon other than the process of photosynthesis will reduce it to the component molecules.

Photosynthesis is the method by which carbon is assimilated by plants. Once assimilated into a carbohydrate form it is ready to be further processed by the plant metabolism. Like oxygen, carbon is a part of virtually every metabolic process and structure within the plant.

Carbon is the keystone of all organic substances. Without it there would be no life. It is the bricking of cell wall construction. The vital component in the carbohydrates which feed the growth process and those hybrid flowers which no longer smell have forgotten how to create the necessary carbon-based molecular chains.

Once assimilated carbon, as a component of the photosynthate (carbohydrates), is translocated both upwards to the younger leaves and downward to the roots. Although the overall majority of the photosynthates exported from the leaves go to the roots it is interesting to note that a significant quantity is required by the younger leaves and apical meristem to supplement the production in these areas.

Even though the growing point of the plant generally receives the highest light levels the young leaves do not efficiently contribute the results of photosynthesis to the rest of the plant. For maximum growth they require more photosynthates than they are able to produce. It is only after they are completely developed that they begin assimilating levels of carbon which make them net contributors to the growth of the rest of the plant.

There is a specific pattern for the movement of the photosynthates related to the location of the leaf on the plant. These patterns explain the different effects of carbon dioxide enrichment at various stages of growth. Young seedlings keep all of the photosynthates within the leaf until the structure is complete. The very small surface area of the new leaf has relatively few stomata so the increase in CO_2 concentration has a significant impact on tissue development.

Older fully developed leaves benefit less as they are restricted in light levels due to their position on the plant. In addition the leaf temperature tends to be less which reduces the rates of carbon assimilation. This is especially true in the high density plantings in greenhouses.

Research at Michigan State University has borne out these observations. On mature tomato plants top growth and flower formation was accelerated and root growth increased due to the increased supply of carbohydrates to the roots from the older leaves. This plays a role in the rapid recovery of the tomato plant from the root death which occurs each time a flower truss approaches maturity.

RELATIONSHIP TO OTHER ELEMENTS

The absorption of carbon through the process of photosynthesis is affected by virtually all of the environmental factors to plant growth. Absorption increases in direct relation to many of the growth factors we can control: water, and nutrient availability, light and heat.

With all of the discussion over the years on the importance of light there are some interesting points on how light actually is used by the plant to "capture" the carbon. While about 70% of the incident light is absorbed by the plant, only about 10% is absorbed by the chlorophyll containing cells, and less than 4% is actually absorbed by the chlorophyll apparatus.

This leaves about 66% of the light energy to vaporize the water in the leaf. The vaporized water not only plays a role in cooling the plant, it also makes the water much easier to process into carbohydrates. This is amply demonstrated by the fact that leaf temperature is a controlling factor in the process of photosynthesis. The lower the leaf temperature the slower the rate of carbon assimilation.

CARBON DIOXIDE ENRICHMENT

There is a long term effect of carbon dioxide enrichment on seedlings. The leaves become "trained" to generate more photosynthates than leaves which have not been exposed to the increased levels. This effect wears off over time but it does give a major boost to production of both new leaves and flowers and fruits. The same effect is noted after high altitude training of athletes although interestingly the oxygen levels are reduced not increased during the training.

Carbon dioxide enrichment of the atmosphere has become very popular over the past decade. Research has shown several critical relationships which influence the economic feasibility of such enrichment:

The most significant return is on seedlings which are exposed to good light levels. Root growth is preferentially stimulated which reduces transplant shock and aids in a rapid recovery to optimum growth levels.

Enrichment is not a valid option on mature plants under low light levels.

Optimum enrichment levels appear to be between 1,000 and 1,200 ppm.

Checking for the results of carbon assimilation is the job of a good laboratory but there are several methods available to do simple testing. For the curious grower there is a simple test which can be done to see what the relative carbohydrate levels in the leaves are.

1. Place a sample leaf in boiling water for a minute to kill it.

2. Soak the leaf in methylated spirit until the green colour is gone from the leaf, (the warmer the spirits the more quickly this will happen)

3. Remove the leaf and add a few drops of iodine to the spirits. If no carbohydrates are present the solution will turn brown. The higher the concentration of carbohydrates the deeper blue the colour of the solution will become.

Note that in light concentrations of carbohydrates the solution may be yellowish in colour.

For hobby growers who wish to experiment inexpensively with carbon dioxide enrichment there is a way. A small bunsen burner or kerosene lamp burning about 3 ounces of alcohol (methyl or ethyl) per photoperiod per 100 square feet provides a simple carbon dioxide generator.

HYDROGEN

Hydrogen is a major constituent of plant structure as a component of water in fresh plant fluids (11.9% of the water), in addition to comprising up to 6% of the dry weight of the plant matter. Supplying hydrogen to the plants is a simple enough matter since water is the base of our nutrient solution. Where hydrogen becomes a critical part of our formulation process is in the free hydrogen we introduce into the solution by our choice of the compounds used to supply the required elements.

pH, the relative acidity or alkalinity of the solution is measured by the concentration of free hydrogen ions in the solution. The absolute balance point on the pH scale is 7, but we are very seldom trying to maintain a perfect balance. What we are usually targeting is a pH between 5.5 and 6.5. In a stable balanced nutrient solution of anions and cations we can "fix" a pH value and maintain it through the use of carbonate buffers. Our biggest problem in "fixing" a pH value is the pH of the water supply we use to create our nutrient solution. It is critical to determine what forms of hydrogen (H^+, OH^-)are in the water supply by doing proper analysis and pH checks.

The Glue of Life
Introduction

Theoretically the original product of the "Big Bang" which created the universe and number one of all the elements we know. Hydrogen is a component of every organic life form known to man, a review of all popular books on plant nutrition reveals it is ignored as a plant nutrient. How can you discuss plant nutrition and ignore the glue of life?

Hydrogen is not more important in plant nutrition than carbon or oxygen; but hydrogen is one of the ions formed by the dissociation of water, the "universal" solvent, around the properties of which life itself is organized.

Description

Gaseous element Atomic number 1 Atomic weight 1.00797 Found generally in three isotopes Protium (99.985%) Deutrium 0.015% and Tritium (prepared by nuclear reaction) with a half-life of 12.26 years.

Two forms of hydrogen are known; ortho-hydrogen in which the two nuclei in the H2 molecule have parallel spins and para-hydrogen in which the nuclear spins are anti-parallel. At ordinary temperatures and above ortho-hydrogen is present to the extent of about 75%; at lower temperatures, the ortho changes to para-hydrogen, until at very low temperatures, as that of liquid hydrogen, the para form is present to the extent of 99.7%. There is some difference in properties between the two, notably in thermal conductivity.

The structure of the hydrogen atom consists of a single electron and a nucleus of positive charge equal in magnitude to the electronic charge. The nucleus of protium is a single proton; that of deutrium is a proton and a neutron and is called a deuteron; while the nucleus of tritium consists of a proton and two neutrons, and is called a triton.

Hydrogen is a colorless, odorless, tasteless gas, composed of diatomic molecules, suffocating but not toxic. Hydrogen was recognized as a substance by Cavendish in 1766, who called it "inflammable air."

Hydrogen occurs chiefly in combination with oxygen in water, with carbon in hydrocarbons, with carbon and oxygen (without and with nitrogen) in a vast variety of organic substances, and with other elements in acids and bases.

Hydrogen is the lightest body or element known to exist. It has some unusual and unique properties. A pressure of 1,000 atmospheres has no effect on condensing hydrogen gas. Combustion of hydrogen creates water which is normally the compound used to suppress fires.

It is interesting to note that any compound containing hydrogen experiences an increase in the amount of heat required to cause it to boil in direct relation to the number of hydrogen atoms bonded to the compound. This characteristic of is a key to plants ability to handle internal heat and the energy required for photosynthesis without boiling to death.

It is a constituent in all organic compounds of which carbon is a constituent. Hydrogen plays a major role in cation exchange in plant-soil relations. It is also the primary bonding agent in organic molecular structures.

As late as 1867, the source, assimilation and role of hydrogen in plant growth was barely recognized. According to Ville in a report of one of his experiments, "*the plants during their growth receive oxygen and hydrogen only in the form of distilled water, yet the water in some way undergoes change and enters into the composition of plants.*"

Role in Photosynthesis

Photosynthesis occurs in two recognizable but integrated steps. The first part of the total photosynthetic reaction involves the absorption of light energy and the production of an energy-rich compound and a hydrogen carrier. A chlorophyll molecule "excited" by the action of a photon of light transfers an energetic electron to an electron carrier, which in turn passes the electron to still another acceptor. The result is the production of energy-rich adenosine triphosphate (ATP) by the addition of a third phosphate group to adenosine diphosphate (ADP). The formation of ATP by means of light is called photophosphorylation.

A second product of the "photo" portion of photosynthesis is the compound, reduced triphosphopyridine nucleotide, or TPN^*H_2. Acting as a hydrogen carrier, TPN is capable of receiving hydrogen from the water which was split during photolysis, thus becoming TPN^*H_2. This compound provides the hydrogen necessary for the synthesis of carbohydrate $(CH_2O)_n$ from CO_2 and H_2 in the dark phase (Step Two) of photosynthesis.

The essential feature in the conversion of carbon dioxide into plant foodstuffs is its reduction by the addition of hydrogen. This is adequately demonstrated by the fact that the oxygen released from the water in the plant which is fractured to release hydrogen plays no further part in the process of photosynthesis and is expelled from the plant.

When the very stable union of water is broken a considerable increase in free energy within the leaf is experienced. The additional energy required for photosynthesis is provided by light energy incident upon the leaf. It should be noted that the process of chemosynthesis in plants which do not utilize sunlight simply substitutes chemical energy for light energy. The balance of the process is virtually identical. Hydrogen is still combined with CO_2 to create carbohydrates.

Role of Hydrogen in Respiration

While photosynthesis is essentially the capture and storage of energy in a carbon associated molecular form, respiration is the release of that energy to fuel plant growth. Hydrogen is one of the keys in the process of releasing the energy. Carbohydrates are broken up and the energy contained in the carbon bonding released, via the movement of hydrogen from the carbohydrates to other molecular structures.

If the carbon released is not required for the new molecular structure it is stored in the form of systemic CO_2. It is this CO_2 which appears as root exudate. The energy released by the breaking of the carbon bonds is what fuels the internal plant metabolism.

There is another energy yield from the breakdown of carbohydrates during the respiration process. The hydrogen released during this process is first ionized into two separate components; the proton (H^+) and the electron (e^-). These components are then passed through a number of organic acceptors of a complex nature until it is recombined to the original state as a hydrogen atom and allowed to combine with oxygen. This combination yields both water and the release of energy which further fuels the respiration process.

Hydrogen is one of the best sources of energy because of its high heat of combustion (34.6 k calories per gram) which makes it eight times as efficient in heating as starch which it was a component of as a gross fuel.

The role of Hydrogen and pH [potential Hydrogen] in plant growth

Hydrogen has for many years been the equivalent balance used as a measuring tool to describe the acidity or alkalinity of soils, water, solutions, and plant fluids. As water dissociates, and the resultant H^+ and OH^- ions are used by plants, or reactions with other elements within the water, the balance of these ions changes. The balance is described by what we have referred to in the past as the pH scale. This scale tells us how much of either ion would need to be added to the solution to bring it back into balance.

It has been determined that other mineral elements required for plant nutrition are most easily available when the balance is tipped in favour of H^+ or a pH of less than 7. The requirement for this balance can only indicate that Hydrogen plays an important role in the osmotic process.

Changes in pH may influence the plant in two ways;

(a) either by directly or indirectly affecting the protoplasm of the root cells and the cell processes therein or,

(b) by changing the relations of the various materials which remain in the nutrient solution.

The concentration of H^+ ions may also be a key to the systemic movement of water within the plant. Photosynthetic sites have a demand for hydrogen and there may be an osmotic demand which influences the movement of water in the plant.

In addition to the already mentioned photosynthesis, the processes of respiration and much of the oxidation within the plant seem to be "powered" by the movement of hydrogen from one organic structure or compound to another.

Hydrogen Bonding

Hydrogen bonding plays a significant role in the structure of water. Frozen water has 100% hydrogen bonding. When ice melts about 15% of the hydrogen bonds (at 0 deg) are broken through the introduction of heat energy. Heating pure water to 25 deg C would result in the breaking of a maximum of an additional 5% of the hydrogen bonds. The average of 80-85% intermolecular hydrogen bonding in water leads to the semi-crystalline order found in aqueous solutions. This extensive amount of intermolecular hydrogen bonding in the liquid state contributes to the unique and biologically important properties of water.

The high rate of intermolecular bonding is what gives water sufficient tensile strength to maintain the sometimes very high columns of water which exist in the xylem vessels within plants. Without this continuous water column the flow of water from the roots throughout the plant would not be possible.

Hydrogen appears to be a mobile element primarily responsible for much of the molecular bonding which occurs within plants. The bonding potential of hydrogen covers all known forms of molecular and atomic bonding. This diversity allows it to be used by plants as a universal, removable glue with which complex organic molecular chains can be pasted together to meet the requirements of the plant metabolism.

Water has the highest heat of vaporization of any liquid known. This means that transpiration engenders a substantial heat loss by plants. Most of this vaporization energy (540 cal/g or 9.75 kcal/mole) is needed to break hydrogen bonds so that the water molecules can become separated in the gaseous phase. This process is a primary means of temperature regulation in plants. It dissipates much of the heat absorbed by radiation as well as that from metabolic activity.

Summary

In spite of the fact hydrogen is often ignored in the discussions of plant nutrients, it plays a critical role which cannot be replaced by any other element. As with the other elements which are not included in nutrient formulations, the availability of hydrogen can be influenced by the grower. Of primary critical importance is the availability of water to the roots of the plants. Potentially equally important is the pH of the nutrient solution and the moisture in the root zone around the plants.

There has been inadequate research done to determine how much hydrogen is supplied by the existence of free H^+ in the water supply. In addition I have found no reference to which form of hydrogen atom is absorbed most readily in the process of osmosis, para or ortho hydrogen, and nothing as to which form is preferred in the metabolic processes within the plant.

From this discussion it is obvious that hydrogen is an important component of plant life. It is a cornerstone of the energy acquisition and utilization process in plants in addition to the fact it is the key component of water. Control of the availability of hydrogen is limited for the grower. It really boils down to ensuring the plant has properly pH balanced water available and that the environment is conducive to effective utilization of water taken up by the plant.

OXYGEN

Oxygen pays a critical role in plant growth. First it is a major component of plants. More in fact than any other element. Oxygen is 88.81056% of water. Water is the solvent we use to dissolve all of the other elements used in feeding plants.

Plants obtain their oxygen from two sources **EXTERNAL & INTERNAL.** The external oxygen is oxygen taken in through the stomata on the leaves, oxygen taken in by the roots as a component of the water in the nutrient solution, and the oxygen absorbed by the roots during the process of respiration. Internal oxygen is the oxygen liberated during the process of photosynthesis. Considerable amounts of this oxygen are released back into the air in combination with nitrogen and carbon.

In nutrient formulation we have the opportunity to enhance the available oxygen to the roots. It is always best to use high oxygen content compounds for our element sources whenever possible. It is this demand for oxygen and the important role of the nutrients in providing it that is the reason for using nitrate instead of ammonial nitrogen in nutrient formulation.

The practice of using ammonial nitrogen during the winter months of cooler temperatures and lower light levels as a partial source of nitrogen is based on the fact that the oxygen demand of a plant varies directly with the temperature. The lower the temperature the less oxygen is required. The use of some ammonial source nitrogen in this circumstance encourages the plant to utilize more nitrogen without conflicting with the plants oxygen demand.

Oxygen forms a part of every cell and fluid in a plant. It is a critical element which in most discussions on nutrient formulation is totally ignored under the assumption that it is uncontrollable or unimportant. Neither is true. The amount of available oxygen provided by the nutrient formula is measurable, controllable and of equal importance to any other element in the formula.

The Fuel of Plant Growth

Introduction

Every living organism is an oxygen reduction machine. Light may be the gasoline of plant growth to fuel the absorbtion of carbon dioxide but oxygen is the internal fuel of the plant.

Description

Oxygen is a colorless, odorless, tasteless, non-toxic gas, found free in the atmosphere (23.15% by weight of oxygen in dry air, 20.98% by volume) mixed with nitrogen, argon, the rare gases, carbon dioxide, and water vapour. Oxygen was discovered by Priestly in 1774 by heating mercuric oxide, and independently in the same year by Scheele. Oxygen is necessary for the burning of substances.

Common Sources

Oxygen occurs combined with silicon, aluminum, iron and other metals in all rocks (average of the solid crust of the earth 46.7% oxygen); as a constituent of practically all plant and animal substances, except hydrocarbons; as the most abundant element in the ocean (8.5% oxygen). It is also about 23.15% by weight of the air we breathe.

Roles in Plant Growth

With all of the oxygen available in the earth and atmosphere you might think that there was no way a plant could ever be short of supply. Consider how much oxygen the process of photosynthesis releases into the environment;

$$6CO_2 + 6H_2O == C_6H_{12}O_6 + 6O_2.$$

By combining the CO_2 and water the plant releases back into the atmosphere 2/3 of the oxygen contained in the two component materials. In addition the remaining oxygen is internalized in a form which is available to the plant.

Oxygen is a vital ingredient to the metabolism of a plant, both as a fuel and a component of virtually all plant compounds. The processes plants have evolved to obtain this element are as varied as the sources which supply it. Oxygen is a major constituent of air (as oxygen and carbon dioxide), water and mineral compounds. Plants use each of these components as raw materials in the growth process. Light may be the external fuel, but oxygen is the fuel which drives the internal plant processes.

SOURCES OF OXYGEN

Leaf source oxygen

So how does the plant extract oxygen from each of the available sources? We have already seen how the process of photosynthesis releases oxygen from both CO_2 and water into usable form as a component of the carbohydrate molecule. The leaves do not absorb oxygen in any other method that has been detected.

Root source oxygen

The roots assimilate atmospheric oxygen which is trapped in water in the root zone and from air pockets in the growing media. The old flood and drain gravel systems of hydroponics were very efficient at aerating the root zone and providing the necessary atmospheric oxygen to the roots. Unfortunately the drawbacks to the system have made it very unpopular. Few other hydroponic systems provide anything similar in air exchange so the amount of atmospheric oxygen carried by the nutrient solution becomes critical.

Nutrient source oxygen

The mineral compounds taken up by the plants are an important source of oxygen. Examination of the specific compounds the plants take up through their roots reveals interesting information. Elements which are absorbed without oxygen tend to require quite sophisticated transport mechanisms dependent on the respiration process. The oxygen associated molecules seem to be more readily transferred through osmosis without carrier involvement.

The oxygen contained in the nitrate molecule is used to break down the carbohydrates created through photosynthesis. In fact if ammonial nitrogen is supplied the growth characteristics of the plant change due to the decrease in oxygen supply from the important nitrate source.

Phosphorus is absorbed only as a PO_4 or compound, and as such provides another important source of oxygen. There are a wide range of additional elements, including sulphur and many trace minerals, which require an association with oxygen for uptake by the roots of the plants.

The pH of water is critical to plant mineral uptake and this pH is, in most hydroponic systems, an indicator of the dissociated oxygen which may be available to the plant roots as a result of water uptake. Water is also an important source of oxygen and hydrogen for a wide variety of processes in the plant metabolism.

The role of oxygen in plant metabolism

It would not be too broad a statement to say that oxygen appears to be of importance in every metabolic process in the plant. It is a key factor in fueling the transport system of the plant. Oxygen is the internal fuel which provides the energy which drives such essential functions as the hydrostatic pressure which moves fluids in the plant.

In addition you find oxygen as a component of virtually every molecular structure in the plant including all proteins and enzymes. Like animals, plants are oxygen reduction machines. The reduction in the availability of oxygen has very detrimental effects on the growth potential of the plant.

Research has shown that low internal oxygen levels can cause mature cells to go dormant as available oxygen is used to bring young cells to maturity. If oxygen levels are low in root cells the uptake of minerals is severely inhibited and nutrient deficiency symptoms may manifest which have nothing to do with the nutrient solution.

Investigations as early as 1865 showed that photosynthesis would not occur in an atmosphere containing no oxygen. The photosynthesis equation does not show the impact of the external atmospheric oxygen nor does it explain the role it plays in the process.

It is also necessary to note that 90% + of plant matter is made up of water. Water could not be without oxygen and through the use of ozone technology can be manipulated to provide previously unavailable oxygen.

Forms of oxygen which can be used to influence plant growth

O_2

Atmospheric oxygen is the most easily available form of oxygen. System design will determine how effectively it is presented to the root zone of the plants.

Ozone

This form of oxygen can be created inexpensively through the use of magnetic fields or electrical discharge units. The use of low strength magnetic fields to treat solution already in the irrigation lines has the potential to increase mineral uptake as well as providing more free oxygen to the roots. Research is currently underway and much more needs to be done before we realize the complete potential impact of this technology.

Hydrogen Peroxide

Many hobby gardeners have known about this for years. If the plants are over-watered and suffering; pour in a little hydrogen peroxide and they seem to pick up like magic. Hydrogen peroxide is unstable and releases proportionally large quantities of oxygen to the roots of waterlogged plants. It will also oxidize metallic elements to make them available for plant use.

Carbon Dioxide

Commonly viewed as the only source of carbon to a plant, carbon dioxide is an important source of oxygen. Increasing the rate of photosynthesis by increasing CO_2 levels provides increased oxygen levels in the plant. This must be balanced by root oxygen levels to ensure rapid carbohydrate reduction and continuation of the photosynthesis process.

Manipulating oxygen availability

There are several areas where a greenhouse or hydroponic grower can influence the oxygen available to plants.

Photosynthesis

This important source is dependent not only on the amount of light and carbon dioxide provided in the growing area. The rate of carbohydrate reduction determines how much photosynthesis can occur in a photoperiod. In CO_2 enriched areas it is not unusual for the stomata to close as the plant attempts to cope with the already assimilated carbohydrates.

Factors which can contribute to stomata closure include; temperature stress, humidity levels too high or low, and excessive EC levels in the nutrient solution, which reduce the quantity of water uptake. Photosynthesis can be enhanced by keeping these factors within the guidelines which are optimum for the plants being grown.

Root zone aeration

This is of critical importance in most modern hydroponic systems. There is often little direct air exchange in the very contained root zone of the plants. There are two areas where the oxygen availability can be increased substantially;

(1) Injection of atmospheric oxygen into the root zone

This is seldom used in a commercial operation since a separate "irrigation system" for air must be installed. It can however be very effectively used in small hobby systems. Research has shown this "air irrigation system" can have a very beneficial impact on containerized systems with overall dry weight accumulation rising by up to 15%. One of the main reasons is the effective flushing of accumulated CO_2 and other effluent gases in the root zone which can inhibit the respiration process.

(2) Increasing the oxygen content of the irrigation water or nutrient solution.

This is something which any knowledgeable grower has incorporated into his irrigation system no matter what type of culture is used. Source water is generally very low in dissolved oxygen and extensive research has shown that roots will not grow or operate in water with little or no dissolved oxygen. It is not excess water around the roots which slows or kills plant growth it is the lack of adequate oxygen levels.

Dissolved Oxygen levels can be increased in several ways: The use of aeration systems in solution reservoirs; Injection of atmospheric oxygen into the irrigation lines; and Injection of oxygen rich air obtained through the use of oxygen concentrators; the use of magnetic field generation of low level ozonation in the irrigation water. The use of liquid oxygen is seldom if ever practiced due to the danger involved in handling liquid oxygen and the high cost.

Mineral Salt determination

Using mineral salts of high quality and maximum oxygen content will ensure the maximum availability of oxygen from this important source. Low grade agricultural chemicals have no place in formulations for hydroponic applications. Keep the use of ammonial nitrogen as low as possible under your specific environmental conditions.

The practice of using ammonial nitrogen during the winter months of cooler temperatures and lower light levels as a partial source of nitrogen is based on the fact that the oxygen demand of a plant varies directly with the temperature. The lower the temperature the less oxygen is required. The use of some ammonial source nitrogen in this circumstance encourages the plant to utilize more nitrogen without conflicting with the plants oxygen demand.

Hopefully this preliminary discussion of the role of oxygen in plant growth has highlighted the importance of oxygen as a plant nutrient. A nutrient which can be manipulated to influence plant growth and one which cannot be ignored by the grower.

Chapter Five

THE MACRO ELEMENTS

Every book on plant nutrients seems to classify the elements differently. The explanation of the reasoning for the categories used is generally missing. My own method of classification is quite simple. The Free Elements you are already familiar with. I classify as Macro Elements any element which may potentially comprise 1% or more of the dry weight of the plant. This will help you understand why the divisions are where they are on the Element Analysis of Plants Chart. All other elements not included as either Free or Macro are classified as Trace Elements.

There are complex inter-relationships which exist amongst all of the elements necessary for healthy plant growth. No matter what % of the plant a particular element is it cannot function properly unless all other elements are present in combination with all of the environmental factors. The significance for each element is not how much the plant uses but rather how it relates to other elements and the metabolic processes it is involved in.

NITROGEN

First of the Big Three

INTRODUCTION

Gardeners are very familiar with nitrogen as a plant nutrient. Every fertilizer they buy lists the nitrogen content on the label. The common understanding is that the more nitrogen you use the higher your plant growth rate and yield will be. An excellent example of the "everybody knows" syndrome being completely wrong.

There is no plant nutrient which has been more misrepresented as a factor to plant growth. Entire companies have built their fortunes on over-billing an element which is simply one of the many essential to plant growth. The misapplication of nitrogen in field culture is responsible for a very large percentage of the destruction of what used to be productive farmland. In hydroponic culture at least we can view nitrogen for what it is, a plant nutrient.

DESCRIPTION

Nitrogen is a colourless, odourless, tasteless, non-toxic gas, found free in the atmosphere (78.03% by weight nitrogen) mixed with oxygen, argon, carbon dioxide, and water vapour. Nitrogen was recognized as a simple gas by Lavoisier in 1776, although previously isolated by Rutherford in 1772. The free gas nitrogen is among the least reactive substances chemically, but many of its compounds display marked reactivity, e.g. nitric acid, glyceryl nitrate, cellulose nitrates etc.

The Nitrogen Cycle

The fixation of atmospheric nitrogen is accomplished naturally by certain bacteria in the soil. The nitrogen cycle is the exchange of nitrogen between animals and plants in which plants convert urea or nitrates to protein, animals digest protein and excrete its nitrogen content as urea, which is again taken up by the plants.

Another aspect of the nitrogen cycle is the fixation of nitrogen from the atmosphere by two types of bacteria. Those free living in the soil are *Nitrosomas* and those which are symbiotic (*Rhizobia*) and live in the roots of legumes. The nitrogen fixing process is actually a part of the natural feeding process of the bacteria. These bacteria are also called heterotrophic due to their main source of nutrition which is the ingestion and breakdown of organic matter.

Nitrification

Nitrification is another portion of the nitrogen cycle whereby processed nitrogen (animal or plant component) is released and recombined into a form optimum for plant growth. This is the formation of nitrous and nitric acids or salts by oxidation of the nitrogen in ammonia: specifically, oxidation of ammonium salts to nitrites and oxidation of nitrites to nitrates by certain bacteria. In soil ecology the common source of ammonia is the decay of woody plant material and the decomposition of animal manures.

History

As early as 1867 it was commonly recognized that different plants needed different forms of nitrogen. M. Georges Villes in his lectures of that year divided plants into three groups based on empirical experiments with various nitrogen sources. It was also interesting to note that agriculturists of the time were familiar and had been for the previous quarter century with the three basic forms of nitrogen; ammonia, nitrate of some base and as nitrogen gas.

According to Villes "nitrogen is absorbed under different forms. For leguminous plants free nitrogen is the most suitable; for wheat and colza, ammonia; for beetroot, nitrates." This was very serious business at the time as Europe felt its agriculture to be threatened by cheap imports from the United States.

Even this early in the development of the use of "artificial manures" the basis was already being laid for the misapplication of nitrogen to fields for decades to come. Agriculturists of the time had not yet identified the nitrogen fixing processes involved in live soils. This source of nitrogen was mis-identified as being supplied by every plant's ability to absorb nitrogen from the atmosphere to some limited extent.

To quote Villes, "*Were we to use double or treble the quantity of phosphate, potash, or lime, the yield would not change, but if we vary the quantity of nitrogenous matter, the crop is immediately increased or decreased in proportion; an evident proof that with respect to these crops (wheat, beetroot and hemp), it is the nitrogenous matter which really fills the most important office.*"

We have definitely come a long way in our understanding of the role of nitrogen in plant growth, but it is necessary to note that we do not know as much today as we will tomorrow.

Role in Plant Growth

There is no question that nitrogen is required in relatively large quantities by plants and that it is essential to healthy plant growth. Nitrogen is found as a component of amino acids, all proteins, coenzymes, nucleic acids and chlorophyll. Dry weight analysis of plant material shows that on average nitrogen makes up about 6% of the dry weight. In addition the amount of nitrogen released as a byproduct of photosynthesis must be replaced on a continual basis.

The roles of nitrogen in plant metabolism link the required levels very closely with light levels. Light is the key which determines carbohydrate production through photosynthesis. Nitrate nitrogen is an important source of the oxygen used for carbohydrate reduction during respiration.

The carbohydrate/nitrogen balance is critical and often results in imbalances. Excess carbohydrates result in the carbohydrates being stored as lignin or cellulose resulting in a hard woody plant with thin brittle stems. The lignin/cellulose also impacts on the nitrogen availability in the plant because it requires ammonium (NH_4) for creation. This also ties up energy because the hydrogen is a mechanism of energy transfer and the long term bonding into lignin/cellulose removes this energy from the plant metabolism. Excess nitrogen (NO_3 source) results in soft succulent plant parts which are very susceptible to mechanical damage, insect damage and disease.

With the wide distribution of nitrogen through the organic molecular structure it is not surprising to find that the use and availability of nitrogen is closely related to and strongly influenced by; phosphorus, carbon, potassium, magnesium, chlorine, light, CO_2 and pH.

The relationship with light is again worth noting as it relates to seasonal variations in the environment especially in the areas of temperature and light. The seasons providing lower light and temperature levels should be balanced with lower nitrogen availability as related to the other plant nutrients.

Sources of Nitrogen

Further complicating the situation is the source of nitrogen. Live soil ecologies have the buffer ability to convert NH_4 to NO_3 in the nitrogen cycle. This process is not available in mineral soil, soilless, or hydroponic culture, which makes the source of nitrogen critical. When plants absorb nitrate nitrogen through the roots the first step is to release the oxygen and incorporate the nitrogen into an organic molecule. Once in an organic molecular form the nitrogen is ready to be further metabolized by the plant.

If the nitrogen is provided in an ammonium form it cannot be incorporated into a usable organic molecule. It is used instead to create lignin/cellulose, removing the nitrogen and the results of photosynthesis from the plant metabolism. Every plant requires a certain amount of woody tissue to provide strength of structure and experience has shown that if an average of 10% of the nitrogen is provided as NH_4 in a full formulation nutrient this essential strength of structure will be created.

There is evidence to indicate that some tropical plants have a requirement for higher percentages of NH_4 source nitrogen than other plants. This is an area which requires far more research.

Nitrogen is relatively mobile within the plant. The maximum concentration is found in the meristem and growing points. Translocation of carbohydrates within the plant from older leaves provide most of the food for these locations resulting in spurts of growth which show up as the elongated internodes associated with excess nitrogen.

Every gardener of any level is familiar with the manipulation of nitrogen as a tool in the manipulation of plant growth at various stages. Growth fertilizers contain high nitrogen and flowering or fruiting fertilizers contain low nitrogen. Almost without fail the availability of high levels of nitrogen result in 'wild' vegetative growth to the detriment of either fruiting or flowering. This is a sure sign that nitrogen availability is a critical factor in the regulating mechanism which determines how and when other than vegetative growth will occur.

Nitrogen definitely pays a major role in plant growth and productivity. It is however a mistake to assume it is more important than any other plant nutrient. There is an essential balance. A great deal more research is required to determine optimum nitrogen levels in relation to other nutrients and environmental inputs for a wide variety of plants (all of them). Claiming nitrogen as the controlling factor to plant growth and productivity is about the same as saying your car goes faster with gas in the tank than it does with your neighbours pushing it.

PHOSPHORUS

INTRODUCTION

Talk about history and the way things were done way back when. Phosphorus was first discovered by Hennig Brandt in Germany in 1669, during an experiment involving the distillation of urine with sand and coal. Some guys get all the breaks!

DESCRIPTION

A non-metallic element, symbol P, atomic # 15, atomic weight 30.9738, periodic table group 5a. The normal (white) P_4 molecule is a tetrahedron with single covalent bonds between the P atoms, and each having an unshared pair of electrons.

Phosphorus ranks 10th in terms of abundance in the earth with an estimated average content of igneous rocks being 0.13% phosphorus. It is 19th in abundance in seawater (est. 325 T/cu.mile) and in terms of cosmic abundance it is ranked 15th among the elements.

Phosphorus is a highly reactive element and highly toxic in its white (yellow) form. From the viewpoint of the chemist there are still many questions related to the structure of phosphorus in its pure form. It does seem to change structure quite readily in response to temperature. This may explain the high rate of transition of form caused by changes in the pH value of a media or solution.

COMMON SOURCES

Phosphorus does not occur in nature in the elemental form. Phosphate rock is the principal source of phosphorus and phosphorus compounds. These phosphate rocks contain 30-37% P_2O_5. The process for reducing the phosphate rock into useable form was originally developed in 1888.

Phosphorus is covalently bound to its neighbouring atoms in all of its compounds except perhaps for some metallic compounds.

Normally when the term "phosphoric acid" is used it refers to orthophosphoric acid H_3PO_4. Numerous organic phosphorus compounds are found in nearly all life processes and will require much more study before we understand the role of phosphorus in plant life processes. Phosphorus is a component of sugar phosphates, adenosinetriphosphate or ATP, an important energy compound in plant metabolism, nucleic acids, phospholipids and coenzymes.

PLANT AVAILABLE FORMS

The most common forms of phosphorus available to the plant from the nutrient solution are $H_2PO_4^{-1}$ the most common, HPO_4^{-2} at normal soil or solution pH values of 4.5-8.5; and $H_3PO_4^{-3}$ which may be available under high (over 9 pH) conditions. At pH 12.3, 50% of phosphate is HPO_4^{2-} and 50% is PO_4^{3-}. At pH 8.5 or below less than one phosphate ion in 6000 is PO_4^{3-}.

Phosphorus is considered to be highly mobile in soils and subject to leaching. In fact phosphate diffuses through soil at about 0.63 to 0.83 mm in four days. For this reason plants in soil can rapidly deplete available phosphates.

ROLES IN PLANT GROWTH

Once in the plant it is relatively mobile and found just about everywhere. Phosphorus as an overall range of the dry weight of plant tissue is generally 0.3-3.0% (Avg concentration 2,000 ppm dry tissue). Concentrations occur in the seeds, fruits and meristemic tissue. It is a constituent of various plant proteins and influences hydrolysis and the synthesis of starch. With these areas of concentration it is easy to understand why fruiting and flowering plants require more than green plants.

Phosphorus appears to be a regulator of the uptake and utilization of nitrogen. If the phosphates are not readily available to the roots, the inorganic forms of nitrogen (NO_3 & NH_4) are rapidly absorbed and accumulate in plant tissue. When the phosphates are abundant the absorption of the inorganic nitrogen compounds is depressed. There is research evidence that phosphates are more rapidly absorbed and accumulated when nitrogen is supplied in the urea form than when the nitrate form is used.

Phosphorus assists in the nitrate/nitrogen reduction process in respiration and acts as a buffering agent on the acidity of cell sap. Excess nitrogen tends to inhibit the uptake of phosphorus. Adequate supplies of phosphorus enhance development of roots and root crops as well as the early ripening of fruit.

Protein synthesis is apparently depressed in phosphate deficient plants. The resulting accumulation of sugars in the vegetative portions of the plants is what causes the characteristic purple or red coloration due to the production of anthocyanins; the red, blue, and purple pigments in plants.

Phosphorus is highly mobile in plants. In times of deficiency the plant will act to modify its metabolism to 'recycle' the phosphates more rapidly and move it to plant parts based on the demand model. Unlike many other mineral compounds, the phosphates are not broken down in the plant but rather becomes linked into organic compounds in highly oxidized forms.

Phosphorus limitation can result in dramatic reduction of respiration rates, photosynthetic carbon dioxide fixation and oxygen evolution as well as an increase in the rate of dark carbon dioxide fixation.

Monitoring & Detection

Most nutrient solution research is done utilizing easily detectable ions such as nitrogen or potassium. There is no inexpensive, easily available test, ion specific monitor, or meter, for the grower to use in tracking phosphate levels. The reagent test for phosphate is complex, time consuming and beyond the technical capabilities of most growers.

For this reason it is important that the grower carefully monitor solution formulation, and pH, in addition to analyzing the inorganic nitrogen/phosphate balance in analyses received from the laboratory.

New Research Notes from Queens

Phosphorus uptake by the roots seems to be in direct proportion to the volume of roots developed by the plant in addition to the amount of phosphorus easily available to the roots. Based on research currently underway at Queen's University in Kingston Ontario, Wm.C. Plaxton et.al., there is an indication that phosphorus starvation situations the plant metabolism can switch to alternate pathways to maintain function. There is evidence that this may be an attempt on the part of the plant to 'recycle' existing phosphorus very rapidly to maintain plant metabolism. This is less effective and no data has been published as to specific duration in common plant varieties or species.

Additional research by this group indicates that phosphorus limitation can result in dramatic reduction of respiration rates, photosynthetic carbon dioxide fixation and oxygen evolution as well as an increase in the rate of dark carbon dioxide fixation.

In addition there appears to be a direct relationship between the requirement for phosphorus based proteins and the rate of nitrogen assimilation as NH_4 after conversion from NO_3.

POTASSIUM

This is the last of the most easily recognized elements which are listed in the NPK ratios found on all fertilizers. Again this information is next to useless for the hydroponic or soilless grower without converting the percentage which is actually K_2O into the elemental form.

HISTORY

Knowledge of the role of potassium in plant growth goes as far back as Theodore de Saussure who noted that the seed content of 'potash' steadily increased as the seed organ approached maturity.

In the last half of the 19th Century potassium was considered to be one of the 4 essential "minerals' for plant growth found in 'manures'. It was however referred to as the compound potash, rather than as the elemental potassium. The chemical sources of potassium which had been identified and in use in agriculture in 1876 included 'potassic nitrate' and 'potassic chloride at 80 deg'.

The principal sources of these "chemical compounds" as listed by M. George Ville in his lectures were;

"*1. The eruptive rocks, which constitute entire chains of mountains, and which often contain as much as 15 per cent of that alkali.*

2. Sea-water, from which we may extract potash with the greatest ease by employing the processes invented by the late M. Balard, and which alone would suffice for all our wants.

3. The deposits discovered at Strassfurth in Prussia some fifteen or sixteen years ago (circa 1850)".

This early reference to naturally occurring sources of potash as "chemicals" has probably had a considerable influence on the incomprehension of 'organic growers' today as to which sources of plant nutrients are in fact natures' chemicals. (It is unfortunate such prejudices have not been as effectively eliminated as a statement by the same author "*I defy the cleverest chemist to tell beforehand what will be the yield of any land submitted to him, and what manure ought to be used.*")

In 1920, Stolkasa attributed many of the functions of potassium in plant growth to the fact that potassium salts are slightly radioactive. The catalytic role of potassium in spite of its physical size and configuration tends to bear out this hypothesis.

DESCRIPTION

A chemical element, symbol K, atomic number 19, atomic weight 39.102; an alkali metal. Also known as kalium, melting point 63.7 C, boiling point 774 deg C, density 0.87 gm/cm3 @ 20C. Discovered by Davy in 1807. Potassium ranks 7th among elements in the earths crust and 8th in abundance in seawater (1,800,000 tons/cu.mi.). In ordinary potassium the three naturally occurring radioactive isotopes ^{39}K through ^{41}K represent an average of 0.0119% of the content.

COMMON SOURCES

Potassium does not occur in the free state in nature due to its highly reactive chemical nature. The major basic potash chemical is potassium chloride. There are significant deposits of potassium found around the world as a result of evaporation of prehistoric lakes and seas. This process is still continuing in bodies of water such as the Great Salt Lake in Utah and the Dead Sea to name two. These 'brine reserves' are used for the commercial production of potash in addition to the mining of mineral reserves. Potassium forms compounds with virtually all of the anions, organic as well as inorganic.

Soil contains anywhere from 0.5% to 2.5% potassium with an average of 1.2%. This means that the average soil which weighs 4 million pounds per acre/foot will contain about 50,000 pounds of potassium. Mineral potassium (an integral part of the structure of various minerals such as feldspar) comprises about 99% of the potassium in the soil environment and is realistically not available for current plant growth. This leaves only 500 pounds available in three forms; fixed, exchangeable, and soluble. The result is that in most cases only 2% of the 1% of total potassium (.02% of total K) is potentially available to a crop cycle.

Roles In Plant Growth

Potassium is usually the most abundant monovalent cation in plant tissue. Its high level of mobility through all plant tissue explains why deficiency symptoms occur with such rapidity. The concentration of potassium found in any tissue is directly related to the relative level of the physiological activity. Thus young tissue tends to have a much higher concentration than mature tissue.

The uptake of potassium is achieved by an active transport system which seems to be related to the osmotic pressure of the plant cells in addition to the balance of the elements which make up the cell fluids. Potassium is the main element used by the plant to regulate cellular osmotic pressure.

Unlike all of the other macro mineral elements, potassium is not known to be definitively built into any organic compound essential for the continued existence of the plant. In essence it behaves like a trace element. Overall it has the general function of optimising photosynthetic activity as the following list shows.

1. Enzyme Activation
2. Water Relations- stomatal control, turgor
3. Energy Relations - ATP production
4. Translocation of Carbohydrates
5. Nitrogen Assimilation & Protein Synthesis
6. Starch Synthesis

Potassium has been called the 'currency' of energy relations in plants. It enables energy produced at one location in the plant to be transferred to another. This movement of energy within the plant is reflected in efficient production of support tissue for strength, conversion of nitrogen to biomass, and movement of carbohydrates to fruit.

It is entirely possible that potassium is viewed by the plant as two separate elements which would explain its unusual relationship with sodium and the relationship of potassium uptake to light levels and quality. I make this observation for several reasons;

1. Potassium is available to the plants in two forms, the stable ^{19}K and the radioactive isotopes $^{39\text{-}41}$K.

2. The radioactive isotopes are available in quantities which are remarkably similar to the quantities of trace elements used by plants.

3. Sodium seems to be able to fill the role of osmotic concentration balancer and calcium antagonizer with no detriment to plant growth. Yet the other functions of potassium do not occur.

4. It seems almost impossible to create a toxicity situation in normal plant culture which suggests there is a demand for more of something related to potassium than the grower is able to provide and we have no current way of manipulating the quantity of the radioactive isotopes available to the plants.

5. All toxicity symptoms seem to be anion related i.e. creating suppression of other element uptake or function, rather than an actual adverse reaction by the plant metabolism to the presence of potassium.

6. Shortwave light radiation is very closely related to the radiation emitted by radioactive substances and the demand for potassium by the plant is related to the light available to the plant. As light radiation decreases the demand for potassium increases. Is this demand related to osmotic pressure alone?

Relationships with other Elements

Sodium - evidence shows that where there is 'adequate' potassium provided it may be suppressed by the presence of sodium in concentrations of over 50 ppm. Raising the potassium levels provided does not necessarily increase potassium uptake by the plant but it has been shown to consistently reduce the uptake of sodium. This may explain why the response to the use of potassium silicate for disease control in areas of high sodium water seems to be more marked than in areas with low or no sodium.

Cations - if potassium is the predominant cation available in solution supplied to a media based culture where the media has a high CEC (cation exchange capacity), the potassium can become electrostatically bound with the resulting release of another cation (eg Ca, NH_4) creating imbalances in the roots zone and causing potassium deficiency problems in addition to other plant nutrition problems.

Ammonium - in the situation of potassium deficiency plants will rapidly develop damage as a result of uptake of nitrogen in the ammonium form.

Form Assimilated

Soluble K (readily available),

Potassium which is in solution, readily available to the plant and moving freely in the solution around particles of soil or growing media. This is the only potassium actually available for plant growth.

Simple plants (grasses) seem to be able to take up potassium much more easily than more complex (broad leaf) plants.

Supply considerations

Once the demand requirements of a crop have been determined it is better to supply the K in the irrigation water at a high rate of application frequency which matches the demand rate instead of a one time application or media amendment which will result in a large percentage of the potassium becoming removed from the solution by soil or media and being held unavailable in an 'exchangeable' form.

General rules of thumb for optimum potassium availability

1. Add K as needed in increments
    - irrigation water
    - foliar application

2. Add at the rate the crop is using

3. Add when the plant needs it most
    - exponential growth phase
    - carbohydrate translocation phase

4. Maintain a balance of N-P-K-S
    - they all interact in maximizing photosynthetic efficiency

Testing

It is important when doing soil/media analysis for potassium to test the level where the majority of feeding roots are and to keep in mind that if ammonial nitrogen is being applied in soil cultures, it can actually prevent the fixed potassium from moving into an exchangeable form.

K is one of the elements for which ion-specific electrodes have been developed. growers will soon be able to monitor K with the same ease as they enjoy for pH and EC.

The same flame emission test can be used to check for the presence of K & Na.

Disease Interaction

Potassium was first reported over 80 years ago as a suppressor of plant diseases. One of the most extensive reviews of research reports was done in 1977 by Perrenoud who summarized 534 reports.

1. Potassium improved plant health in 65 percent of the studies and was deleterious 23 percent of the time.

2. Potassium reduced bacterial and fungal diseases 70 percent of the time, insects and mites 60 percent of the time and nematodes and virus influences in a majority of the cases.

3. Fungal disease infestation was reduced by the addition of K an average of 48 percent where soils tested low in K, and 14 percent where soil test levels were unknown.

4. Potassium's influence upon crop yield varied according to the parasite group. The average yield or growth increase was 48 percent for fungal diseases, 99 percent for viruses, 115 percent for nematodes, 14 percent for insects and mites and 70 percent for bacteria.

5. The modes of action are primarily through plant changes in metabolism and morphology.

6. Crop response was not consistently different for K carriers.

7. Balanced N-K nutrition, significantly affected disease susceptibility of plants.

8. Benefits were noted more frequently in the field than in laboratory or greenhouse experiments.

Common Sources

Potassium is one of the elements which is described by a published number required on all fertilizers. Unfortunately it is expressed as K_20 rather than K. To convert to elemental potassium; multiply the published number x 0.83 and then multiply the result by the purity percentage of the salt or fertilizer in question.

CALCIUM

INTRODUCTION

Growers have more calcium related problems than with any other plant nutrient. This may seem surprising in light of the fact that it is seldom deficient in either the soil or full formulation solutions. A thorough look at this metal and its roles and interactions in plant growth may make the reasons easier to understand.

History

It is not surprising that growers have so many calcium related problems. Accurate information has only recently become available on the role of calcium in plant metabolism. It has simply been too common to be noticed. As late as the 1930's even the form taken up was misunderstood. In the 19th Century calcium was all but ignored as an essential mineral. Mention was only made in relation to the fact it was found in combination with what was considered a far more important plant nutrient, phosphorus, in the form of "*calcic phosphate*".

Description

Chemical element symbol Ca, atomic no. 20, atomic wt. 40.08, periodic table group 2a (alkaline earths), melting point 840 +-1C, boiling point 1,484C, density 1.55 gm/cm3 (solid @ 20C), 1.54 gm/cm3 (single crystal). Elemental calcium has a face-centred cubic crystal structure when at room temperature.

Calcium is a silver-white metal, somewhat malleable and ductile, stable in dry air, but in moist air or with water reacts to form calcium hydroxide and hydrogen gas; when heated burns in air to form calcium oxide emitting a brilliant light. Discovered in 1808 by Davy.

There are six stable isotopes ^{40}Ca, ^{42}Ca, ^{43}Ca, ^{44}Ca, ^{46}Ca, and ^{48}Ca, with a predomination of ^{40}Ca. In terms of abundance, calcium ranks fifth among the elements occurring in the earth's crust, with an average of 3.64% in igneous rocks. In terms of content in seawater, the element ranks seventh, with an estimated 1,900,000 tons of calcium per cubic mile of seawater.

Natural Sources

Calcium occurs generally in rocks, especially limestone (average 42.5% CaO) in igneous rocks; as the important minerals limestone (Calcium carbonate $CaCO_3$), gypsum (calcium sulfate dihydrate $CaSO_4*2H_2O$), phosphorite, phosphate rock (calcium phosphate $Ca_3(PO_4)_2$), apatite (calcium phosphate-fluoride, $Ca_3(PO_4)_2$ plus CaF_2) fluorite, fluorspar (calcium fluoride CaF_2); in bones and bone ash as calcium phosphate, and in eggshells and oyster shells as calcium carbonate.

Roles In Plant Growth

Calcium is unique among the elements in that it is both an essential plant nutrient as well as a soil amendment. Calcium is absorbed as the Ca^{2+} ion with normal concentration in plant leaves between 0.2 to 1.0%. Calcium plays an essential role in cell division and elongation. It also plays an important role in the structure and permeability of cell membranes. Without calcium, the cell membranes break down, causing a loss of diffusible compounds. Calcium also enhances uptake of some nitrogen forms, as well as transport and retention of other nutrients within the plant.

Although the highest concentrations of calcium are found in the leaves and seed coats, there is not a single cell which does not contain it. It is the foundation on which the cell structure is built. An absence or deficiency of calcium will stop plant growth totally.

Protein synthesis, carbohydrate translocation, amino acids, permeability of cytoplasmic membranes and the degree of hydration of cell colloids are all calcium dependent. The uptake of the other elemental ions; especially potassium, are influenced by calcium. If in fact calcium is absent then there is no potassium uptake at all.

Relationships with Other Elements

The critical inter-relationships affecting calcium include magnesium, potassium, phosphorus, sodium, nitrogen and pH.

Many of the elements in plants would cause toxic effects very quickly if not balanced or buffered. Calcium plays an important role here. It neutralizes the potential toxic effects of magnesium, but only within the critical calcium/magnesium ratio which varies from plant to plant. In my experience the ratio has varied from a low of 3:1 to a high of 9:1. An influencing factor in this ratio as expressed in the amounts required for the nutrient solution is the ability of the individual plant to absorb magnesium.

Calcium also assists in the neutralization of organic acids. The use of ammonial nitrogen dramatically reduces the amount of organic acids created within the plant. This may play a role in the reduced uptake of Ca as less is then required for the buffering role.

Nitrogen: Nitrogen fertilizer applications can be antagonistic to calcium uptake, but the nitrogen source must be considered. In low calcium soils, ammoniac nitrogen can reduce the absorption of calcium and may exacerbate calcium deficiency. Supplying soluble calcium and nitrate can have an additive effect in combatting this disorder through the ready supply of calcium and the positive effects of nitrogen, without source-related antagonism. Phosphorus can have an indirect effect simply by its growth-stimulating properties on roots that allow improved foraging and nutrient uptake.

The use of ammonium source nitrogen can reduce the cation uptake dramatically especially with divalent cations such as Ca. The reason is that the monovalent ion is easier for the plant to take up and cation uptake is either passive which is a less selective process or active which involves the expenditure of energy and leaves the divalent ions at a disadvantage as more energy is required.

Potassium: For fruiting crops such as tomatoes and peppers it has been clearly shown that it is important to maintain K^+ levels at least equal to the Ca^{2+} levels in the solution. If the K levels are lower than Ca, then the uptake of potassium is severely inhibited.

Magnesium: Evidence shows that the balance of Mg & Ca is critical in the nutrient solution. If the ration of Ca to Mg is greater than 10:1 there will be a suppression of the uptake of Mg. If the ratio is less than 1:1 the uptake of Ca will be suppressed. Excess Ca will interfere with the ability of Mg to activate enzymes

Iron: As a heavy metal, iron is in competition with a range of elements for uptake. If present in inadequate concentration then Ca will suppress the uptake. If the concentration of Fe is too high then the uptake of Ca can be restricted.

Oxygen: A lack of oxygen in the water and the root zone can inhibit Ca uptake even if there is adequate Ca in the solution. The roots will not uptake nutrients where there is no O_2 in the solution or media. The result is root growth and the reduced ability to uptake Ca through the older root membrane which has changed as a result.

Boron: Deficiencies of boron can result in calcium deficiency even if adequate supplies are present in the solution.

Forms Assimilated

Calcium is taken up as Ca^{2+}. Cation Exchange, especially in media based systems plays a role in the uptake of calcium which lodges on the negatively charged media and is released in exchange for 2 H^+ ions for every Ca^{2+}. This transfer mechanism provides a buffer in media based systems which is not available in water culture systems such as NFT.

Supply Considerations

In soilless culture it has been shown that we are quite restricted in the salts available for formulation. Growers who have tried field grade salts have found the results to be unsatisfactory. The most commonly used source salt is the greenhouse grade calcium nitrate from Norsk Hydro. In systems using injectors and concentrates it is essential that the calcium salt solution be concentrated separately from other salts or the result will be precipitation as gypsum or plaster of paris in the concentrate tank and the irrigation lines.

Testing

Although it is possible to do tissue testing for Ca levels, it is important for the greenhouse grower to remember that correcting deficiencies so found is essentially a waste of time. The time is long past for action when a deficiency is noted from tissue analysis. The leaf or fruit involved is generally damaged beyond commercial value and will not recover.

Ongoing solution testing of the drain water will provide information on how much Ca is available to the roots. It is up to the grower to ensure that environmental conditions optimize the uptake of the calcium.

Calcium Carbonate equivalent

This rating is shown on many acidic fertilizers and indicates how much $CaCO_3$ the fertilizer will neutralize when applied at the recommended rates.

MAGNESIUM

A Pivot for Plant Energy Balance

HISTORY

Magnesium was first extracted in 1695 as epsom salts by Nehemiah Grew who obtained it by evaporating the mineral waters at Epsom England. In 1808 Sir Humphrey Davy isolated, and identified magnesia as an oxide of an heretofore unknown element, which he first termed magnium. Metallic magnesium was first isolated by A. Bussy in 1828, but it was not until 1883 that the first metallic magnesium was produced electrolytically by Michael Faraday.

Electrolytic processes today account for 80% of the magnesium production. The balance is produced using thermal processes. Over half the metallic magnesium produced is extracted from seawater.

DESCRIPTION

Chemical element symbol Mg, atomic # 12, atomic weight 24.312, periodic table group 2a (alkaline earths).

Magnesium is a silver-white metal, malleable and ductile when heated. It occurs extensively in the earth's crust, ranking 8th. An average composition of igneous rocks contains 2.09% magnesium. It ranks 5th as a component of seawater (est 6.125,000 tons/cu.mi.) and is a constituent of over 150 minerals. The most commercially important magnesium mineral is dolomite. There are three naturally occurring isotopes ^{24}Mg through ^{26}Mg. There are three radioactive isotopes which have been identified but the short half-lives (seconds to hours) make them of no interest for discussion as a plant nutrient.

The effect of hydration on the diameter of the Mg^{+2} ion is quite marked and can affect the uptake of the ion. Hydrated ions have a diameter of 0.64 nm while non-hydrated are only 0.16 nm. Both kieserite ($MgSO_4{*}H_2O$) and epsom ($MgSO_4{*}7H_2O$) salts of Mg are hydrated with water but, the effect of hydration is more marked in the epsom form due to the higher # of water molecules incorporated.

NATURAL SOURCES

Only one ionic form, Mg^{2+}, is common both in soils and crops. For agricultural purposes many soils contain adequate quantities of magnesium. In circumstances where amendment is required, dolomite is the most commonly used source material. For purposes of nutrient formulation for soilless culture there are no 'naturally occurring' soluble sources although dolomite is commonly used as an amendment in organic based soilless mixes.

ROLES IN PLANT GROWTH

Magnesium is a key to the assimilation of CO_2 in plants. Mg^{+2} is the central component of the chlorophyll molecule and the amount of chlorophyll present in the leaf determines the CO_2 assimilation capability of the plant. Research indicates that free magnesium in the leaf is as critical to CO_2 assimilation and reduction as the chlorophyll content which initiates the CO_2 assimilation.

There are now meters available which can quite simply test for the chlorophyll content of the leaves enabling more direct control of the magnesium content of the nutrient formulation. Magnesium is highly mobile and the result is that deficiency symptoms tend to occur in the older portions of the plant first. If you are monitoring chlorophyll content in the leaves then the older leaves will give a more accurate picture of the situation.

Magnesium also serves as a cofactor in most enzymes that activate phosphorylation processes, serves as a bridge between pyrophosphate structures of ATP or ADP and the enzyme molecule, and stabilizes the ribosome particles in the configuration for protein synthesis. It is this activity which has led to the belief that Mg acts as a 'carrier' for Ca facilitating the movement of Ca through the plant and into the cells.

Magnesium also serves in non-specific functions establishing osmotic potentials. Specific reactions by which the conformation of the enzyme protein is brought into optimum status (enzyme activation) are the result of magnesium activity. There is an almost linear relationship between protein content in the plant and the Mg concentration in the nutrient solution. Bridging of reaction partners and balancing indiffusible and diffusible anions are additional metabolic activities.

In its activities in enzyme processes it resembles Mn^{+2} and frequently the two ions can replace each other. On the other hand in its enzymic role it is very different from Ca and K.

Plant content of magnesium ranges from 0.15% to 1.00% of the dry weight of leaf tissue, with the sufficiency value being 0.25% in the leaf tissue of most crops. Critical values vary among crops, with the lowest being in grain crops and the highest for legumes and some fruits and vegetables. Tissue concentrations is usually in the order of 0.5% of the dry matter.

The mobility of Mg can easily be noted by the fact that the concentration of Mg^{+2} in the phloem sap is 2-10 times that for Ca. In spite of the fact that Mg is critical in the formation of chlorophyll, in healthy plants only 15-20% of the Mg in the plant is actually contained in chlorophyll compounds.

Unlike many other nutrient elements (N, P, K, Cu, Ca, Fe, Al, B, Zn) the relative plant tissue content of magnesium does not change over the life of the plant tissue.

RELATIONSHIPS WITH OTHER ELEMENTS

Potassium, calcium and magnesium compete for similar uptake sites at plant root surfaces. Increasing concentration of one relative to the others changes their availabilities. Similarly a high sodium (Na) level may depress potassium, calcium, or magnesium uptake. Hence, the balance among the essential plant nutrients, especially potassium, calcium and magnesium is important.

The antagonistic relationship between cations is also related to pH. Ca competition is more effective at higher pH levels while at low pH, H^+ and Al^{3+} can become competitors.

Low levels of K have been shown to result in dramatic increases in the rate and amount of Mg uptake in plants. This relationship can be manipulated to advantage in seasonal adjustments of nutrient solutions for greenhouse plants in relation to available light as well as ensuring timely flowering and fruiting. While high levels of K may suppress Mg uptake, research has shown that increased levels of K (below suppression levels) encourages the translocation of Mg to the reproductive organs of plants resulting in lower concentrations in roots and shoots.

There is also evidence that Mg is antagonistic to the uptake of Mn. Low pH (under 4.5) restricts the availability of magnesium quite dramatically. The optimum pH for the uptake of Mg is about 5 with uptake declining only slightly between 5 & 6. There is quite a sharp decline between 6 & 7 so Mg concentrations must be adjusted to compensate for the pH of the media in most soilless growing operations.

FORMS ASSIMILATED

The only form assimilated is Mg^{+2}.

SUPPLY CONSIDERATIONS

In soilless culture there are only two commonly used source salts, kieserite and epsom salts. It is important to ensure you know which you are getting since both are manufactured by the company which supplies most of the industry. Supplies of kieserite are not always consistent and on one occasion bags marked kieserite actually contained epsom with some pretty drastic results on crops.

OPTIMISING AVAILABILITY

For formulation the critical inter-relationships of magnesium are with calcium and phosphorus. Magnesium needs to be present in the nutrient solution in quantities in excess of actual plant requirements in order to allow uptake.

There is often confusion of the ideal concentrations of magnesium in a nutrient solution. This arises from the common practice of using soil science source material for information on nutrient solutions. What is often forgotten is that the soil provides a buffering capacity which is non-existent in nutrient solutions and only provided on a limited basis by even the best sphagnum moss media.

Soil recommendations are based on the assumption that there is a reservoir of non exchangeable magnesium which will become exchangeable. For solution or soilless culture the levels of Mg^{+2} must be kept levels above 60 ppm. Below this level the plant will potentially develop a low grade deficiency which can affect phosphorus uptake and utilization.

Most of the Mg^{2+} taken up by plant roots moves by diffusion and mass flow of the water. Plant uptake is reduced by the interference of either potassium or ammonium ions competing for the same uptake system. Under very acid conditions aluminum becomes a competing ion.

TESTING

Most of the Mg in the plant can be extracted by using 2% acetic acid or dilute hydrochloric acid.

SULFUR

The ignored primary nutrient

INTRODUCTION

Although many species of plants contain as much or more sulphur than phosphorus, it is often ignored by growers and nutrient manufacturers alike. Sulphur is more commonly relied on to control pest and disease problems which may not have occurred had the plants not been sulphur deficient.

HISTORY

Sicily was the world producer of sulfur until the beginning of the 20th century when Herman Farasch, by inventing the super-heated water method of mining sulfur, made available the great Louisiana and Texas deposits. Sulfur has been used as both a fertilizer and fungicide for many centuries.

It is interesting to note however, that in the mid-19th century the importance and role of sulfur in plant growth was completely ignored. This in spite of the fact that potash was commonly used as a source of potassium and provided levels of sulfur which were critical to plant growth. The research techniques used were basically empirical and the results were constantly misinterpreted.

DESCRIPTION

Chemical symbol S, at. no. 16, at. wt. 32.064, non-metallic element of periodic table group 6a, melting point 112.8C (rhombic), boiling point 444.6C (all forms). Atomic weight varies slightly because of naturally occurring isotopes.

In terms of abundance, sulfur ranks fourteenth among the elements occurring in the earth's crust, with an estimated 520 grams per metric ton. In seawater, the element ranks fifth, with an estimated 894 grams per metric ton.

NATURAL SOURCES

Sulfur is found naturally in soils, the earth's crust being comprised of an estimated 0.06 to 0.10 percent sulfur bearing minerals. Most soil sulfur is found in the form of organic matter, soluble sulfates in the soil solution or absorbed on the soil complex. In humid regions, most of the soil sulfur is associated with the soil organic matter because soluble sulfates are lost by leaching. In arid regions, moderately soluble sulfate salts such as gypsum will accumulate in soils.

Sulfur occurs as free sulfur in many volcanic districts. Another source of S is from the atmosphere. Most fuels contain S and when burned, release SO_2 which may be deposited on the soil by rainfall or taken up directly by the soil or plants. Estimates of atmospheric S deposited range from 1 lb/acre per year to 100 lbs/acre per year near industrial sites and near the ocean.

In some areas a primary source is aerosol sulfate salts whipped up from the ocean and redeposited inland. Irrigation waters may contain dissolved sulfates in varying amounts. The ocean has been the most important source of sulfates in the history of the planet. The sulfur bacteria (*Beggiatoa* and *Thiothrix*), through the process of chemosynthesis, take in hydrogen sulfide and oxidize it, in the presence of sufficient calcium salts to neutralize the sulfuric acid produced, to form calcium sulfate.

River water in the western U.S. has been found (in extreme cases) to contain as much as 2000 lbs S per acre ft. Average amounts are 50 lbs S/acre ft., but quite variable. Well water and mountain streams generally contain much less S, although well water high in S can be found.

Air Pollution - Acid Rain

One of the most significant components of acid ran is sulfur. Combustion results in the introduction of SO_2 into the atmosphere where several reactions take place in the presence of moisture and light energy.

1. $SO_2 + H_2O + O_2$ ---> H_2SO_4 (sulfuric acid)

2. $SO_2 + H_2O$ ---> H_2SO_3 (sulfurous acid)

These acids are produced by and ultimately delivered as precipitation. They have both direct and indirect effects. That is, they can directly damage the plant's structure and metabolism as well as the surrounding environment.

In addition to its contribution to acid rain, SO_2 can enter the plant as a gas and be converted to an acidic form. Sulfur dioxide has long been used as a preservative, so its biocidal prospects are well known. Long-term emissions of SO_2, have and will continue to damage forests and croplands as a direct toxicant and as one of the constituents of acid rain.

ROLES IN PLANT GROWTH

Sulfur is a plant nutrient whose importance in maximizing crop yield and improving crop quality is often overlooked. Sulfur is considered a secondary plant nutrient yet many plants require amounts similar to that of phosphorus, a primary nutrient. The need for sulfur in plant growth and metabolism is well established. It is required for the synthesis of the sulfur containing amino acids cystine, cysteine, and methionine, which are compounds in protein.

Approximately 90 percent of the sulfur found within a plant is contained in these 3 amino acids. Sulfur is needed in the synthesis of important metabolites such as, coenzyme A, which is involved in the oxidation and synthesis of fatty and amino acids.

Sulfur is contained in other substances important in the plant such as S-adenosylethionine, lipoic acid, sulfolipid, and ferredoxin. These compounds are involved in such processes as photosynthesis, nitrite and sulfate reduction, and the synthesis of chlorophyll.

Sulphur is one of the base building blocks for plant proteins as well as for many other plant constituents. Due to its role as a critical component of the results of the respiration cycle it strongly influences the nitrate/nitrogen reduction cycle. This also affects the CO_2 assimilation rather directly. It is also found in amino acids, coenzyme A (found in all living cells) plus vitamins thiamine and biotin.

In legumes the number of root nodules are affected by the availability of sulphur. In other plants the size and health of the root system is affected by the adequate supply of sulphur.

RELATIONSHIPS WITH OTHER ELEMENTS

Nitrogen *esp. nitrate* Nitrogen and sulfur are both required for plant protein production, and normally the tissue ratio is about 15:1. When the ration is greater than 15:1 it indicates a sulfur deficiency, and when the ratio is less than 15:1 it indicates a nitrogen deficiency.

Magnesium Adequate supplies of sulphur improve the chlorophyll supply indicating a close relationship between sulphur and magnesium utilization.

Calcium Excessive levels of sulfates can cause suppression of calcium uptake even when calcium is present in adequate levels.

FORMS ASSIMILATED

SO_2 enters the plant through its stomates. In small quantities SO_2 can be utilized by the plant. However, higher concentrations can cause phytotoxicity.

The sulfate form, SO_4^{2-}, is taken up by plant roots.

SUPPLY CONSIDERATIONS

The only form useful in liquid formulation nutrients is sulfate sulfur. There is no conversion activity which will make any other form of sulfur useful and as a result other forms can result in phytotoxicity and damage to the plants

Potential hazards of sulfate fertilizers

The problem with the thiosulfate ($S_2O_3^{-2}$) ion is that it has been shown to be phytotoxic. Studies dating back to the mid-1940's have shown specific toxicity of thiosulfate, whether it was the sodium, potassium, or ammonium salt that was applied.

Thiosulfate ($S_2O_3^{-2}$), to be detoxified, must be oxidized to the sulfate form SO_4^{-2}. Under most circumstances this conversion is rapid and the $S_2O_3^{-2}$ is not present long enough to damage seedlings. Due to the direct contact with plants in fertigation and hydroponic culture systems it is not recommended that thiosulfate fertilizers be used. Thiosulfate caused toxicity is an all too common occurrence in these systems when it is used in liquid starters and blends. The results are often mis-identified as dampingoff and attributed to other causes.

TESTING

Solution testing for sulfur is seldom done 'in system'. If the formulation has sufficient sulfur incorporated, problems are seldom encountered. Most lab reports provide sulfur level data in both solution and tissue analysis. If your lab does not report this as a standard it would be worth asking for its inclusion.

CHLORINE

from the greek ***chloros***

INTRODUCTION

Chlorine has been one of the ignored nutrients for a number of reasons. It is virtually impossible to create a deficiency in plants. Just the touch of a human hand can be enough to eliminate the potential for any such symptoms showing up. So many water supplies are chlorinated that almost all growers have more than adequate supplies already in the raw water supply.

Since all experience has been related to toxicity damage, many growers and researchers have assumed that chlorine is not a required plant food. This is ridiculous in light of the fact that chloride can be as much as 1% of the dry weight of a plant. For this reason I believe that chlorine should be classified as a macro-nutrient, rather than as the trace element it is generally considered to be.

HISTORY

Chlorine was discovered in 1774 by Scheele, who thought it contained oxygen; named as an element by Davy in 1810.

DESCRIPTION

A chemical element, symbol Cl, atomic number 17, atomic weight 35.453; periodic table group 7a (halogens), mp -101C, bp -34.6C, density 3.24 g/l (0C). Chlorine gas is approximately 2.5 times heavier than air at standard conditions. Chlorine in the gaseous phase is diatomic (mol wt 70.906), pale greenish-yellow, of marked odor, irritating to the eyes and throat, poisonous. At 10C, 3.1 volumes of Cl_2 will dissolve in 1 volume H_2O.

Chloride- A compound which is derived from hydrochloric acid and contains the chlorine atom in the -1 oxidation state. This is the form used by plants and the form discussed for the balance of this section.

NATURAL SOURCES

In nature it is found in the combined state only, chiefly with sodium as common salt (NaCl), carnallite ($KMgCl_3*6H_2O$), and sylvite (KCl).

ROLES IN PLANT GROWTH

One of the main functions of chloride appears to be as an enzyme actuator in the photosynthesis process releasing oxygen from water. Deficiencies appear to adversely affect the root structure and metabolism indicating a role in respiration as well.

Current research indicates there is a critical relationship between chloride, nitrogen assimilation and plant yields. Early results indicate that the nitrogen uptake and utilization by a plant may be cut without detriment to the growth rate or yield as long as the plant receives adequate supplies of chloride. I must stress that this information is at the early research stage only. If and when it is proven we may have another powerful tool available in our art of nutrient formulation.

Chloride is also a critical factor in the drought resistance of plants because of its effect on tissue water content.

Functions in the plant include activity as a counter ion (Cl^- balances the positive electrical charge of Ca^{+2}, K^+, Mg^{+2}, etc.), as a contributor to cell hydration, turgor and growth, and as an enzyme cofactor and photosynthesis aid. Chloride is also important as an osmotic adjustor. The most common physical expression of this is succulence, i.e., thick rubbery leaves and stems.

FORMS ASSIMILATED

Chloride is taken up by plant roots by what is known as active transport. That is, the plant expends energy to acquire Cl^- from the solution.

DISEASE RESISTANCE

For years we have seen reports on the beneficial effects of potassium and, to a lesser degree, sodium in providing disease protection in a variety of crops. Upon re-examination of much of this accumulated data, we see that at least part of the time the beneficial effects may have been due to the fact that KCl or NaCl was the salt used. In many instances it has been suggested or proven that it was indeed the chloride that was beneficial rather than, or in addition to, the Na or K.

Chloride has been shown to be effective in controlling root rot and common rot in a number of soil grown crops. There is evidence of a positive effect on certain leaf diseases in both small grains and broadleafs. The mechanisms of protection are not completely clear, but are not associated with chloride nutritional status. The best evidence points toward root zone osmotic and pH effects which produce a less than optimum environment for the pathogen and produce a more disease resistant host.

SODIUM

*(English soda; Medieval Latin, **sodanum**, headache remedy)*

INTRODUCTION

Sodium has long been a problem in all types of agriculture. Once dissolved in water it can only be removed through reverse osmosis, a very expensive procedure. It is a major contributor to salinity problems in soils and high EC in water supplies. In fact users of reverse osmosis equipment contribute significantly to ground water contamination since they use water softeners to exchange sodium for calcium and then the sodium is discharged with the waste water. Work is underway to determine if potassium salts can be substituted for sodium in water softeners as the contamination in hard water areas with high population is very significant.

Sodium ions are hydrophilic (water loving) and, when wetted, take on a very thick water shell. It is this property which makes it so difficult to remove sodium from the water supply. Growers who obtain raw water from live water sources are advised to pay attention to the changes in water analysis. Sodium levels can be reduced by mixing rain water with the source water if the sodium concentrations are not too high. Sodium tends to be a severe problem is areas with gas fields or deposits, such as central Alberta.

HISTORY

Long recognized in compounds, sodium was first isolated by Davy in 1807 by electrolysis of caustic soda.

DESCRIPTION

Symbol Na (L. natrium) atomic wt. 22.9898; atomic # 11; melting point 97.81+-0.03C; boiling point 882.9C; sp.gr. 0.971 (20C), valence 1.

Sodium is a soft, bright, silvery metal which oxidizes instantly on exposure to air, and reacts with water violently, yielding sodium hydroxide and hydrogen gas. There is only one naturally occurring isotope ^{23}Na. There are five known radioactive isotopes 20Na through ^{22} Na, ^{24}Na and ^{25}Na, all with short half-lives except ^{22}Na with a half-life of 2.6 years.

NATURAL SOURCES

Sodium is present in fair abundance in the sun and stars. Sodium is the sixth most abundant element on earth comprising about 2.6% of the earth's crust; it is the most abundant of the alkali group of metals of which it is a member. In terms of content in seawater, the element ranks fourth (due mainly to the excellent solubility of its compounds), with an estimated 50,000,000 tons of sodium per cubic mile of seawater.

It is a very reactive element and is never found free in nature.

ROLES IN PLANT GROWTH

Very little research has been done on the role of Sodium in plant metabolisms. It forms up to 1% of the dry weight of plants and as such must play significant roles in plant growth. This level of accumulation qualifies it as a macro-nutrient. Yet it is often referred to as the 'non-essential nutrient'. This in spite of the fact that on a biochemical level there is some evidence that Na has a positive effect on carbon fixation pathways such as the so-called C_4 and crassulacean acid metabolism systems. This evidence is very preliminary and will have to be verified.

SILICON

(L. silex, silicis, flint)

HISTORY

Davy in 1800 thought silica to be a compound and not an element; later in 1811, Gay-Lussac and Thenard probably prepared impure amorphous silicon by heating potassium with silicon tetrafluoride. Berzelius, generally credited with the discovery, in 1824 succeeded in preparing amorphous silicon by the same general method as used earlier, but he purified the product by removing the fluosilicates by repeated washings.

DESCRIPTION

Symbol Si. at.wt. 28.086; at.no. 14; m.p. 1410C; b.p. 2355C; sp.gr. 2.33 (25C); valence 4.

NATURAL SOURCES

Silicon makes up 25.7% of the earth's crust, by weight, and is the second most abundant element, being exceeded only by oxygen. Silicon is not found free in nature, but occurs chiefly as the oxide, and as silicates. It is estimated that a cubic mile of seawater contains about 15,000 tons of silicon. In universal abundance silicon is ranked seventh.

ROLES IN PLANT GROWTH

Many plants do benefit from the uptake of silicon. Specific pluses include improved resistance to lodging and general stem strength improvement. This is brought about by the formation of a "silica-cellulose framework" which strengthens cell walls. There is also evidence that silica deposits in cell walls provide a physical barrier to fungal diseases. An additional benefit of Si may be from a competitive reduction in Mn and Fe uptake, which prevents the buildup of toxic levels in the tissue. There is evidence that Si accumulated in both shoots and roots also contributes to drought tolerance in some plants. There may be some relationship between silicates and phosphate availability under certain conditions. Some researchers have proposed enzyme-silicon complexes which act as enzyme regulators in photosynthesis.

The numerous benefits associated with Si include; amelioration of the toxic effects from manganese, iron, and aluminum; disease resistance, greater stalk strength, increased phosphorus availability, reduced transpirational water loss, and even as a filter for ultraviolet radiation which causes frickling on leaves. For an element which is seldom discussed relative to plant nutrition that is an impressive list of "non-essential" contributions.

DISEASE RESISTANCE

It has become standard practice among growers of Long English Cucumbers to add 100 ppm of $Si0_2$ to the nutrient solution to control powdery mildew. Any less has proven ineffective. The treatment must be started immediately upon planting out for maximum control.

Work on a number of crops has shown a foliar application at the rate of 400 ppm is effective on knocking back powdery mildew.

If you start with a silicone program it is wise to test your variety as the Si may have a negative impact on P and K uptake. This may require some reformulation of the solution.

Potassium silicate

SiO_2===K_2O - A compound existing in two forms, solution and solid.

Generally 40% SiO_2. (100 ppm SiO_2 = 0.25 gm/l.) Use in the nutrient solution can cause clogging of emitters. Rockwool growers can apply directly to the rockwool slabs which can anturally contain silicon.

Diatoms extract silica (SiO_2) from both fresh and salt water to build up their cell walls. Deposits of dead diatoms are the source of diatomaceous earth which has proven an effective ally in controlling certain plant pests.

Chapter Six

Deficiency & Toxicity Symptoms for the Macro-Elements

NITROGEN

Toxicity Symptoms

Plants usually dark green in colour with abundant foliage but usually with a restricted root system. Potatoes form only small tubers and flowering and seed production can be retarded or reduced.

Deficiency Symptoms

Plant light green; lower leaves yellow, drying to light brown colour; stalks short and slender if element is deficient in later stages of growth. Growth is restricted and plants are generally yellow (chlorotic) from lack of chlorophyll, especially older leaves. Younger leaves remain green longer. Stems, petioles and lower leaf surfaces of corn and tomato can turn purple.

PHOSPHORUS

Toxicity Symptoms

Overall symptoms are: General yellowing of older leaves, older leaf tips and margins later become yellowish or brownish, followed by coloured necrotic spots; leaf abscission develops (similar to potassium deficiency in some plants and nitrogen excess in others).

Initially mature leaves may appear 'crushed' or wrinkled.

Older leaves may 'brighten' in colour while others appear to go dark green.

In extreme cases leaf internodes will harden and bright dry spots or colour spots may appear on the leaves or fruits.

Excess phosphates in the nutrient solution will precipitate the iron ions. This becomes much more pronounced at low pH. In addition copper and zinc deficiency may appear rather than phosphorus toxicity.

Deficiency Symptoms

This is a mobile element and as such symptoms appear first in older leaves. These symptoms are; Stunted, abnormally dark green plants usually with narrow petiole angles; Abundant reddish or purplish pigmentation or leaves may appear bluish green or black. Sometimes chlorosis of older leaves. Roots may be yellow brown in colour. Stem may be slender similar to nitrogen toxicity, In extreme cases the growing point will be affected. There is commonly no necrosis of tissue:

Seeds produced under conditions of phosphorus deficiency will be fewer in number, smaller, and less viable with resulting lower yields when they are grown.

Fruit production is similarly reduced in size, quantity and quality.

POTASSIUM

Toxicity Symptoms

Seldom if ever occurs due to the fact plants do not generally over absorb potassium. However high levels can cause interactions with other elements such as; magnesium, manganese, zinc, and iron, resulting in deficiency of these elements.

Deficiency Symptoms

Plant roots have to compete directly with soil, media, or any negatively charged surface, for available soluble potassium. As a result growers who feel the levels of potassium supplied are adequate may find their crop displaying deficiency symptoms.

The effects of potassium deficiency on plant metabolism are wide ranging. Starch production is dramatically reduced, cells elongate and fail to divide, and respiration control fails to a marked extent. The result is a weak plant with a high susceptibility to both temperature shock and disease. The onset of deficiency symptoms can be delayed by the presence of available sodium with the resulting increase in actual damage to the plant metabolism.

As a mobile element - symptoms will occur first in the older leaves and move through the plant in reverse order to the ability of the plant parts to demand water. Potassium deficiency is often related to calcium deficiency as either a cause or effect.

Note: As a positive ion K^+ potassium is an active participant in Cation Exchange so the Cation Exchange Capacity of the media can affect K^+ availability in an imbalanced solution.

Plant symptoms

necrosis - older leaves first, initially at tips and between veins, more marked at margins
    dicots - initially chlorotic
    monocots - initially necrotic - tips & margins first
- newer leaves slightly darker than normal
- stunting of growth
- small leaves
- downward cupping of leaves
- short petioles

fruit - soft or puffy - poor shelf life
    uneven ripening
- slender stalks

Correction

foliar spray for correction of deficiency
    - 2% potassium sulphate

typical healthy tissue concentration - dry weight - 1%

CALCIUM

Toxicity Symptoms

Excess calcium is seldom expressed by the plant as a direct toxicity symptom. Rather the symptoms which show are in the related elements such as iron, potassium, or magnesium.

Plant Symptoms

Yellowing of whole leaves, interveinal spots in mature leaves.

Deficiency Symptoms

Pure calcium deficiencies are quite rare; even acid soils almost always have adequate calcium for normal plant growth. Calcium is taken up at the root tip, and any conditions which limit root elongation can cause a calcium deficiency. Because calcium is immobile within the plant, the deficiency is exhibited at the growing point. Calcium deficiencies occur in tomato (blossom end rot), apples (bitter pit), potatoes (black heart), and watermelons, as well as other crops.

Calcium deficiency due to an actual lack of calcium in the soil is uncommon, particularly in western soils where calcium is a common soil constituent. Despite this, deficiencies do occur for several reasons. The ability of the plant to take up calcium is limited since it can be absorbed only by young root tips that have not yet suberized (impregnated by a waterproof and non-absorbent lipoid substance, suberin). Because of this, any condition that limits root growth will also severely restrict calcium uptake. If a deficiency occurs in the growing points of the plant or in the fruit, calcium will not move from the older tissue to where it is deficient. Additionally, calcium competes with other elements, particularly ammonic nitrogen, magnesium, and potassium, for uptake by the plant.

Of particular interest is the interaction of nitrogen and calcium. Some studies have shown that ammonium (NH_4^+) can reduce uptake of calcium, whereas nitrate (NO_3^-) does not reduce uptake or may even have a positive effect. This would indicate that, where calcium is deficient, the addition of soluble calcium and nitrate-nitrogen would be most beneficial.

Because calcium is required for cell division and elongation, deficiencies first appear at root tips and other growing points. Weakened stems, premature shedding of blossoms and buds, and abnormal dark green colour of foliage are also symptoms of calcium deficiencies. Tissue analysis is a good way to determine calcium levels in plant tissue (although not in the fruit). However, tissue analysis should be considered as just a guideline, since calcium levels vary widely between plants, depending on climate, variety, and sampling differences.

The inability of the plant to move calcium to the fruit or tubers can cause certain disorders once thought to be pathological in nature. Blossom end rot of tomatoes and bell peppers, bitter pit of apples, internal brown spot of potatoes, and tip burn in lettuce and cabbage, as well as other disorders, are attributed to localized calcium deficiencies. In many of the these disorders, it is too late to correct the problem once the symptoms are observed. Initial damage often occurs when the fruit is very small and the demand for calcium is greater than the plant can supply.

Correcting Deficiencies

Correction of calcium disorders can be addressed in a number of ways which are related to the actual cause of the problem.

Direct calcium sprays to the fruit have been effective in reducing or correcting calcium disorders. Time for 50% absorption of calcium when applied as a foliar spray 10-94 hours. For foliar sprays a 1% solution of calcium nitrate or a 0.5% solution of calcium chloride are common. This is not a commonly used procedure in greenhouse applications.

Deficiencies in solution concentration can be corrected by the addition of calcium nitrate to the solution. In situations where chlorine is also deficient a minimal amount of calcium chloride can also be used.

Where calcium is actually deficient in a soil, a calcium-containing fertilizer such as gypsum should be used.

Certain cultural factors can improve calcium uptake in the plant. Most of these are easily corrected in greenhouse environments if proper equipment is in place.

Uneven wet and dry periods can disrupt osmotic balances and translocation of calcium and other nutrients in the plant. Therefore, improved irrigation will provide a more consistent flow of calcium to the plant. Frequency and volume of irrigation should be related to the light levels for optimum uptake.

Any environmental condition which reduces the rate of solution uptake will reduce the calcium taken in by the roots; high humidity, low temperature, and low light are common problems in winter growing periods. Temperature can be used to compensate in part for low light conditions. The key is to keep the plant working.

When correcting a calcium deficiency, it is important to keep in mind the interaction with other nutrients. Over-correcting a nutrient deficiency can create a deficiency of another required nutrient. The key is a balanced nutrient approach.

Plant Symptoms

It is important to note that plant symptoms may be a toxic response to other nutrients which are suppressing calcium uptake or an overall response to poor cultural or environmental conditions, in addition to the following symptoms.

Growing point: stunted with discoloration varying according to species.
Young leaves: marginal discoloration, upward curl, spotting depending on species, dry leaf margin, bright leaf between veins.
Fruit: cat facing, blossom end rot, mis-shapen fruit, buds abort or flowers do not set.
Older leaves: downturn, marginal chlorosis or discoloration.

Blossom End Rot

Blossom end rot of tomatoes and bell peppers is probably the most commonly encountered and economically important calcium- related disorder in vegetable crops. Originally blossom end rot was confused with rot organisms and categorized as a pathological phenomenon. Research in the 1950's demonstrated that the problem could be remedied with calcium sprays under certain circumstances, and we now know conclusively that the disorder is nutritional in nature and related to adverse environmental conditions.

Necrosis on the distal end of developing tomatoes and peppers is the most obvious symptom, but by the time this damage is visible, it is too late to correct the deficiency. The initial damage occurs when the fruit is no bigger than the size of a pea, and occurs because the fruit's rapid growth actually outstrips the plant's ability to supply calcium. This relates to the poor mobility of calcium in the plant.

Irrigation scheduling is often a contributing culprit since water alone can have a direct effect through hormonal influence. Under dry conditions the concentration of abscisic acid within plant tissues is higher, while under wet conditions benzyl adenine predominates. These hormonal changes affect nutrient absorption and utilization.

Nutritional effects of calcium, and even nitrogen and phosphorus, have also been implicated in blossom end rot. Tissue levels of calcium in recently matured leaves should be above one percent, with one and a half being optimum. The time frame in which blossom end rot develops is rapid once the concentration drops below the one percent level, and definite symptoms usually show up within two weeks.

Blossom end rot occurs very early in the development of the fruit, so control measures must be applied long before symptoms are evident. For example, if blossom end rot is a problem in the spring, start calcium sprays in the late winter. Remember, the time frame for occurrence of this disorder is quick, so calcium should be applied shortly after first bloom. At this stage there is a large calyx-to-fruit ratio; as with the awns on small grains and the tendrils on peas, the small organs in close proximity to the fruit do most of the nutrient supplying during its initial development.

Since the calyx of the tomato is responsive to nutrient uptake (the skin is impervious), and it supplies most of the energy during the critical early growth of the fruit, the calyx is the most likely target to aim for when making nutrient spray applications, rather than the leaves. Of course, adequate and steady irrigation (as with drip emitters) and proper nutrient source should be considered first, before trying to catch up with nutrient sprays.

Thus, prevention is the key to avoiding blossom end rot due to calcium deficiencies. Properly-timed applications to the correct part of the plant, uniform irrigation schedules, and fertilizer considerations will all aid in avoiding this destructive problem.

MAGNESIUM

Toxicity Symptoms

These are seldom encountered. I have never seen a case or heard a report of one. If a grower were to make a mistake in formulation, such as inadvertently using kieserite instead of epsom, the result would be suppression of another cation with the resulting deficiency symptoms for the affected cation.

There are no specific toxicity symptoms as the content can be high (> 1.0% in plant tissue without inducing a deficiency of either Ca or K. However, an imbalance among these three elements when the Mg content in the plant is high may reduce growth.

Deficiency Symptoms

This is a mobile element in the plant so the symptoms will appear in the older leaves first as an interveinal chlorosis. In cases of moderate deficiency the overall plant colour is a lighter green.

Magnesium deficiency can be induced by high concentrations of either NH_4, K, or Ca in the rooting media, since Mg is the poorest competitor among these cations. It is interesting to note that the uptake of Mg is less affected by elevated NH_4 levels than are Ca (-30%) or K (-50%).

Deficiency of Mg results in loss of green colour, dead brown margins and spots in leaves, often bordered by broad yellow-orange bands. In crops of the grass family, the dead spots form in rows along the leaf, creating a streaked appearance. The critical leaf concentration (Dry Weight) appears to be 0.2% Mg. Anything below this level can result in visible symptoms. Overall plant deficiency will possibly occur at levels higher than this and be compensated for by either Mn or Zn.

When plants are exposed to strong sunlight the Mg deficiency can result in a general withered appearance, reminiscent of K deficiency, where the water content of the plant is disturbed. Individual leaves suffering from Mg deficiency, however, are stiff and brittle and the intercostal veins are twisted. Mg deficient leaves often fall prematurely. Plants inadequately supplied with Mg^{2+} often show a delay of the reproductive phase.

The early symptoms of Mg deficiency may be mistaken for Mn deficiency if the grower forgets the differences of sites in initial appearance. Mg symptoms will appear first on the older leaves while Mn will appear first on the younger leaves near the head of the plant.

The symptoms begin as purple brown 'rectangular' interveinal areas located close to the midrib and major veins of trifoliate leaves. These spots radiate outwards in a characteristic regular pattern. The spotted areas rapidly become necrotic and coalesce into larger scorched areas. The leaflets become generally bright pale green or yellow green then totally bleached.

Adverse rooting conditions such as 'root bound', waterlogged, or water stress can create Mg deficiency symptoms even though there may be adequate supplies of Mg in the root zone. Foliar sprays will alleviate the problem but the solution is to eliminate the adverse environment in the root zone.

Magnesium is unusual in causing very marked visual deficiency symptoms with little or no effect on yield. Even when the symptoms are very severe the plant continues to grow and the yield is affected far less than would be expected. This is due to many reasons which include the mobility of Mg and the ability of both Mn and Zn to take over certain functions normally served by Mg.

Plants especially sensitive to Mg deficiency include apples, corn, potatoes, tomatoes, cotton, citrus, and sugar beets. The range of sensitive crops increases when they are grown in greenhouse conditions and are fed with nutrient solutions. The most sensitive of the greenhouse crops to Mg deficiency is tomatoes.

Correcting Deficiency

Foliar magnesium applications are effective, particularly when used to correct a deficiency caused by heavy fruit load. Magnesium nitrate applied at 20-40 pounds per acre or 3-5 pounds per 100 gallons is effective. Magnesium nitrate can be made by tank mixing calcium nitrate and epsom salts in a ratio of 4 pounds calcium nitrate to 6 pounds epsom salts.

A foliar application of epsom as a 2-4% solution is commonly used on greenhouse crops for treatment of acute deficiencies.

SULFUR

Toxicity Symptoms

Plants are quite tolerant of sulfur and symptoms do not usually show up until concentrations exceed 600 ppm in the solution or root zone. The salts used for formulation seldom yield concentrations this high in any formulas in common use which I am aware of.

There is a general hardening of the plant with a bluish-green coloration of the leaves. Leaves are smaller and stems become hard. Later leaves may curl inward and become pimpled similar to oedema. Extreme toxicity results in browning of leaf margins and terminal growth becomes pale yellow.

High sulfate concentrations may limit calcium uptake and cause calcium deficiency symptoms, even if calcium levels are at optimum.

Deficiency Symptoms

Because of the close relationship with nitrogen assimilation processes deficiencies of sulphur are quite often mistaken for nitrogen problems. Sulphur is another of the elements quite often found in water supplies so care must be taken to ensure the content is included in the formulation process.

Deficiencies should be rare in hydroponic cultures if full formulation solutions are used. They are more likely when 'supplementary formulas' are used for containers or hanging baskets. Symptoms are slow to develop and initially resemble nitrogen deficiency.

Plants are stunted and woody with slender stems. The entire plant may be light to yellowish green in colour. Chlorosis appears in older leaves and may be more pronounced in young leaves which will become yellow. Internodes are longer than normal and older leaves may be thicker than younger leaves.

Chapter 7

THE TRACE ELEMENTS

The Trace elements are so called because of the minute quantities required by the plants. These elements tend to be in the role of catalysts rather than fixed in any structure. They are quite mobile in the plant and the difference between optimum and toxic levels is minute indeed.

IRON

HISTORY

This is such an important element to Man that we have even named an archaeological age after it, The Iron Age which began somewhere around 1000 BC. Plants, being smarter than people, had been making much more effective use of iron for millennia before man discovered its characteristics and uses.

The importance and roles of iron in plant growth are relatively recent. As late as 1867 there was a recognition that plants took up iron as an element but there was no inclusion of this element in discussions of plant nutrition or roles in plant metabolism.

DESCRIPTION

Transition metal of group 8 of the periodic table. A silvery-white metallic element, symbol Fe from the Latin ferrum, atomic number 26, atomic weight 55.847, melting at 1530 C.

NATURAL SOURCES

A heavy, magnetic, malleable, and ductile metal occurring in meteorites and combined in a wide range of ores and most igneous rocks. It is seldom found as a pure native element except in meteorites. The element iron is fourth in abundance of the elements of the earth's crust (5.1%)

Iron constitutes about 4 percent of average soils. This amounts to about 80,000 pounds per acre (90,000 kg/ha) in the first 6 inches of soil depth. In spite of this iron deficiency is very common in the Western half of North America. This is due to the fact that somewhat less than 0.1% of the total iron is actually available.

This is the result of the activity of *Lepothrix* and *Crenothrix*, commonly called iron bacteria. They oxidize ferrous compounds, especially ferrous bicarbonate, into ferric hydroxide and carbon dioxide. Other iron bacteria can reduce ferrous sulfate in the presence of lime. In all cases the iron so reduced remains in the bacteria and is deposited on the death of the bacteria as a compound unavailable to plants.

ROLES IN PLANT GROWTH

Iron acts as an oxygen carrier and as an enzyme catalyst. This makes iron critical to the processes of chlorophyll production, protein synthesis and respiration. As a component of the electron carrier cytochromes iron is very much involved in both photosynthesis and respiration and as a catalyst in chlorophyll production it could be termed a photosynthesis regulator. It is a cofactor in several enzymes and is responsible for their activity. Specific examples are catalase, peroxidase, ferredoxin, and the cytochromes. The participation of iron in the form of such compounds in the oxidative mechanism of cells is undoubtedly one of its more important roles in cellular metabolism.

Iron is comparatively immobile within the plant, and cannot readily be withdrawn from a place of occurrence to newer organs. The proportionate amount of iron in plant tissues is very low; much of that present is a constituent of organic compounds. Iron is one of the most immobile of all elements in plants.

Plants vary considerably in the amount of iron they contain:

Cucumbers and watermelons <0.0004%
Tomatoes, celery, carrots and onions 0.0004-0.00079%
Asparagus and beetroot 0.0008-0.00159%
Parsley, spinach,watercress as much as 0.0020%

RELATIONSHIPS WITH OTHER ELEMENTS

Iron has a special relationship with manganese which appears to act as a counter-reactant, oxidising excess ferrous iron to ferric form. If manganese is deficient then excess active ferrous iron occurs with the unlikely potential of iron toxicity. Excess manganese can oxidize too much ferrous iron to ferric iron resulting in deficiency symptoms.

pH is critical to iron availability in the nutrient solution since under alkaline conditions iron combines very readily with phosphates, carbonates and the hydroxyl ions.

The most critical relationships for iron are with pH, phosphorus, calcium and manganese. Iron uptake is particularly depressed by high pH, phosphorus and calcium. Iron phosphate precipitation can occur within the conducting tissues of the plants in addition to precipitation in the solution or media.

Cu^{2+}, Mg^{2+}, K^{+}, and Zn^{2+} also compete with iron for uptake by the roots. This competition continues within the plant as both Cu and Zn can displace Fe from chelate complexes.

FORMS ASSIMILATED

Both ferric (Fe^{3+}) and ferrous (Fe^{2+}) forms of iron occur in soils. Plants primarily absorb Fe^{2+}. The low solubility of compounds containing Fe^{3+} severely limits its availability and uptake. Plants can also take up chelate compounds. The only physiologically active form in plants is the Fe^{2+} and any Fe^{3+} absorbed has to be reduced to Fe^{2+} immediately upon absorption in the roots. The chelates are generally separated from the iron before absorption although there are circumstances under which the chelates themselves will actually be absorbed.

TOXICITY SYMPTOMS

With all of the problems inhibiting the uptake of iron one could reasonably expect that iron toxicity would be a rare phenomenon. This is in fact the case. The only symptom of toxicity I have seen occurred after foliar application to correct deficiency. The result was some necrotic spots on the leafs where high concentrations had been absorbed.

The only water culture where iron toxicity commonly occurs is in rice paddies where anaerobic bacteria reduce Fe^{3+} to Fe^{2+}. Initial symptoms are the spotting of the leaves (necrosis) with the eventual spread into a uniform brown colour (bronzing).

DEFICIENCY SYMPTOMS

Deficiency symptoms correspond to the role played by the nutrient in a plant's life cycle. If the leaves at the growing tips of new branches turn yellow to nearly pure white while the veins remain green (interveinal chlorosis), the plant lacks adequate iron. Similarly, when only younger leaves exhibit interveinal chlorosis as a sole symptom then the cause is iron deficiency.

Bypassing the rootzone by using foliar sprays is the common method for correcting acute iron deficiency. Sprays enable ferrous iron to be introduced directly into the above-ground parts of the plant. Several chelated and organic materials are available which help avoid the unwanted combining effects of iron with soil or even with dust on leaves. They are the synthetic forms EDTA, EDDHA, DTPA, and HEDTA, as well as organic mixes of iron polyflavonoids and lignosulfonates.

A foliar spray of Iron Chelate (Sequestrene 330) or ferrous sulfate at the rate of 4 ounces per 100 gal of water is commonly used to correct acute deficiencies.

Tissue analysis of 'deficient' plants can be misleading as the iron can be present in the non-active Fe^{3+} form as a result of excessive manganese.

BORON

(Arabic Buraq, Persian Burah)

HISTORY

Boron compounds have been known for thousands of years, but the element was not discovered until 1808 by Sir Humphry Davy and by Gay-Lussac and Thenard.

DESCRIPTION

A non-metallic chemical element; Symbol B; atomic wt. 10.81; atomic # 5; melting point 2300 C; boining point (sublimes) 2550 C; sp.gr. of crystals 2.34 valence 3. Boron exists naturally as 19.78% $^5B^{10}$ isotope and 80.22% $^5B^{11}$ isotope.

NATURAL SOURCES

The element is not found free in nature, but occurs as orthoboric (H_3BO_3) acid usually in certain volcanic spring waters and as borates in borax ($Na_2B_4O_7*10H_2O$) and colmanite. By far the most important source of boron is the mineral rasorite, also known as kernite, found in the Mojave desert of California.

ROLES IN PLANT GROWTH

In spite of the fact that boron is one of the most commonly deficient elements in field crops very little is actually known about its role in plant growth. I have found no definitive research which confirms unconditionally the following suspected roles for boron.

Boron is immobile in the plant so it is necessary that adequate B be available during the complete life of the plant. Deficiencies show up rapidly. Tomato root tips will quit growing within six hours in a B deficient nutrient solution. H_3BO_3 (neutral) is the form taken up by plants from soil solution. The availability is very closely related to pH and is usually unavailable at pH above 6.5. Reduced flowering and seed set are common when a plant is boron deficient.

Boron influences and may even control the ratio in which anions and cations are taken in by the plant. The presence of boron enhances the uptake of cations and limits the uptake of anions. Boron also facilitates the uptake of calcium so there is an important relationship here for nutrient formulation. Both carbohydrate and nitrogen metabolisms are influenced by boron as are the water relations of cell protoplasm and the formation of pectic substances in cell walls. This indicates boron may be a critical factor in the transport metabolism in plants.

RELATIONSHIPS WITH OTHER ELEMENTS

High potassium levels reduce the calcium/boron ratio indicating that potassium may have some substitutional characteristics for boron functions. For formulation purposes our critical inter-relationships are with potassium and calcium. Boron may also be involved in the oxidation processes but sufficient research has not been done to determine the role if any.

NOTES

It is not unusual to find high boron content in some water supplies. Quite often where it exists in water sources the concentration is too high so the boron content of the water must be filtered and the boron removed from the nutrient formulation.

The boron requirements of plants do vary considerably. Generally the dicotyledons (broadleaf plants) have a greater B requirement than the monocotyledons (grasses).

MANGANESE

(L. magnes, magnet from magnetic properties of pyrolusite;
It. manganese, corrupt form of magnesia)

HISTORY

Recognized by Scheele, Bergman, and others as an element and isolated by Gahn in 1774 by reduction of the dioxide with carbon.

DESCRIPTION

A transition element; Symbol Mn; at.wt. 54.9380; at.no. 25; m.p. 1244 C; b.p. 1962 C; sp.gr. 7.21 to 7.44 depending on allotropic form; valence 1, 2, 3, 4, 6 or 7.

NATURAL SOURCES

Manganese is present in igneous rocks to an average extent of 0.10% (weight). In terms of cosmic abundance, the estimate by Harold C. Urey (1952), using a base figure of 10,000 for silicon, the figure for manganese is 75. Manganese is estimated as 34th among the elements in seawater, an estimated 9.5 tons per cubic mile.

Manganese minerals are widely distributed; oxides, silicates and carbonates are the most common. The recent discovery of large quantities of manganese nodules on the floor of the oceans appears promising as a new source of manganese. These nodules contain about 24% manganese together with many other elements in lesser abundance. Large deposits of nodules, extending over many square miles, have been found in Lake Michigan and Lake Superior. Pyrolusite (MnO_2) and rhodocrosite ($MnCO_3$) are common ores.

ROLES IN PLANT GROWTH

The function of manganese can be generally described as that of a catalyst. The highest concentrations occur in the leaves where manganese is involved in carbohydrate metabolism and chlorophyll formation. Mn is required for the synthesis of chlorophyll, but is not actually found in the molecule. It also plays an important role in root aeration. In conjunction with nitrogen it accelerates plant growth.

As an essential element for the oxidizing enzymes in plants manganese plays several key roles. As noted above it is involved in carbohydrate reduction and if it is deficient in the plant growth is retarded, chlorosis occurs, ash content decreases which indicates a relationship with magnesium and calcium plus the plant may fail to reproduce. It is also the controlling catalyst for nitrate reduction so is a factor in the respiration cycle.

As an activator for the enzymes responsible for RNA and DNA formation the presence of manganese is critical. It is also a key factor in the energy storage metabolism of plants in the form of high-energy phosphate bonding. Manganese is a direct participant in the reduction of O_2 from H_2O during photosynthesis.

Another role of manganese is to oxidize excess iron in the plant. The iron/manganese ratio is critical for formulation since an imbalance will result in iron deficiency or toxicity if the manganese is too high or too low. There is an antagonistic relationship between manganese and calcium with each being able to inhibit the uptake of the other.

Manganese is relatively immobile in the plant. Deficiency symptoms, therefore, are most pronounced in new leaves and shoots due to the inability of the plant to mobilize adequate Mn from other areas and move it to points of new growth. Symptoms are similar to, and sometimes easily confused with, those of zinc and iron.

RELATIONSHIPS WITH OTHER ELEMENTS

Critical inter-related ratios exist for nutrient formulation between manganese, iron and calcium. These ratios have not been satisfactorily defined.

FORMS ASSIMILATED

The manganous ion, Mn^{2+}, is actively absorbed by plant roots. Movement is by both diffusion and mass flow. Both inorganic ions and chelated forms can be absorbed directly through leaf surfaces. Caution should be exercised when using chelated forms of Mn. If an iron sulfate is used then the chelates will exchange the Mn for the iron very quickly with the resulting reduction in Mn uptake and a possible result of deficiency.

Solution pH is the dominant determining factor in solubility of Mn. Its solubility (Mn^{2+}) increases 100 times for each unit decrease in pH.

Sources

Manganous sulfate, manganous chloride, manganous carbonate, and manganese chelates EDTA, HEEDTA, and lignosulfonates.

ZINC

German Zink, of obscure origin

HISTORY

Centuries before zinc was recognized as a distinct element, zinc ores were used for making brass. Tubal-Cain, seven generations from Adam, is mentioned as being an "instructor in every artificer in brass and iron." An alloy containing 87% zinc has been found in prehistoric ruins in Transylvania. Metallic zinc was produced in the 13th Century A.D. in India by reducing calamine with organic substances, such as wool. The metal was rediscovered in Europe by Marggraf in 1746. It was recognized as an essential plant nutrient in the U.S. in 1926.

DESCRIPTION

Symbol Zn; atomic wt. 65.38; atomic # 30; melting point 419.58 C; boiling point 907 C; sp.gr. 7.133 (25C) valence 2

Naturally-occurring zinc contains five stable isotopes; ^{64}Zn, ^{66}Zn, ^{67}Zn, ^{68}Zn, and ^{70}Zn. Ten other unstable nuclides and isomers are recognized.

NATURAL SOURCES

The principal ores of zinc are sphalerite or blende (sulfide), smithsonite (carbonate), calamine (silicate) and franklinite (zinc, manganese, iron oxide). Zinc ranks 27th in order of abundance of the chemical elements in the earth's crust, an estimated 0.004% content of igneous rocks on an average basis. It is estimated that a cubic mile of seawater contains about 48 tons of zinc.

ROLES IN PLANT GROWTH

Best described as a regulating catalyst, zinc utilization is closely related to the quantity of light available to the plant. The higher the light levels, the more zinc the plant will uptake, and the result is higher metabolic activity. It is both an enzyme actuator and a component of the plant growth hormone indoleacetic acid.

Zinc aids in the removal of CO_2 from the plant so it may be a specific regulator in plant transport metabolism. There appears to be a critical relationship between zinc and sulphur in its role of regulation of oxidation reduction processes within the cell. There may be a special inter-relationship with copper.

RELATIONSHIPS WITH OTHER ELEMENTS

Zinc interacts with a number of plant nutrients.

Phosphorus Best known is "P induced Zn deficiency" which is commonly associated with high level of available P. It may be that Zn and P are mutually antagonistic whenever either element exceeds some threshold level. Because P is more readily available and translocates more efficiently than Zn, plant parts have a more even distribution of P than Zn. Zinc tends to concentrate at the point of entry. Readily available P may induce Zn deficiency through a dilution effect related to rapid growth.

Nitrogen

This may also induce Zn deficiency. Zn concentration in the roots correlates with root protein N. Thus, increases in N supply may cause more Zn to be retained in the roots as zinc protein complex. The result may be a deficiency of Zn in the tops of the plants.

Copper

Copper strongly inhibits zinc uptake by being a better competitor for absorption sites. In plant tissue Cu deficiency does not affect Zn concentrations but, excess Cu will markedly reduce Zn levels. Zn deficiency is often associated with increased copper levels.

Iron

The mechanism which connects iron metabolism directly to zinc levels is unknown. An excess of either will result in suppression of the other.

FORMS ASSIMILATED

Zinc uptake appears to be active and metabolically controlled. It seems to compete for the same carrier sites as Cu, Mn, and Fe.

NOTES

Zinc deficiency sharply reduces the level of RNA and reduces the stability of ribosome systems. Foliar applications of zinc are best made when the crop is not under stress and the temperature is under 80 deg F. A spreader surfactant is advised. The best compound to use is a chelated zinc.

COPPER

(L. cuprum from the island of Cyprus).

INTRODUCTION

In spite of the fact it is an essential element for plant growth, copper is much better known as an agricultural poison and an algicide in water purification. The toxicity of copper is probably due in part to its combination with thiol groups of certain enzymes, thereby inactivating them.

HISTORY

The discovery of copper dates from prehistoric times; it is said to have been mined for more than 5,000 years. Copper may have been the first metal used by humans and today ranks second, exceeded only by iron, in annual consumption.

DESCRIPTION

A chemical element; [non-ferrous metal] Symbol Cu; atomic wt. 63.546; atomic #. 29; melting point 1083 C; boiling point 2567 C; sp.gr. 8.96 (20 C); valence 1 or 2.

NATURAL SOURCES

Copper occasionally occurs native, and is found in many minerals, such as cuprite, malachite, azurite, chalcopyrite, and bornite.

ROLES IN PLANT GROWTH

The activity of copper in plant metabolism manifests itself in three forms:

(1) synthesis of chlorophyll,
(2) activity of enzymes, and
(3) as an electron carrier.

In leaves most of the copper occurs in close association with chlorophyll, but little is known of its role in chlorophyll synthesis, other than the fact copper is required and is a constituent of plastocyanin. Copper is a definite constituent of several enzymes catalyzing oxidation-reduction reactions (oxidases) in which the activity is believed to be due to the shuttling of copper between the +1 and +2 oxidation state. Copper also influences the disease resistance of plants. It may also play a role in the fixation of N_2 which would indicate a higher requirement in legumes.

RELATIONSHIPS WITH OTHER ELEMENTS

The important ratios for copper appear to be with magnesium, phosphorus, zinc, iron, and molybdenum. Phosphorus can be used to offset the toxic effects of excess copper in saline waters or nutrient solutions. Toxic accumulations normally occur in the roots. Excessive levels of phosphorus can create a deficiency of copper.

FORMS ASSIMILATED

Copper is actively taken up by the plant as Cu^{2+}.

NOTES

The effects of copper deficiency in plants are varied and include; die-back, inability to produce seed, chlorosis, and reduced photosynthetic activity.

Depending on the species and variety, plant symptoms include; shortened internodes, undeveloped seed heads, new leaf stunting, top yellowing, a blue-green colour (vegetables) leaf curl, lack of turgor, reduced flowering; severe cases can resemble potassium deficiency.

MOLYBDENUM

(Gr. molybdos, lead)

HISTORY

Before Scheele recognized molybdenite as a distinct ore of a new element in 1778, it was confused with graphite and lead ore. It was the first of the uncommon elements to be identified. The metal was prepared in an impure form in 1782 by Hjelm.

DESCRIPTION

A chemical element [non-ferrous metal]; Symbol Mo; atomic wt. 95.94; atomic # 42; melting point 2617 C; boiling point 4612 C; sp.gr. 10.22 (20C); valence 2, 3, 4?, 5?, or 6.

NATURAL SOURCES

Molybdenum does not occur native, but is obtained principally from molybdenite (MoS_2), Wulfenite ($PbMoO_4$) and powellite ($Ca(MoW)O_4$) are also minor commercial ores.

Molybdenum is listed as the 42nd element in terms of estimated occurrence in the universe. The element ranks 25th among the elements occurring in seawater, there being an estimated 50 tons of Mo per cubic mile of seawater.

ROLES IN PLANT GROWTH

Molybdenum appears to be a factor in both nitrogen and carbohydrate processes as well as an enzyme coordinating catalyst. It acts as an electron carrier in the nitrate/ammonium reduction cycle and is involved with N_2 fixation.

Mo is a part of the plant enzyme complex that converts nitrogen from the NO_3 state as taken up by the plant to the NH_4 state. Research indicates that only one atom of Mo is required for every million atoms of nitrogen based on actual plant content not presence in the nutrient solution. The more acid the solution becomes, the less available the molybdenum is. A shortage of molybdenum causes the nitrate nitrogen to accumulate in the leaves, resulting in a nitrogen deficiency with the typical symptoms. Mo is also necessary for the N fixation process in legumes. Analysis of the leaf petiole for nitrate levels can provide a check on the availability and uptake of Mo by the plant.

FORMS ASSIMILATED

Mo is unique among the trace elements in that its availability increases as the pH rises. Mo is taken up as MoO_4^{-2} which explains this pH response. Plant requirements are extremely small yet plants seem tolerant to quite high levels of Mo in the tissue. Sulfate ions (SO_4^{-2}) compete for uptake with the molybdenum ions (MoO_4^{-2}). Adequate supplies of phosphorus seem to increase the availability of Mo.

NOTES

Melons and cantaloupes and legumes are excellent indicator plants for Mo deficiencies.

Soluble Mo fertilizer salts commonly used are sodium molybdate (Na_2MoO_4) and ammonium molybdate ($(NH_4)_6Mo_7O_{24}$), however for hydroponic solutions it is best to use chelated molybdenum.

Chapter Eight

WATER,

The Basis of Nutrient Formulation

Compared to outside gardening, hydroponic and soilless culture systems are very water efficient. However, many gardeners ignore the importance of the largest volume material they use in their gardens. More water is used than any other single factor supplied by the grower. Yet most growers simply accept their water as it arrives from source and add what they believe to be the best recipe of nutrient salts.

This commonly results in problems which are blamed on the supplier of the fertilizer. Every grower needs to recognize that the water must be treated in exactly the same manner as any other component of the nutrient solution. In this chapter we will address the process used to create nutrient solutions from the viewpoint of preparing, analyzing, and monitoring, the largest volume ingredient, water.

The Separate Stages to Feeding Plants

There are actually a number of separate stages which must be considered when you are feeding plants.

1. Obtaining or sourcing and determining the analysis of the raw water to be used.

2. Conditioning the raw water before adding any nutrients. This is not always required.

3. The addition of the proper formulation of nutrients in the required concentration PLUS the enhancement of the oxygen levels.

4. The delivery of the solution to the roots of the plants.

5. Monitoring the root zone of the plants.

6. In recycling systems monitoring the solution reservoir.

7. In one-way systems monitoring the waste solution.

Ignoring any of these stages can dramatically reduce the benefits of your feeding program or in some cases simply kill your plants. This is the danger with using the same system as the "guy next door" or "the successful gardener across the country". Successful feeding programs need to be developed by every gardener for their own specific garden. The level of control and monitoring will vary with the garden. It is not much sense to go computer high tech for a hand watering system but, it is important to know what you are doing and what the results are.

Going about this is not really very difficult and help is available at every step along the way. Let's look at things step by step. The first step is to have the proper equipment available and to know how to use it.

Water testing Equipment

The same equipment can be used for testing raw water, nutrient solutions and media from the root zone. How sophisticated and accurate the equipment is will be determined by the garden you are maintaining. As with all equipment there are some basic rules to follow and the equipment must be properly maintained.

Every gardener should own **and use** equipment to test the following properties of water; pH, conductivity and temperature. Oxygen testing equipment should be used by commercial growers.

Raw Water

We all get our water from somewhere. No matter whether it is processed or not, it is considered raw water for our purposes. It is important to know what this water contains. Few municipal water supplies treat for mineral content in their water source and many times they add various elements we need to know about. If you are operating under the fantasy that because you are on a municipal water supply everything is the same year round, you had better wake up quickly.

I have seen analysis on municipal supplies which indicated the water did not even meet local health department standards. I am not referring to tiny remote towns here, I am referring to major cities of North America. In addition the actual mineral content in the water can swing dramatically over the period of the year. No matter where you obtain your water you need a professional analysis from an independent laboratory.

Every water supply should have a complete analysis done a minimum of 4 times per year. In between times the water should be tested for pH and conductivity every time you prepare to mix a nutrient solution. Any dramatic change in either reading indicates the necessity of checking out the reason immediately.

I don't know what the attitude in your local area is but there are a couple of tricks I have learned. If you are asking the municipality to do an analysis of their own water, tell them the sample you provide is well water. In our area if you say the analysis is for horticultural purposes, the price increases by 5 times but the information doesn't change.

Ideally whatever your source of analysis it should cover every mineral in the nutrient solution in addition to pathogens, conductivity, hardness and pH. The things that show up on analysis which cause us the most problems are the trace elements. It helps a lot if your report tells you the actual concentration of the elements found in the water and the state of the elements. In the case of iron you need to know if it is Fe^{2+} or Fe^{3+}.

CONDITIONING RAW WATER

There are many things which can be done to improve the quality of raw water. Many potential problems can be eliminated by treating the water before nutrients are added. There are a wide range of raw water characteristics which can cause problems in your nutrient solution. All can be dealt with and there are some which require more extensive equipment than others. After you have obtained your water analysis you can then judge the extent of your problem and what you need to do. When in doubt, check with your extension agent, local university, or supplier.

TEMPERATURE

I think the most commonly overlooked item is water temperature. The temperature of the source water can be considerably lower than what is beneficial for the plants. Changing the temperature of the water will prevent shock to the roots of the plants. If the water is too cold it can actually cause temporary dormancy in the plant roots.

FILTRATION

This is a standard treatment which should be used on all water sources including municipal. The actual filtration system will relate to the amount of filterable residue in the raw water. This is normally shown on a standard water analysis. The best way to achieve good filtration is to stage several filters in line with the largest mesh treating the water first and the smallest treating it last. This will reduce both pressure and cleaning requirements. To further reduce maintenance it is best, whenever possible, to use a filter which can be flushed rather than having to replace a clogged cartridge. Any time raw water is treated with a catalytic water conditioner, chlorine, ozone, or UV, the treated water should be filtered through a 10 micron filter to capture the precipitates.

HARD WATER

By dictionary definition hard water is: water that contains certain salts, such as those of calcium or magnesium, which form insoluble deposits in boilers and form precipitates with soap.

Raw water which is "chalky", i.e. contains bicarbonates, should be treated to remove the carbon dioxide. This will prevent many of the wild swings in pH experienced by some growers with recycling systems. It will also reduce rapid changes in media pH in drain to waste systems. A combination acidification and oxygenation process is one way to accomplish this.

Filtration will remove a limited amount of dissolved minerals if a fine enough screen is used. This generally increases the water pressure requirements, resulting in quite an expensive installation.

The hardness of untreated water is caused by dissolved materials, calcium bicarbonate being one of the most important. In water the bicarbonate anions are in equilibrium with carbonate anions and carbonic acid, with the latter being formed by the dissolved carbon dioxide gas in water.

$2HCO_3^-$	------->	CO_3^{--}	+	H_2CO_3
bicarbonate	<-------	carbonate		carbonic
anion		anion		acid

In normal uses undersaturated and even saturated waters are not concentrated enough in calcium and carbonate ions to cause scaling. However, carbon dioxide may be lost from water if the water is heated or if the water pressure drops significantly in its transport system. The bicarbonate anions are converted to carbonate anions and the water becomes supersaturated with calcium carbonate. This causes calcium carbonate to precipitate and become a scale problem in various end uses.

$$\underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2} \text{ -----> } \underset{\text{calcium (cation)}}{Ca^{++}} + \underset{\text{bicarbonate (anion)}}{2HCO_3^-}$$

$$2HCO_3^- \text{ ------> } CO_3^{--} + CO_2 + H_2O$$

$$Ca^{++} + CO_3^{--} \text{ -------> } \underset{\text{calcium carbonate}}{CaCO_3}$$

There is a system which has shown excellent results in treating hard water on a non-intrusive basis. It is called a catalytic water conditioner which in fact is a perforated metal bar made of a mixture of heavy metals such as copper, zinc and nickel. Each metal retains its own individuality rather than being an amalgamated alloy - like copper and zinc becoming brass. All of the metals used in the bar are non-ferrous.

When water flows through the perforated metal bar, the pressure drops drastically, causing the dissolved carbon dioxide to escape, which results in the water being supersaturated with calcium carbonate..... The surface of the metal bar has millions of tiny spots with a lattice structure similar to that of calcium carbonate. These tiny spots provide a site for the calcite crystal to form. Because the surface of the bar is non-uniform and these small areas are interrupted by imperfect lattice structures, the calcite crystals can only grow to subcolloidal sizes that are not visible by the light microscope. These tiny crystals are eventually dislodged into the water due to the shearing force of the flow and remain suspended in water.

There is another effect of treatment which is of value to the grower. The reduction in the number of charged ions in the water actually has the effect of making water wetter. This is the result of giving the water fewer points around which to 'organize' itself into the large clumps which create a high surface tension. The reduction in surface tension means less pressure loss in lines and an more even distribution of water in systems such as NFT and the reduction of the tendency of the water to channel when introduced into media.

Sources for the catalytic water conditioner:

Canada: Western Water Farms
103-20120 64th Ave., Langley BC V3A 4P7
1-604-533-9301

USA: Fre-Flo Water Systems Inc.
Box 1136, Williamsburg IA 52361
1-319-668-2881

REVERSE OSMOSIS

Although this water treatment system can yield some very clean water there are some serious drawbacks to its use. It is expensive to install, operate, and maintain. It yields relatively little clean water, generally about 25% of the input water. The most serious concern is the fact that a water conditioner is required to exchange the calcium for sodium before the water reaches the treatment unit. This results in the introduction of sodium into the waste water and this is being recognized as a serious problem. The sodium is seldom present in the raw water and is detrimental to the health of plants, animals and humans. More municipalities are beginning to pass bylaws which prohibit the introduction of sodium into the groundwater for this reason.

DISEASE

Unfortunately there are few laboratories which include plant pathogens as a standard item in routine analysis. The problems usually manifest after the crop is in place and the damage can be considerable. There are three methods of treating raw water which can help reduce disease problems:

A: Chlorination; this is the same treatment used by many municipal water supplies. If chlorination is used the water must be thoroughly aerated to flash off the chlorine before the water is used. If you can smell chlorine the water needs to be aerated before it is used to create a nutrient solution.

B: Ozone Treatment; this is the least expensive and most effective treatment available today. The ozone generators are inexpensive to buy and operate. The ozone is 6,000 times more effective than chlorine and lasts only a matter of seconds in the water before breaking down into oxygen. It has the additional benefit of precipitating excess iron from the raw water making nutrient formulation easier.

C: UV Sterilization; this is seldom used to treat raw water due to the volumes of water involved.

pH ADJUSTMENT

The raw water should be adjusted to a pH which will allow the nutrient salts to be added without further pH correction. If the formula you are using drops the pH of the water by .5 pH then, you would treat the raw water to make the pH just over .5 pH above the final desired solution pH.

OXYGENATION

The water is an important source of oxygen for the plant roots. The raw water is most often very low in oxygen content and can hold quite a bit more. Air misting the raw water as it enters a reservoir, or injecting air into the irrigation tube using a Mazzei injector, can enhance the oxygen content considerably. In one way systems [drain to waste] this is the only opportunity you will have to properly oxygenate the water.

PESTICIDES

(adapted from ATNHC Bulletin)

Even if you operate a garden which never makes use of pesticides or other chemicals, you are not free from the potential they will impact on your water supply. This is a situation where it is imperative that you know what the chemical practices of your neighbours are if you draw your raw water from a well or a live water source (lake or stream).

Pesticides can enter groundwater (spring and well water) by moving downward through the soil or by accidental discharge into wells. They can enter surface water (lakes, streams and ponds) by runoff, soil erosion, spray drift, misapplication and spillage

PREVENTIVE MEASURES TO PROTECT WATER RESOURCES FROM PESTICIDE CONTAMINATION

1. Use pesticides only when required. Follow the label closely and keep spray equipment maintained and calibrated.

2. Learn about soil mobility and persistence of available pesticides used in your watershed area. Consult with your Agricultural Field-person, and check the product label for precautionary statements.

3. Assess the susceptibility of the soil to erosion and pesticide leaching. Soil texture, organic matter and site characteristics should be considered.

4. Consider the location of the water table, and used or abandoned wells and any surface waters. Create a spray free zone of 100 feet (30 meters) next to water and around well heads.
5. Check weather predictions prior to spraying. Avoid spraying for one day prior to predicted rain. Do not irrigate sprayed areas to runoff.

6. Use application procedures which reduce spray drift.

7. Do not fill spray tanks directly from any water source. Use a nurse tank as a direct water source. Do not immerse spray equipment directly into open water.

8. Store pesticides in a separate room away from water supplies (minimum 100 feet; 30 meters). The floor should be impermeable and should have not floor drain.

9. Spray equipment should not be washed or transported in or through a water body.

10. Triple or pressure rinse pesticide containers before disposal at an Agricultural Chemical Container Collection Site in the area (consult your Agricultural Field-person for locations). Rinsings should be re-added to the spray mixture.

11. Use common sense to plan pesticide use and handling procedures so as to prevent the contamination of water.

12. Communicate with other growers, especially field, in your area to learn what their practices are and to ensure you can take precautions to prevent unnecessary contamination.

FACTORS INFLUENCING THE RISK OF WATER CONTAMINATION

1. PESTICIDE PROPERTIES

Solubility: Whether a pesticide dissolves in water will influence whether it moves through the soil (leaches) or is carried away in runoff water. Water soluble pesticides will be more likely to move away from the application site by leaching or runoff.

Absorption: The ability of a pesticide to stick to the surface of a soil particle depends on the type of pesticide and on the characteristics of the soil. Absorptive ability increases with the amount of clay and organic matter in the soil. Pesticides that are absorbed may still move via soil erosion.

Degradation: Pesticides are broken down naturally by sunlight, microbes and chemical reactions in the soil. Some break down slower than others. The longer a pesticide remains in the soil, the greater the chance that it will eventually move into the surface or groundwater.

2. SOIL PROPERTIES

Texture: Soil texture is the composition of sand, silt and clay in the soil. Coarse soils have a high percentage of sand, and allow for fast passage of water (less opportunity for pesticides dissolved in the water to absorb to soil particles). Texture is directly related to soil permeability. Permeability is a measure of the quickness with which water can move through the soil.

Organic Matter: Organic matter absorbs pesticides and holds water, therefore preventing soil erosion and pesticide leaching. Organic matter also provides a good environment for microorganisms which break down pesticides.

3. SITE/ENVIRONMENTAL CONDITIONS

Water Table: A high water table means there is less soil available to retard or filter the movement of dissolved pesticides. It will take less time for a pesticide to reach the groundwater level and therefore less opportunity for breakdown or absorption.

Soil Profile: The permeability of the soil layers between the topsoil and groundwater will influence the risk of groundwater contamination. If the topsoil is underlain by gravel or sand, the risk is increased.

Weather: High rainfall can cause erosion of soils containing pesticides into drainage basins and surface waters. Areas having a wet climate, have more water percolating into groundwater thus higher risk of groundwater contamination.

Slope: Land having a steep slope has a greater potential for soil erosion and runoff, therefore more potential for pesticide movement.

Land Use: Cropping patterns and the use of irrigation will influence pesticide movement away from the field. Incorporated pesticides have a greater opportunity to enter groundwater, over-irrigation can cause runoff or increased leaching, and cropping patterns will influence soil texture as well as the choice of pesticides used.

From this discussion of water, it is easy to realize that understanding your water supply is critical to successful nutrient formulation. Water is the largest volume ingredient to successful formulation and must be addressed in the same way as you approach every other ingredient you use.

Chapter Nine

CREATING YOUR OWN NUTRIENT FORMULAS

After reading the information on each of the elements you should begin to understand that every element in the nutrient solution is in some way related to every other element. The watchword when creating or adjusting formulas is caution. There are 2 concepts you will need to understand in order to work with nutrient formulation. pH and PPM.

pH

In outdoor gardening the terms sweet and sour are applied to soil conditions of alkalinity and acidity. What these terms actually refer to is a scale which tells us how high, or low, the pH (potential hydrogen) is in the water or media. Let's look at the scale.

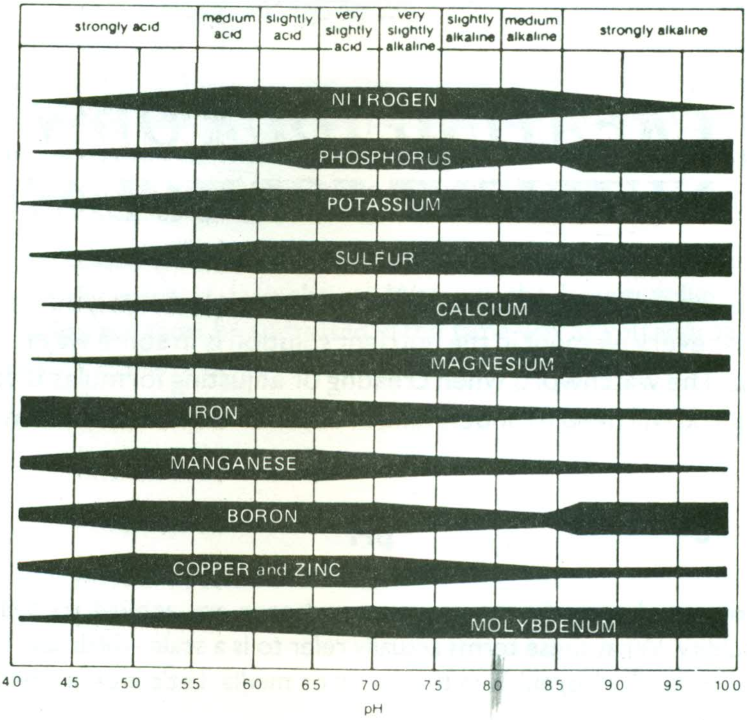
```
                              neutral
                                 V
---------------------------------------------------------------------------
1                                7                                       14
increasingly acid       <----        ---->       increasingly alkaline
```

There are a number of ways of testing the pH of your water supply. The 2 most common are pH test strips and electronic meters. Also used quite often are the "Bromo Blue" test kits from the aquarium industry but they are generally unsatisfactory for our application due to the narrow range of indication. If you have any form of colour blindness at all (I am amazed at how many gardeners do) you will have to use a meter to accurately check your pH.

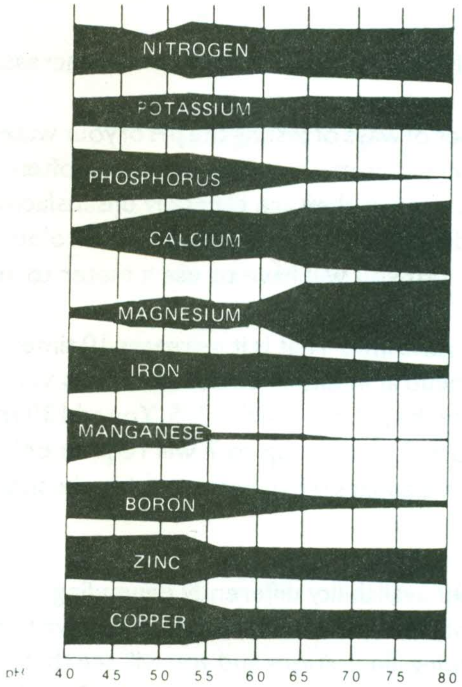
The pH scale is logarithmic. That is it increases 10 times every time you move one unit on the scale out from neutral in either direction. This is very important when it comes to adjusting the pH. Let's say the pH of the water is 5. You add 30 grams of potassium bicarbonate and the reading rises to 6. To adjust up to 7 will require only about 3 grams or 1/10th the original amount. The same applies when you are using phosphoric or nitric acid to move the pH down.

pH affects nutrient availability differently depending on the type of culture being used. Traditionally nutrient availability has been discussed relative to mineral soil or organic culture. Take a look at the following illustrations and you will see that soil-less culture is very different than mineral soil culture in how pH affects nutrient availability.

(MINERAL SOILS)



(SOILLESS MIX)



PARTS PER MILLION (PPM)

This little method of determining concentration seems to cause a lot of confusion because it is related to the metric system of measurement. Metric is the system of science and always has been. In nutrient formulation it is the simplest system to work with since it is based on the number 10.

The term "parts per million" or PPM is merely a way of describing concentration. It is convenient for us because in formulating nutrients we deal in such small concentrations.

1 liter of water = 1,000 cubic centimeters
1 cubic centimeter = 1,000 milliliters
1 cubic centimeter = 1 gram (of water)
1 gram = 1,000 milligrams

so 1 liter = 1,000 grams

and 1,000 x 1,000 = 1,000,000

and 1 liter holds 1,000,000 milliliters or 1,000,000 milligrams

so if we divide the volume of a liter by the volume of 1 gram
the result is 1,000 ppm.

and if we divide the volume of a liter by the volume of 1 milligram
the result is 1 ppm

Here is a chart which may make the conversions a little simpler to understand.

PER CENT	/	GRAMS PER LITER	/	PARTS PER MILLION
100%	=	1,000	=	1,000,000 ppm
10%	=	100	=	100,000 ppm
1%	=	10	=	10,000 ppm
.1%	=	1	=	1,000 ppm
.01%	=	0.1	=	100 ppm
.001%	=	0.01	=	10 ppm
.0001%	=	0.001	=	1 ppm

So how do we go about turning all the information covered to this point into a nutrient formula the plants can use. The easiest method I have found is to follow some simple steps.

1. Get accurate information on the available salts.
2. Determine the formula you want to create.
3. Use a formulation worksheet to do the necessary calculations.
4. Add it all up and make up the formula.

Step 1 is already done. The information on the salts has already been covered. Take a look at the worksheet.

FORMULATION WORKSHEET

DATE ______________________ **CROP**___________________________

SALT	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
TARGET PPM												
WATER PPM TDS ______ **(total dissolved solids)**												
NEEDED PPM												
$Ca(NO_3)_2 * 4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4 * 7H_20$ gm												
TRACE MIX 7% Fe gm												
S gm												
Fe gm												
Mn gm												
Zn gm												
Cu gm												
B gm												
Mo gm												
TOTALS												

(T)___________ total gm all salts incl. TDS in water (B)___________ total gm all salts excl. $Ca(NO_3)_2$

Step 2 was to decide what formula to create. We are going to cheat a bit and use one of the formulas in this book as an example. The last pages of this book are blank worksheets so you can use one as an exercise worksheet. Take out the exercise worksheet and go back and have a look at the Leafy and Preflower formula. This is the formula we are going to use.

Record the PPM shown for each nutrient on the worksheet as your TARGET PPM Your worksheet will now look like this:

FORMULATION WORKSHEET

DATE ______________________ CROP ___________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGETPPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06

Next you would take your water analysis to determine how much of each element is already in the water you are using. For the sake of this example we are going to assume the water is absolutely pure. For your own formulation in actual practice never ever forget to transfer the information from your water analysis to your formulation worksheet. After it is recorded you then subtract the amount of each element already in the water from the total amount recorded as the target ppm.

For our example your worksheet now looks like this.

FORMULATION WORKSHEET

DATE ______________________ CROP ___________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGET PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06
WATER PPM												
TDS												
NEEDED PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06

Now we start to work out the quantity of each salt we need to use to obtain the needed elemental ppm. When you look at the information on each salt in chapter 2 (or Chapter 10) you will see a chart at the end of each description that looks like this.

SALT	**1 gm/l**	**= PPM**	**PPM x factor = gm/l salt**
$Ca(NO_3)_2 * 4H_2O$		155 N	6.4516
NORSK refined		188 Ca	5.319

The first column tells us what salt we are working with.

The second column tells us what the concentration of each element will be if we put one gram of salt into 1 liter of water.

The third column tells us how to calculate how many grams of salt we need to provide the ppm concentration of the element we need.

Since we are looking at the chart for Calcium Nitrate let's fill in the necessary calculations on the worksheet for calcium nitrate. Since we only have one calcium source salt we know that it will have to provide all of the required calcium. Since we need 282 ppm of Ca we need to know how many grams of calcium nitrate will be required. The calculation is simple.

Column 3 of the chart tells us that if we multiply the required ppm by 5.319, the result will be the required weight of salt in grams. (if you recall 1 ppm = 1 milligram per liter). Rather than get involved in more decimal places simply do the multiplication and the result is the grams required for a 1,000 liter mix. It is then simple to move the decimal 3 places to the left to obtain the required answer in grams per liter.

282 x 5.319 = 1,499.958 = 1.499958 grams per liter

Since even a triple beam scale won't measure 1000 th of a gram I simply round off the answer to 1,500 or 1.5 grams per liter.

Now that we know how much salt we are going to use we need to know how much of what other elements the salt will provide. Back to the chart we go. This time to column 2. What we are looking for is the other single elements the salt will provide. In this case there is only nitrogen (N).

Simply multiply the weight of salt in gm/l (in this case 1.5) times the ppm shown in column 2 for N.

1.5 x 155 = 232.5 ppm of N

Record your calculations on the worksheet. It will now look like this.

FORMULATION WORKSHEET

DATE ______________________ CROP__________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGET PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06
WATER PPM												
TDS												
NEEDED PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06
$Ca(NO_3)_2$ * $4H_20$												
gm 1.50	232			282								

Now we continue on with the calculations for the other salts using exactly the same procedure for each in order down the sheet. We also must do the required calculations to determine how much of what we require at each step along the way.

Since the KNO_3 will provide the rest of the N you calculate the balance of ppm for N required by subtracting the amount already provided from the amount originally required.

$$304 - 232 = 72$$

Use column 3 from the KNO_3 chart to determine how much salt will be required then column 2 to determine how much K will be provided. Record the results.

KH_2PO_4 is the only phosphorus source we have so use the required ppm for P to determine the salt weight required then use column 2 for the KH_2PO_4 to calculate the amount of K provided. Record the results.

Add up the K already provided by the KNO_3 and the KH_2PO_4 and subtract the total from the original amount of ppm required for K. The balance is the ppm you use to determine the salt weight of K_2SO_4. Then use column 2 to determine how much S is provided. Record the results.

Use the ppm of Mg required to determine how much salt is necessary. Column 2 calculation will tell you how many ppm of S will be provided. Record the results.

For the formula we are working on we are using a premixed trace element compound. It works out nice and simple here but as soon as you have your water analysis done you may find this type of mix totally useless. It may be necessary to use individual trace element sources to make your calculations come out right or a combination of both may be used.

To do the trace element calculations for this example use which ever of the elements provided that you want to determine the salt weight required and finish your calculations using column 2. Record the results.

Your worksheet should now look like this:

FORMULATION WORKSHEET

DATE ____________________ CROP ________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGET PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06
WATER PPM												
TDS												
NEEDED PPM	304	79	299	282	60	99	7	2	.4	.1	1.3	.06
$Ca(NO_3)_2 * 4H_20$ gm 1.500	232			282								
KNO_3 gm 522	72		149									
KH_2PO_4 gm 348		79	89									
K_2SO_4 gm 115			51			21						
$MgSO_4 * 7H_20$ gm 606					60	78						
TRACE 7% Fe gm 100							7	2	.4	.1	1.3	.06

You will note that on your worksheet there is still a lot of area not used. Only very simple formulas can be created with the limited range of source salts we are using. There are about 200 more available to allow you to cope with any situation or create any formula you may desire. Any of these source salts may be obtained from A FULL SERVICE DISTRIBUTOR along with the required analysis information. The purpose of this book is just to get you started on the simple formulas and explain the techniques used.

Additional formula sheets may be ordered from Growers Press Inc or purchased from the store where you obtained this book.

We are still not finished with this sheet however. Time to double check and see if everything came out right. To do this simply total up the columns on the worksheet and compare the results with the TARGET PPM at the top of the sheet.

PRESTO!! Everything comes out just perfect. This is probably the last time that will ever happen. Quite often when I am working on a new formulation I have to change source salts or compromise on the results. Where I require perfection on a complex formula or where no compromise is possible it can take me a full day of work to obtain the results I want. And I have every bit of information at my fingertips. These resources may soon be available to you as I continue to work on the "The Magic of Nutrient Formulation".

Determing NPK

It is always fun to find out the NPK for the formula you have created so the calculations are shown in the following table. There is a copy of this table on the back of your worksheet.

NPK CALCULATION FOR FORMULA

PPM OF ELEMENT
DIVIDED BY TOTAL SALT WEIGHT (T) TIMES FACTOR FOR NPK

N______________ X .1 = N for NPK
(T) .

P______________ X .22912943 = P2O5 for NPK
(T) .

K______________ X .120464824 = K2O for NPK
(T) .

MIXING CALCULATIONS FOR PREMIXES OR INJECTORS

For concentrate tanks:

multiply grams per liter by injector ratio
and divide by capacity of concentrate tank

INJECTOR 1 OR A MIX

SALT	***GM/L***	***%OF DRY***	***WT FOR 100 KG MIX***
$Ca(NO_3)_2$			
INJECTOR 2 OR B MIX			
KNO_3			
K_2SO_4			
KH_2PO_4			
$MgSO_4 * 7H_20$			
TRACE 7% Fe			

Since most of the commercially prepared fertilizers do not contain calcium in quantities anywhere near the required amount if at all, a separate NPK calculation can be done to compare your fertilizer with commercial preparations. The other thing you should also compare is the actual % content of all of the elements.

NPK CALCULATION FOR B OR INJECTOR 2 FORMULA

PPM OF ELEMENT
DIVIDED BY SALT WEIGHT OF B
TIMES FACTOR FOR NPK

N______________ X 1 = N for NPK
(B)

P______________ X 2.2912943 = P2O5 for NPK
(B)

K______________ X 1.20464824 = K2O for NPK
(B)

Chapter Ten

Conversion Factors for Salts & Compounds

Compound or salt name
Chemical formula   Molecular or atomeic weight

Mult for element \\ Element/Compound (Valence) [M.W.] // **Mult for orig compound**

Note that valence is shown only for elements and compounds which are taken up by the plants.

Ammonium
NH_4 M.W. 18.038300 ↗ Szorzó az alkotóra

.22348	\\H (1) [1.007900]//	4.474650
.776425	\\N [14.006700]// MW	× 1.287955 =M

Ammonium molybdate
$(NH_4)_6Mo_7O_2*4H_2O$ M.W. 883.877200

Ammonium nitrate
NH_4NO_3 M.W. 80.075300

.225387	\\NH_4 (1) [18.038300]//	4.436807
.349993	\\N [14.006700]//	2.857204
.774613	\\NO_3(-1) [62.003700]//	1.290968

Ammonium sulfate - mascagnite
$(NH_4)_2SO_4$ M.W. 132.132600

.211998	\\N [14.006700]//	4.717028
.242621	\\S [32.060000]//	4.121647
.273044	\\NH_4(1) [18.038300]//	4.436807
.726938	\\SO_4 (-2) [96.056000]//	1.375633

Ammonium-orthophosphate mono H
$(NH_4)_2HPO_4$M.W. 132.054260

.022898	\\H (1) [1.007900]//	43.671660
.212142	\\N [14.006700]//	4.713816
.234561	\\P [30.973760]//	4.263286
.273230	\\NH_4(1) [18.038300]//	3.659922
.719208	\\PO_4 [94.969760]//	1.390419

Bicarbonate

HCO_3M.W. 61.015900

\\HCO_3 (-1) [61.015900]//

Borax

$Na_2B_4O_7*10H_2O$ M.W. 381.370000

.113381	\\B (-3) [10.810000]//	8.819843
.120564	\\Na (1) [22.989800]//	8.294341

Boric Acid

H_3BO_3 M.W. 61.830700

Boron

B M.W. 10.820000

Calcium

Ca M.W. 40.080000

Calcium carbonate

$CaCO_3$ M.W. 100.090000

.400440	\\Ca (2) [40.080000]//	2.497256
.599560	\\CO_3 (-2)[60.008000]//	1.667887

Calcium carbonate hexahydrate

$CaCO_3*6H_2O$ M.W. 208.180000

.192526	\\Ca (2) [40.080000]//	5.194112
.288260	\\CO3 (-2)[60.008000]//	3.469089

Calcium chlorate

$Ca(ClO_3)_2$ M.W. 206.990000

.193633	\\Ca (2) [40.080000]//	5.164421
.342558	\\Cl (-1) [35.453000]//	2.919217

Calcium chloride

$CaCl_2$ M.W. 110.990000

.361114	\\Ca (2) [40.080000]//	2.769212
.638850	\\Cl (-1) [35.453000]//	1.583400

Calcium hydroxide

$Ca(OH)_2$ M.W. 74.090000

.459098	\\OH (-1) [17.006900]//	2.178182
.540964	\\Ca (2) [40.080000]//	1.848553

Calcium mganesium carbonate

$CaCO_3*MgCO_3$ M.W. 184.410000

.131799	\\Mg (2) [24.305000]//	7.998766
.217342	\\Ca (2) [40.080000]//	4.601048
.617355	\\CO_3(-2) [60.008000]//	1.619813

Calcium nitrate

$Ca(NO_3)_2*4H_2O$ M.W. 236.150000

.169723	\\Ca (2) [40.080000]//	5.891966
.525090	\\NO_3(-1) [62.003700]//	1.904436

Calcium nitrate - pure

$Ca(NO_3)_2$ M.W. 164.090000

.244256	\\Ca (2) [40.080000]//	4.094062
.755683	\\NO_3(-1) [62.003700]//	1.323306

Carbon

C M.W. 12.010000

Carbon dioxide

CO_2 M.W. 44.010000

.272915	\\C [12.011000]//	3.664141
.727080	\\O [15.999000]//	1.375364

Carbonate

CO_3 M.W. 60.008000

.200150	\\C [12.011000]//	4.996253
.799837	\\O [15.999000]//	1.250255

Carbonic acid

H_2CO_3 M.W. 62.030000

.032497	\\H (1) [1.007900]//	30.771902
.967435	\\CO_3(-2) [60.008000]//	1.033661

Chlorine

Cl M.W. 35.460000

Cobalt

Co M.W. 58.933200

Copper

Cu M.W. 65.340000

Copper II chloride

$CuCl_2$ M.W. 134.440000

.472672	\\Cu (2) [63.546000]//	2.115633
.527417	\\Cl (-1) [35.453000]//	1.896031

Copper II nitrate hexahydrate

$Cu(NO_3)_2*6H_2O$ M.W. 295.640000

.094755	\\N [14.006700]//	10.553520
.214944	\\Cu (2) [63.546000]//	4.652378
.419429	\\NO_3(-1) [62.003700]//	2.384194

Copper II sulfate pentahydrate

$CuSO_4*5H_2O$ M.W. 249.680000

.128404	\\S [32.060000]//	7.878977
.254510	\\Cu (2) [63.546000]//	3.929122
.384723	\\SO_4 (-2) [96.056000]//	2.599274

Fluorine

F M.W. 18.998400

Hydrogen

H M.W. 1.0079

Iodine

I M.W. 126.904500

Iron

Fe M.W. 55.850000

Iron III nitrate

$Fe(NO_3)_2*6H_2O$ M.W. 349.950000

.080050	\\N [14.006700]//	12.492235
.159566	\\Fe3 (3) [55.840000]//	6.267013
.354336	\\NO_3(-1) [62.003700]//	2.822177

Iron III sulfate enneahydrate

$Fe_2(SO_4)_3*9H_2O$ M.W. 562.010000

.171136	\\S [32.060000]//	5.884332
.198715	\\Fe3 (3) [55.840000]//	5.032325
.512754	\\SO_4 (-2) [96.056000]//	1.950254

Iron III sulfate heptahydrate

$FeSO_4*7H_2O$ M.W. 278.005000

.115322	\\S [32.060000]//	8.671388
.200860	\\Fe2 (2) [55.840000]//	4.978594
.345525	\\SO_4 (-2) [96.056000]//	2.894146

Iron chelate

NaFeEDDHA M.W. 614.000000

Iron sulfate (ic)

$NH_4Fe(SO_4)_2*12H_2O$ M.W. 482.167900

.029048	\\N [14.006700]//	34.425667
.037413	\\NH_4(1) [18.038300]//	26.728935
.115805	\\Fe2 (2) [55.840000]//	8.635208
.132977	\\S [32.060000]//	7.520119
.398422	\\SO_4 (-2) [96.056000]//	2.509900

Iron sulfate (ous)

$(NH_4)_2SO_4*FeSO_4*6H_2O$ M.W. 392.117400

.071437	\\N [14.006700]//	13.998300
.142398	\\Fe3 (3) [55.840000]//	7.022565
.163513	\\S [32.060000]//	6.115721
.489915	\\SO_4 (-2) [96.056000]//	2.041171
.920080	\\NH_4(1) [18.038300]//	10.868625

Magnesium

Mg M.W. 24.320000

Magnesium sulfate - Epsom

$MgSO_4*7H_2O$ M.W. 246.480000

.098608	\\Mg (2) [24.305000]//	10.141123
.130071	\\S [32.060000]//	7.688085
.389718	\\SO_4 (-2) [96.056000]//	2.565960

Magnesium sulfate - Kieserite

$MgSO_4*H_2O$M.W. 138.390000

.175627	\\Mg (2) [24.305000]//	5.693890
.231664	\\S [32.060000]//	4.316594
.694108	\\SO_4 (-2) [96.056000]//	1.440698

Magnesium sulfate - pure

$MgSO_4$ M.W. 120.370000

.201919	\\Mg (2) [24.305000]//	4.952479
.266345	\\S [32.060000]//	3.754523
.798019	\\SO_4 (-2) [96.056000]//	1.253102

Manganese

Mn M.W. 54.940000

Manganese II sulfate monohydrate

MnSO4*H2O M.W. 169.010000

```
.189693     \\S        [ 32.060000]//        5.271678
.325058     \\Mn  ( 2) [ 54.938000]//        3.076377
.568355     \\SO4 ( -2) [ 96.056000]//       1.759465
```

Manganese II sulfate tetrahydrate

MnSO4*4H2O M.W. 223.060000

```
.143728     \\S        [ 32.060000]//        6.957580
.246292     \\Mn  ( 2) [ 54.938000]//        4.060213
.430636     \\SO4 ( -2) [ 96.056000]//       2.322148
```

Manganese sulfate

MnSO4*3H20 M.W. 205.040000

Molybdenum

Mo M.W. 95.950000

Monammonium phosphate

NH4H2PO4M.W. 115.023860

```
            \\NH4(  1) [ 18.038300]//
            \\H2PO4( -1) [ 96.985560]//
```

Monopotassium phosphate

KH2PO4 M.W. 136.090000

```
.014812     \\H   (  1) [  1.007900]// 67.511658
.227598     \\P        [ 30.973760]//        4.393719
.287236     \\K   (  1) [ 39.090000]//       3.481453
.697857     \\PO4 [ 94.969760]//             1.432958
```

Nitrate

NO3 M.W. 62.000000

```
.225915     \\N        [ 14.006700]//        4.426453
.774165     \\O        [ 15.999000]//        1.291715
```

Nitric acid

HNO3 M.W. 63.010000

```
.222293     \\N        [ 14.006700]//        4.498561
.159959     \\H   (  1) [  1.007900]// 62.516123
.983971     \\NO3( -1) [ 62.003700]//        1.016290
```

Nitrogen

N M.W. 14.010000

Orthophophoric acid

H_3PO_4 M.W. 98.000000

	\\HPO_4(-2) [95.977660]//	
.030854	\\H (1) [1.007900]//	32.410623
.316059	\\P [30.973760]//	3.163969
.969096	\\PO_4 [94.969760]//	1.031890

Orthophophoric acid hydrate

$2H_3PO_4$*H_20M.W. 214.010000

	\\HPO_4 (-2) [95.977660]//	
.047096	\\H (1) [1.007900]//	21.233257
.289461	\\P [30.973760]//	3.454698
.887541	\\PO_4 [94.969760]//	1.126708

Oxygen

O M.W. 15.999000

Phosphate

PO_4 M.W. 94.971360

.326138	\\P [30.973760]//	3.066188
.673635	\\O [15.999000]//	1.484484

Phosphoric anhydride vs

P_2O_5 M.W. 141.940000

.436435	\\P [30.973760]//	2.291294
.563407	\\O [15.999000]//	1.774916

Phosphoric tetraoxide vs

P_2O_4 M.W. 125.950000

.491842	\\P [30.973760]//	2.033173
.507948	\\O [15.999000]//	1.968707

Phosphorus

P M.W. 30.980000

Potassium

K M.W. 39.100000

Potassium bicarbonate

$KHCO_3$ M.W. 100.120000

.010067	\\H (1) [1.007900]//	99.335251
.390431	\\K (1) [39.090000]//	2.561269
.599381	\\CO_3(-2) [60.008000]//	1.668389

Potassium carbonate

K_2CO_3 M.W. 138.210000

.434194	\\CO_3(-2) [60.008000]//	2.303116
.565661	\\K (1) [39.090000]//	1.767843

Potassium chloride - murate

KCl M.W. 74.560000

.475496	\\Cl (-1) [35.453000]//	2.103066
.524276	\\K (1) [39.090000]//	1.907393

Potassium hydroxide

KOH M.W. 56.110000

.303106	\\OH (-1) [17.006900]//	3.299172
.696667	\\K (1) [39.090000]//	1.435405

Potassium nitrate - saltpeter

KNO_3M.W. 101.110000

.138529	\\N [14.006700]//	7.218688
.386609	\\K (1) [39.090000]//	2.586595
.613194	\\NO_3(-1) [62.003700]//	1.630806

Potassium sulfate

K_2SO_4M.W. 174.270000

.183967	\\S [32.060000]//	5.435746
.448614	\\K (1) [39.090000]//	2.229087
.551200	\\SO_4 (-2) [96.056000]//	1.814224

Selenium

Se M.W. 78.960000

Selenium dioxide

SeO_2 M.W. 110.960000

.288381	\\O [15.999000]//	3.467630
.711608	\\Se [78.900000]//	1.405268

Selenium sulfur oxide

$SeSO_3$M.W. 159.020000

.201610	\\S [32.060000]//	4.960075
.496541	\\Se [78.900000]//	2.013931
.503459	\\SO_3 [80.057000]//	1.986260

Silicon

Si M.W. 28.080000

Sodium

Na M.W. 22.989800

Sodium Molybdate dihydrate

$Na_2MoO_4*2H_2O$ M.W. 241.950000

.190037	\\Na (1) [22.989800]//	5.261231
.396528	\\Mo [95.940000]//	2.521889
.661029	\\MoO$_4$ [159.936000]//	1.512755

Sodium tetraborate pentahydrate

$Na_2B_4O_7*5H_2O$ M.W. 291.300000

.148438	\\B (-3) [10.810000]//	6.736818
.157843	\\Na (1) [22.989800]//	6.335427

Sulfur

S M.W. 32.070000

Sulfuric acid

H_2SO_4 M.W. 98.090000

.020551	\\H (1) [1.007900]//	48.660581
.326843	\\S [32.060000]//	3.059576
.979280	\\SO$_4$ (-2) [96.056000]//	1.021158

Water

H_2O M.W. 18.014800

.1118968	\\H (1) [1.007900]//	8.937047
.888101	\\O [15.999000]//	1.125999

Water - dissociation

H_2O M.W. 18.014800

.0559484	\\H (1) [1.007900]//	17.873598
.9440515	\\OH (-1) [17.006900]//	1.092641

Zinc

Zn M.W. 65.380000

Zinc sulfate monohydrate sl. s

$ZnSO_4$*H2O M.W. 179.453000

.178654	\\S [32.060000]//	5.597411
.364329	\\Zn (2) [65.380000]//	2.744769
.535280	\\SO$_4$ (-2) [96.056000]//	1.868181

Chapter Eleven

Formulation Notes

NITROGEN

Excess nitrogen (NO_3 source) results in soft succulent plant parts which are very susceptible to mechanical damage, insect damage and disease.

With the wide distribution of nitrogen through the organic molecular structure it is not surprising to find that the use and availability of nitrogen is closely related to and strongly influenced by; phosphorus, carbon, potassium, magnesium, chlorine, light, CO_2 and pH.

The relationship with light is again worth noting as it relates to seasonal variations in the environment especially in the areas of temperature and light. The seasons providing lower light and temperature levels should be balanced with lower nitrogen availability as related to the other plant nutrients.

PHOSPHORUS

When formulating a nutrient solution phosphorus is the element you use as a starting point. The other elements supplied by the salts or compounds used will then lead you through your formulation. As you proceed to utilize your other salts to provide all necessary elements, balance the anion/cation ratios as you go. The general formulation range of concentrations are;

Deficiency <30 ppm;
Optimum 30-90 ppm (80);
Excess 100 ppm.

Notes on water supply:

Analysis is required to determine phosphate levels. Levels can be high from various industrial processes and domestic gray water waste contamination of the water table. This tends to be more prevalent in rural areas on well water supply or in water drawn from rivers downstream of industrial plants dumping phosphate wastes. Another source is the local laundraumat in areas with no waste water treatment.

When preparing your nutrient solution always ensure that the phosphorus is not mixed in extreme concentration with the calcium salts especially and to a lesser extent the magnesium salts or you will cause the phosphorus to combine with the calcium or magnesium in an insoluble form. Calcium and phosphorus combine to make a great plaster of Paris.

The use and availability of phosphorus is inter-related with calcium, nitrogen, potassium, iron and pH. Especially in situations of low pH the phosphorus will precipitate the iron ions.

POTASSIUM

The relationship between potassium and sodium is based on the fact that both have the potential to neutralize the effects of calcium. Unfortunately sodium cannot play any of the nutritive roles of potassium. Sodium is one of the most active elements which plants can take up yet it is required only in trace quantities. If there is a potassium shortage and a presence of sodium the plant will take up the sodium. The problem is that the excess sodium will have no nutritive use to the plant and results in an increase in the salinity of the plant fluids. This has a severe restriction on the operation of the plant metabolism and can result in death. **It is important to ensure that in areas where sodium is present in the water (<100 ppm) that an equal amount of potassium, in addition to the formulation amount, is included in solution to ensure sodium suppression.**

When raising osmotic pressure of nutrient solutions for low light or winter growing the ratio between potassium and calcium must be kept in balance as a key starting point for the macro-element formulation balance.

As with nitrogen the amount of potassium in a nutrient solution can be manipulated according to seasonal and environmental changes. This is an inverse relationship with the changes being in the opposite direction. Higher light levels mean less potassium but more nitrogen while lower light levels mean more potassium and less nitrogen.

CALCIUM

Magnesium deficiency has been observed where calcium levels in rockwool slabs start climbing over 300 ppm, and that can happen because all the calcium we supply is not used up and can build up in the slab.

The ratios in the fertilizer solution which we try to achieve are:

Potassium:Calcium	2-3 : 1
Calcium:Magnesium	3-4 : 1

Those growers who check slab leachate should remember that ratios of the above nutrients in the slab are likely to be closer and may approach 1:1 Potassium:Calcium during early picking or when there is a heavy load of fruit on the plants.

The best source of calcium for drip irrigation, fertigation or hydroponic or soilless formulation has been the greenhouse grade calcium nitrate from Norsk Hydro.

MAGNESIUM

As with any element, an analysis of raw water is necessary to determine magnesium levels. Acceptable raw water levels of magnesium range from 6-24 mg/l with no reformulation necessary.

Growers must keep in mind how pH affects Mg availability and the fact that it is easily leached from the root zone media. Other cations such as calcium can buildup and suppress magnesium uptake. Often availability can be enhanced by simply dropping the pH of the feed solution to just below 6 which is quite normal for soilless media culture.

For fruiting plants there can be a considerable buildup of Potassium and Calcium in the rootzone when there is a heavy load of fruit. Many plants take up only water for a few critical hours when flowers are initiated and the result is a temporary sharp increase in slab EC.

High conductivity and pH reduces magnesium uptake. At the time of maximum fruit load and natural root loss there may be problems with the root environment which result in reduced Mg uptake and also affecting phosphorus utilization which will reduce root regeneration.

Low temperature in the root zone also inhibits root development. Combined with high EC a low temperature will inhibit magnesium uptake severely. For tomato, cucumber and pepper growers where flowering, fruit set, fruit development and harvest are all occurring at the same time, ensuring adequate availability of magnesium can be quite a balancing act to maintain EC, pH, cation balance, and root zone temperature within optimal ranges.

When kieserite is used as an Mg source and Mn levels are in the upper range of acceptable concentration the appearance of Mn toxicity symptoms may in fact be an indication that the salt being used is Epsom rather than kieserite.

SULFUR

Time for 50% adsorption of sulfur when applied as a foliar spray is 5-10 days. This application automatically occurs when foliar sprays of magnesium sulfate are used to correct magnesium deficiencies which may in fact be induced by sulfur deficiency.

Sulfuric acid is exothermic in reaction when mixed with water, i.e. large quantities of heat are generated. For this reason water should never be poured into sulfuric acid. The acid should always be added slowly and in small quantities to the water.

The amount of elemental sulfur in sulfate form in a complete formulation should be at least equal to or higher than the phosphorus concentration. A target level of 100-150 ppm has shown good results.

A gallon of distilled water with a thimble full of sulfuric acid will register roughly the same pH as a gallon of 50 percent H_2SO_4 as urea sulfuric fertilizer, even though the fertilizer contains much more acid. Poorly buffered and light textured soils are especially susceptible where acid mixes are included in the drip system. The application of an acid containing fertilizer to an already acidic soil or media will not produce the same results as when applied on a neutral or alkaline one.

Urea sulfuric formulations have the added advantage of removing carbonates, algae and bacterial slimes when used according to manufacturer's recommendations. Areas with hard water or high lime soils have benefitted significantly from their use. Other areas of poorly buffered soils with a high potential for acidification are not recommended sites for the prolonged use of acid containing or acid forming fertilizers.

CHLORINE

Extreme caution must be taken with chlorine in nutrient formulations. Usually sufficient exists in the source salts of other elements. Because of its role as a catalyst it can very quickly accumulate to toxic levels in the plant. Quite often there are considerable quantities of chlorine in municipal water supplies. If excessive quantities are present the water must be aerated for 24 hours prior to use to eliminate the chlorine.

TRACE ELEMENTS

It is important not to use excessive chelates in formulation where non-chelated sources are used to supply the heavy metal elements copper and zinc.

IRON

The type of nitrogen fertilizer used can affect Fe absorption. Nitrate (NO_3^-) fertilizer leads to an alkalization effect in the root zone, therefore lowering iron availability. Using NH_4^+ acidifies the root zone and encourages iron availability. In soilless culture nitrate is the best source of nitrogen so it is important to offset the pH to compensate and maintain iron availability.

Chelates are the most commonly used form of iron for all forms of soilless culture. The chelates are cyclical or cage-shaped molecules which are negatively charged and hold a positively charged metal ion such as iron in its interior. The strength with which a chelate holds a particular micronutrient depends on the solution acidity/alkalinity. For example, Fe-EDTA is poorly chelated above pH 7. Fe-EDTA is excellent for use in foliar sprays but is susceptible to high Ca as EDTA has an affinity for Ca ions. Fe-DTPA is preferable for use in nutrient solution formulation.In recycling systems where steps have been taken to sterilize the solution it is essential to replace iron which will precipitate out of solution when exposed to UV or ozone sterilization.

Chapter Twelve

pH & EC

The tools that measure them.

pH

There are a number of products available for testing the pH of water. They fall into two general categories; reagent testers which depend on colour change and electronic sensors. Historically the reagent testers have been the most popular because they are seen to be the least expensive. This is very seldom true today.

Reagent Based pH Testers

Included in this group are things such as bromothymol blue and phenol red. Most are familiar with these as part of the kit provided to test the swimming pool or aquarium. In addition the testing strips such as ColorpHast and Merquant are reagent based testers. There are limitations common to all reagent testers.

1. The range is very limited. If you are outside of the range you don't know how far and too much adjustment can put you off the other end of the scale.

2. Different reagent solutions are required for raw water and the high saline content of nutrient solutions. Many gardeners attempt to use the same solution to check raw water and nutrient solutions and get wrong answers as a result.

3. The testing results are based on colour. Over the years I have discovered that over 70% of the North American population is colourblind in one area of the spectrum or another. If there is only one colour check and the colour variations are subtle it can be very difficult to obtain an accurate reading. In my experience I have seen gardeners operating from readings as far out as 1.5 pH points and swear they were doing everything right even though their plants were dying.

4. The type of light the comparisons are done under will affect how accurate the colour comparison is. If you take a reading one day in the greenhouse and the next day do your test under fluorescent lights the results will be dramatically different.

5. Virtually all reagents are light sensitive. If the material is accidentally exposed to light the accuracy of the results of testing is definitely suspect.

6. All reagents whether in solution or impregnated on a material are susceptible to humidity. If you accidently leave the container open, especially in the high humidity of a growing environment, water will be absorbed and future readings will be inaccurate.

Electronic pH Testers

Over the years I have come to the conclusion that you are wasting your money if you buy an electronic pH meter with any sensor other than a gel filled glass probe. In the past this type of meter was expensive. Today these meters are available for less than the cost of a years supply of reagent testers.

There are many options available and it is important to know the accuracy and range of the meter you are considering. For most growing applications the meter need only be accurate to .2 of a pH point.

The features you should look for in a pH meter are as follows.

1. Calibration Capability. Some meters can be adjusted only to a standard 7 buffer solution. Better quality meters utilize both the buffer 4 and buffer 7 solutions. There are very expensive models which have built-in calibration memories which a grower will seldom be able to justify the cost of.

2. Temperature Compensation - Manual or Automatic. this is an important feature and is unfortunately not available on most pen type meters. Readings do vary with temperature and it is important for accuracy to be able to compensate for temperature. The non-compensating pens are fine for quick readings if they have been calibrated to 7 at the temperature of the solution you will be checking.

3. Probes. The probe must be of the semi-permeable glass, gel-filled or refillable type. I have yet to see any other type of probe which will consistently give an accurate reading. The type of probe construction is important. There are many things which affect pH measurements; electromagnetic noise, humidity, and dirty environments. For a pH probe a greenhouse is a dirty, humid environment. Probes do not last forever. The life for a non-refillable probe used every day is about 18 months maximum if it is well cared for. If the meter you purchase does not have a replaceable probe you are buying a throw away meter.

4. Accuracy. This is related to two things, the quality of the meter and the probe construction. For horticultural purposes a range from 2-12 is more than adequate. At either end of the scale your plants are already dead. The inexpensive meters should be accurate to within .2 pH while the more expensive the meter the more accurate it should be. There are meters available to an accuracy of up to .001 pH but I doubt if any grower will ever require one.

5. Power supply. Batteries are still the best. They give a more consistent power supply than most adapters available and they eliminate a lot of electromagnetic noise. A battery check feature is one you will want on any meter used for bench work. The first culprit to check on fluctuating or "out-to-lunch" readings is the battery. If you like to forget to turn the meter off after use, I suggest you buy shares in a battery company.

6. Readout. I prefer the dial over LED. The reason is that the dial is easier to read in bright sunshine even though the LED is more precise.

7. Accessories. If you are like me, if it is not handy you ignore the requirement. There are up to 5 items which are essential to accurate readings, depending on the quality of your meter; **1**- pH buffer 4, **2**- pH buffer 7, **3**- distilled water, **4**- a thermometer, and **5**- a protective carrying case.

For hobby gardeners or spot checks in the commercial greenhouse the inexpensive pen type meters are great. They can identify a problem on the spot. For more accuracy and bench testing in a commercial range I always use a remote probe meter which can be temperature compensated and is dual buffer calibrated for accuracy.

Care and Maintenance of a pH Meter

Maintaining the accuracy of your meter and extending its useful life requires attention to proper operation and care of the meter. Failure to follow these steps will result in inaccurate readings and a short life for your probe at the least.

1. Always ensure the glass probe is kept moist. Distilled water in the cap covering the probe is a good way of doing this. On the pens a bit of wet cotton batten holds more moisture and eliminates the need to carry distilled water. If you leave the probe uncovered for any period of time it will dry out and rapidly become useless. Some probes can be refilled but if they cannot you may have to invest in a new meter or probe.

2. Rinse the probe after every use. If you test a solution and do not rinse the probe, salt can build up resulting in inaccurate readings. Also the semi-permeable glass bulb can be clogged or damaged.

3. Calibrate the meter each time you take it out for use. Even the temperature of the air can affect the electronics and therefore your readings. By calibrating each time you use the meter you will get much more accurate readings.

4. Protect your meter from wide temperature swings. If you leave the meter in full sun on a summer day in the greenhouse don't be surprised if the readings are inaccurate. The internal board can have been heated to ridiculous temperatures.

5. Check your batteries regularly. This is where the battery check feature is really handy. When readings appear to be way off, or if there is rapid fluctuation in the reading, the primary suspect is the batteries. There are meters which can use both batteries and an adaptor but my experience has shown the adapters seldom deliver the precise current levels of batteries. If the adaptor does not deliver a precise current your reading can be out to lunch. I prefer to stick to the batteries. You do have to remember to turn the meter off after each reading. The alternative is to buy shares in your favorite battery company.

6. No electronic meter gives an "instant reading", you must allow time for the reading to stabilize. Know what the manufacturers recommendations are for your meter.

7. Remember that no pH probe will last forever. If the probe on the meter you are considering is not replaceable, you are essentially buying a throw-away meter. Good quality probes can also be refilled reducing the need for replacement.

Conductivity Meters

The reason I will discussing only one system is I have yet to find another one that works. Amongst the meters, which are essentially based on a very old principle, the Wheatstone bridge, there are many variations in the readouts which are offered. The meters all work on the electrical conductivity of the solution being tested.

You have to pay attention to correlating the information from the fertilizer company and the information from your meter. I had to sort out one grower who was accepting instructions from his brother who used a different readout than the one on his meter. The result was disaster.

These meters are available with readouts in micromos, millimos or parts per million. It really doesn't matter which scale you use, they can be converted back and forth with ease. What is important is to know which scale you are using and to ensure that when you are getting advice or instructions you find out which scale the other party is using.

By the way, none of these meters will identify the actual individual mineral content of the solution. Again there are essentials to the proper care and maintenance of a conductivity meter.

With these meters as with the pH meters they are available in a range of models. The features you should look for in the meter are as follows.

1. Calibration capability. Some meters feature an automatic calibration check which is very useful. Any meter you purchase should have a calibration adjustment. Standard calibration solutions are available to ensure accuracy.

2. Temperature Compensation - Manual or Automatic. Readings vary dramatically at different temperatures. It is important to be able to get an accurate reading at the temperature of the solution.

3. Properly designed probe. I still prefer the remote probe type of meter although I do use a pen type for quick checks. Experience with cup type probes has shown a tendency for leaks to occur around the cup in several brands. This leakage causes corrosion of the electronics and is not covered by warranty.

4. Accuracy. A good general meter should be accurate to 2% of full scale with a repeatability of within 1% for readings. A less accurate reading leaves the potential for quite inaccurate readings. Keep in mind a 2% error on a scale of 10,000 ppm is 200 ppm while the same error on a scale of 5,000 is only 100.

5. Scale. Obtain a meter which gives you readings within the range of the solution you will generally work with plus about 1,000 on either side of the high/low range you require. This will keep the meter readings as accurate as possible.

6. Power Supply. Batteries are preferred to adapters for consistent voltage supply and more accurate readings. Just remember to turn the meter off when not in use.

Care and Maintenance of Conductivity meters.

As with the pH meters the conductivity meter you use will look after you only as well as you look after it.

1. Calibrate the meter each time you first take it out for the day.

2. Rinse the probe in distilled water after every reading and before putting the meter away. Leaving solution water on the meter will lead to salt build up and inaccurate readings.

3. Periodically rinse the probe in a solution such as 7% acetic acid vinegar to dissolve any salts which may have accumulated on the probe. Do Not use strong solutions of acid. Rinse the probe in distilled water before putting it away or using it.

4. Check your batteries regularly to ensure accurate readings.

5. Periodically examine the probe electrodes to ensure they are clean. Never use an abrasive material to clean the electrodes.

Temperature Meters & Thermometers.

A thermometer is no less accurate than any temperature meter. The advantage the meters have is the response time and the readability. So much for temperature measurement and monitoring. Oh, right, the glass in thermometers breaks easier, I almost forgot that.

Tips and tricks

All of the above noted meters can be used for all three types of analysis and monitoring; raw water, nutrient solution and media [including soil.

Media Analysis

To do a media analysis with either a pH or conductivity meter you need a container which is marked for volume and some de-ionized distilled water. Put 2 parts water and 1 part media into the container. Let it sit for at least 2 hours. Shake the mixture vigorously and let sit for an additional hour. If the minerals haven't entered into solution by now they will not affect the root zone in the short term. Strain the mixture through a coffee filter and take your readings.

Chapter Thirteen

Carbon Dioxide Enrichment

When everything else is in balance, the proper application of carbon dioxide enrichment will produce worthwhile results.

Sources of Carbon Dioxide

There are two common sources of CO_2 for horticultural applications; Bottled CO_2 and the combustion of either propane or natural gas. The following chart provides a comparison of these options.

ITEM	BOTTLED CO_2	PROPANE	NATURAL GAS
Safety	no flames, non-explosive	burner required, CO production	burner required, CO production
Installation	simple, inexpensive	relatively simple, moderate cost	professional, expensive
Handling	easy, safe, tanks	tanks of combustible gas	easiest, no bottles
Operation Cost	most expensive	moderate	least expensive
Maintenance	minimal	regular	professional
Efficiency	100%	best conversion	poorest conversion, high water production
Gas Quality	varies by supplier	best	sulfur contamination possible
Equipment Required	tank, regulator, flowmeter, solenoid valve	tank, regulator, generator with specific nozzles	certified connection, regulator, generator with specific nozzles.
Controls	The same controls may be used for all systems		

USING BOTTLED CO_2

Bottled CO_2 is contained in a highly pressurized tank (839 psi) which is rated by the number of pounds of CO_2 gas which it holds. The actual tank weight is considerably higher so for the hobby grower a tank with an 80 pound rating is about the maximum you would ever want to consider. For commercial growers, suppliers send out trucks to refill the permanent installation tanks.

There are a variety of flowmeter regulators sold for CO_2 gas but not all are designed to do the job. CO_2 gas is very cold and improperly designed units commonly freeze-up. For large commercial systems it is often better to zone the operation with a number of regulator/flowmeters and solenoid valves than trying to do the whole range directly from the tank.

Research has shown that the optimum levels of CO_2 in the growing area (greenhouse or phytotron/growroom) can vary from 400 to 1,200 ppm depending on the species and age of the crop. One advantage of bottled gas is that control of small area systems can be left to mechanical timers by using some simple calculations.

Calculating the gas delivery time required for any growing area.

1. Calculate the cubic area of the environment LxWxH

[e.g. 15x8x10 = 1200 cu. ft.]

2. Determine the concentration of CO_2 desired for your area, then subtract the ambient level (300 ppm usually) to arrive at the enrichment required.

[eg 1,500 desired - 300 ambient = 1200 required]

3. Convert the ppm required to a decimal [e.g. 1200 ppm = 0.0012] and multiply by the cubic feet in the area to arrive at the number of cubic feet of gas required.

[e.g. 1200 cu.ft. x 0.0012 = 1.44 cu.ft. of CO_2 gas.]

4. Divide the result of step 3 by the flow rate set on the flow meter to arrive at the time the system must be on to achieve the desired concentration.

e.g. if the flow rate is 2 cu.ft./hr then

1.44 cu.ft. divided by 2 cu.ft./hr = 0.072 x 60 minutes = 43 minutes on time.

This is the rate which would be required if the growing area is periodically cleared by a complete air exchange to control humidity or temperature. If no air changes are occurring and the greenhouse is tight (one air change per 4 hours) then the rate is valid only for the first cycle of the day. Subsequent cycles at 2 hour intervals would be on 1/3 of this time, or 15 minutes.

Note that commercial growers should always use a proper monitor controller to maintain desired levels economically and to integrate the system with other environment control equipment.

COMBUSTION SOURCE CALCULATIONS

CO_2 generators are rated in a number of ways. To help straighten things out and make conversions simple, use the table. Once you have determined what your combustion requirements are, it is simple to choose the proper generator. Keep in mind you should choose the smallest generator which will service your needs. I have seen greenhouses for hobby and research which had large commercial CO_2 generators installed. The pilot light alone was enough to keep CO_2 levels excessively high 24 hours a day.

To calculate your required burner operation time:

1. Convert the generator rating into cu.ft./hr of CO_2
2. Follow steps 1-3 as outlined for CO_2 gas.

Again it is important that commercial growers use a proper infra-red sensor equipped monitor controller.

This information will allow you to choose the proper CO_2 source for your application. There are other integrated factors to be considered in the operation of such a system including the effects on temperature and humidity. Optimum results will only be achieved if you maintain a proper environmental balance. Carbon Dioxide is in fact a plant nutrient and as such can be manipulated. However it will only yield results when it is part of a complete environment and nutrient control program.

When examining the potential in your system you can keep in mind that optimum economical response to CO_2 enrichment has been shown to vary according to both environment and stages of plant growth. The order of response as related to economy and effectiveness is as follows.

1 Propagation and seedlings
2. Transplant
3. Winter growing conditions
4. Main growing area with maturing and producing plants.

Keep in mind that the plant's ability to assimilate CO_2 is increased for a considerable time after the enrichment program is ended.

CO_2 Source Specifications Chart

Characteristic	**Propane**	**Natural Gas**	**Pure CO_2 Gas(839 psi tank)**
Cu.f.t/lb of tank	8.88	N/A	8.74
BTU/cu.ft. of combustion	2,520	1,000	N/A
cu.ft. air required per cu.ft. gas burned	23.5	9.85	N/A
cu.ft CO_2 produced per cu.ft. burned	3.0	1.04	N/A
cu.ft. CO_2 per 1,000 BTU	1.19	1.04	N/A
cu.ft. H_2O per cu.ft. CO_2 produced	1.3	2	N/A
cu.ft. N_2 produced per cu.ft. burned	18.5	8	N/A

Chapter Fourteen

Nutrient Formulas from Around the World

BABACO FORMULA

from Chaim Kempler *Ag. Cda Agassiz, BC*

Throughout the duration of our experiments with growing the babaco in the greenhouse, we had success in using an 18 deg C day temperature and 12 deg C night temperature, and providing nutrients through a trickle irrigation system. In 500 l. of water we included the following nutrients:

380 g calcium nitrate (15.5-0-0)
275 g potassium nitrate (13-0-46)
125 g magnesium sulphate
140 g monopotassium phosphate
7.5 g PlantProd chelated micronutrient mix

Each plant received up to 6 litres of nutrient solution per day. Sulfuric acid was used to adjust the pH in the range of 6.0-6.5.

Basic CUCUMBER

Feeding Formula for Sawdust

Salt	**For 1000 L.**
Calcium nitrate $Ca(NO_3)_2$ 15.5-0-0 + 15% Ca	900 g
Magnesium sulphate $MgSO_4$ 0-0-0 + 10% Mg	320 g
Monopotassium phosphate KH_2PO_4 (0-53-34)	200 g
Potassium nitrate KNO_3 (13-0-46)	350 g
Potassium sulfate K_2SO_4 (0-0-50)	100 g
Iron Chelate (10% Fe)	10 g
Manganese sulphate (28% Mn)	1.07 g
Solubor (20.5% B)	2.43 g
Zinc sulphate (36% Zn)	276 mg
Copper sulphate (25% Cu)	170 mg
Sodium molybdate (39% Mo)	78 mg

PPM
185 N
46 P
229 K
170 Ca
32 Mg
42 S

1.0 Fe
0.3 Mn
0.5 B
0.1 Zn
0.05 Cu
0.05 Mo

Note: Growers with alkaline water sources should make the following changes:

1. Delete Monopotassium phosphate
2. Add 75% Phosphoric acid (0-53-0) 46 P 200 g
3. Add Potassium chloride (0-0-60) 56 K 115 g
   or Potassium sulphate (0-0-50) 56 K 135 g

Formulation notes

Target pH 5.8-6.0

Australian Nutrient Solutions

from Eugene Diatloff

The nutrient formula used for **strawberries** is:

N (as nitrate)	101 ppm	N (as ammonia)	3 ppm
P	44 ppm	K	208 ppm
Ca	123 ppm	Mg	51 ppm
S	134 ppm	B	0.6 ppm
Mn	0.3 ppm	Zn	0.1 ppm
Cu	0.05 ppm	Mo	0.02 ppm
Fe	3.0 ppm		

We aim to keep the pH at 6.0-6.5 and EC at 1.6-1.8 mS/cm (CF 16-18). During fruiting we increase K slightly as K_2SO_4 and during the vegetative phase more potassium nitrate is added. With this nutrient solution we have not experienced any nutrient deficiencies. However, we have had problems early this season with high boron levels in older leaves when solution B levels were around 1.0 ppm.

Lettuce

For lettuce we make the following adjustments to the basic formula outlined for strawberries:

N	increase to 156 ppm	P	decrease to 28 ppm
K	increase to 252 ppm	Ca	decrease to 93 ppm
Mg	decrease to 26 ppm	S	decrease to 34 ppm

All of the formulation values are the theoretical calculations from the actual amounts of technical grade fertilizer added. We use pH and conductivity meters as well as nitrate colour test strips daily but, tissue/nutrient analysis is done only when needed. Most recipes have been designed for the following conditions:

- pH 5.5 to 6.5 - Oxygen 3 ppm to 10 ppm
- Nutrient temp. 18 deg. C to 25 deg. C
- Air temp. 10 deg.C to 35 deg.C
- Light; full sunlight - CO_2 above 200 ppm
- Water Sodium less than 50 ppm
- CF 5 to 35 - Metal contamination: None

Basic PEPPER Feeding Formula
for Sawdust Culture

Salt	**For 1000 L.**
Calcium nitrate $Ca(NO_3)_2$ 15.5-0-0 + 15% Ca	900 g
Magnesium sulphate $MgSO_4$ 0-0-0 + 10% Mg	320 g
Monopotassium phosphate KH_2PO_4 (0-53-34)	200 g
Potassium nitrate KNO_3 (13-0-46)	350 g
Potassium sulfate K_2SO_4 (0-0-50)	100 g
Iron Chelate (10% Fe)	15 g
Manganese sulphate (28% Mn)	1.07 g
Solubor (20.5% B)	2.43 g
Zinc sulphate (36% Zn)	276 mg
Copper sulphate (25% Cu)	170 mg
Sodium molybdate (39% Mo)	128 mg

Note: Growers with alkaline water sources should make the following changes:

1. Delete Monopotassium phosphate
2. Add 75% Phosphoric acid (0-53-0) 46 P 200 g
3. Add Potassium chloride (0-0-60) 56 K 115 g
   or Potassium sulphate (0-0-50) 56 K 135 g

The target pH of the dilute fertilizer solution should be 5.3 - 6.2. The addition of an acid (Phosphoric, Sulphuric, or Nitric) or a base material (Potassium Bicarbonate or Potassium Hydroxide) may be necessary to achieve the proper pH range.

PPM
185 N
46 P
231 K
170 Ca
32 Mg
50 S

1.5 Fe
0.3 Mn
0.5 B
0.1 Zn
0.05 Cu
0.05 Mo

FORMULATIONS FOR PERLITE CULTURE

Liquid Feed Formulations

Houseplants

Stock A	***gm/l stock soltn***
Calcium nitrate	78 g
Potassium nitrate	20 g
Iron EDTA (13% Fe)	1.5 g

Stock B	
Potassium nitrate	20 g
Monopotassium phosphate	14 g
Magnesium sulphate	30 g
Manganese Sulphate (32% Mn)	160 mg
Borax	300 mg
Zinc sulphate (23% Zn)	400 mg
Copper sulphate (25%)	80 mg
Sodium molybdate	13 mg

Dilute to give a conductivity of 1500 uS/cm prior to feeding.

Carnations

Stock A	**gm/l stock soltn**
Calcium nitrate	40 gm

Stock B	
Potassium nitrate	23 gm
Potassium sulphate	11.5 gm
Monopotassium phosphate	8.74 gm
Magnesium sulphate	16.1 gm
Trace element mix	0.985

Gerberas

Stock A	***gm/l stock soltn***
Calcium nitrate	40 gm

Stock B	
Potassium nitrate	21.1 gm
Potassium sulphate	15.1 gm
Mono ammonium phosphate	8.11 gm
Magnesium sulphate	16.2 gm
Trace element mix	1.19 gm

SWEET POTATO IN CELLS TUSKEGEE NFT *NUTRIENT FORMULATION*

The preferred nutrient solution composition and protocol is the continuous application of a solution which consists of in ppm, 58-116 N as NO3; 7-14 N as NH4; 117 K; 80 Ca; 24 Mg; 16 P; 32 S; 0.25 Mn; 0.025 Zn; 0.01 Cu; 2 Fe; 0.25 B; 0.005 Mo; and 254 Cl, replaced bi-weekly with a fresh supply. The pH of the system preferably is between 5.5 and 6.5, with the electrical conductivity of the solution ranging between 500 and 2200 micromhos per centimetre, with the preferred range being between 900 and 1800.

STRAWBERRY FORMULA *from Chaim Kempler*

N - 80 ppm P - 45 ppm K - 100 ppm
Ca - 200 ppm Mg - 50 ppm B - 0.5 ppm
Mn - - 0.5 ppm Zn - 0.5 ppm Cu - 0.05 ppm
Mo - 0.05 ppm Fe - 3 ppm

Basic TOMATO Feeding Formula
for Sawdust Culture

Salt	**For 1000 L.**
Calcium nitrate $Ca(NO_3)_2$ 15.5-0-0 + 15% Ca	760 g
Magnesium sulphate $MgSO_4$ 0-0-0 + 10% Mg	320 g
Monopotassium phosphate KH_2PO_4 (0-53-34)	200 g
Potassium nitrate KNO_3 (13-0-46)	600 g
Iron Chelate (10% Fe)	15 g
Manganese sulphate (28% Mn)	1.78 g
Solubor (20.5% B)	2.43 g
Zinc sulphate (36% Zn)	280 mg
Copper sulphate (25% Cu)	170 mg
Sodium molybdate (39% Mo)	128 mg

Note: Growers with alkaline water sources should make the following changes:

1. Delete Monopotassium phosphate
2. Add 75% Phosphoric acid (0-53-0) 46 P 200 g
3. Add Potassium chloride (0-0-60) 56 K 115 g
   or Potassium sulphate (0-0-50) 56 K 135 g

The target pH of the dilute fertilizer solution should be 5.3 - 6.2. The addition of an acid (Phosphoric, Sulphuric, or Nitric) or a base material (Potassium Bicarbonate or Potassium Hydroxide) may be necessary to achieve the proper pH range.

PPM
192 N
46 P
275 K
144 Ca
32 Mg
42 S

1.5 Fe
0.5 Mn
0.5 B
0.1 Zn
0.05 Cu
0.05 Mo

General & Historical Formulas

Rothamsted Hoagland & Snyder Date:1933 Component:all Basis:ppm
N:139 P:117 K:593 Ca:116 Mg: 48 S:157 Fe:8.000 Mn: .250 Cu: B: .200 Zn: Mo:

Rothamsted Hoagland & Snyder Date:1938 Component:all Basis:ppm
N:210 P: 31 K:234 Ca:200 Mg: 48 S: 64 Fe: .100 Mn: .100 Cu: .014 B: .100 Zn: .010 Mo: .016

A.J.Abbott Date: Component:all Basis:ppm
N:150 P: 60 K:200 Ca:210 Mg: 50 S:147 Fe:5.600 Mn: .550 Cu: .064 B: .500 Zn: .065 Mo: .050

California - UC Davis Date: Component:all Basis:ppm
N:211 P: 31 K:234 Ca:160 Mg: 48 S: 64 Fe: Mn: Cu: B: Zn: Mo:

Dr. Elizabeth Pilgrim NC Date: Component:A Basis:ppm
N: 72 P: 47 K:200 Ca:136 Mg: 27 S:119 Fe: Mn: Cu: B: Zn: Mo:

Dr. Elizabeth Pilgrim NC Date: Component:B Basis:ppm
N:108 P: 70 K:300 Ca:204 Mg: 41 S:178 Fe: Mn: Cu: B: Zn: Mo:

Dr. Elizabeth Pilgrim NC Date: Component:C Basis:ppm
N:143 P: 93 K:400 Ca:272 Mg: 54 S:238 Fe: Mn: Cu: B: Zn: Mo:

Dr. H.M.Resh UBC Date:1971 Component:A Basis:ppm
N: 90 P: 40 K:200 Ca: 99 Mg: 22 S: 83 Fe:2.000 Mn: .500 Cu: .030 B: .500 Zn: .050 Mo: .020

Dr. H.M.Resh UBC Date:1971 Component:B Basis:ppm
N:130 P: 55 K:300 Ca:148 Mg: 33 S:144 Fe:2.000 Mn: .500 Cu: .030 B: .500 Zn: .050 Mo: .020

Dr. H.M.Resh UBC Date:1971 Component:C Basis:ppm
N:175 P: 65 K:400 Ca:197 Mg: 44 S:198 Fe:2.000 Mn: .500 Cu: .030 B: .500 Zn: .050 Mo: .020

Duclos Date:1957 Component:all Basis:ppm
N:210 P: 27 K:234 Ca:136 Mg: 72 S: 32 Fe:3.000 Mn: .250 Cu: .150 B: .400 Zn: .250 Mo:2.500

E.B.Kidson Date: Component:all Basis:ppm
N:208 P: 57 K:234 Ca:340 Mg: 54 S:114 Fe:2.000 Mn: .250 Cu: .050 B: .500 Zn: .050 Mo: .100

Eaton Date:1931 Component:all Basis:ppm
N:168 P: 93 K:117 Ca:240 Mg: 72 S: 96 Fe: .800 Mn: .500 Cu: B:1.000 Zn: Mo:

Hoagland Date:1919 Component:all Basis:ppm
N:158 P: 44 K:284 Ca:200 Mg: 99 S:125 Fe: .100 Mn: Cu: B: Zn: Mo:
Fe as reqd

Hoagland & Arnon Date:1938 Component:all Basis:ppm
N:210 P: 31 K:234 Ca:160 Mg: 48 S: 64 Fe: .600 Mn: .500 Cu: .020 B: .500 Zn: .050 Mo: .010

Jones & Shrive Date:1921 Component:all Basis:ppm
N:243 P: 65 K:102 Ca:292 Mg:172 S:227 Fe: .830 Mn: Cu: B: Zn: Mo:

Knop Date:1865 Component:all Basis:ppm
N:206 P: 57 K:168 Ca:244 Mg: 24 S: 32 Fe: .200 Mn: Cu: B: Zn: Mo:

Long Ashton Soln Date: Component:all Basis:ppm
N:140 P: 41 K:130 Ca:134 Mg: 36 S: 48 Fe:5.600 Mn: .550 Cu: .064 B: .500 Zn: .065 Mo: .050

New Jersey Date: Component:all Basis:ppm
N:147 P: 71 K: 90 Ca:180 Mg: 55 S: 96 Fe:Mn: Cu: B: Zn: Mo:

Purdue Date:1948 Component:A Basis:ppm
N: 98 P: 63 K:390 Ca:200 Mg: 96 S:607 Fe:***** Mn: .300 Cu: .020 B: .500 Zn: .050 Mo:

Purdue Date:1948 Component:B Basis:ppm
N:168 P: 63 K:390 Ca:200 Mg: 96 S:447 Fe:1.000 Mn: .300 Cu: .020 B: .500 Zn: .050 Mo:

Purdue Date:1948 Component:C Basis:ppm
N:238 P: 63 K:390 Ca:120 Mg: 96 S: 64 Fe:1.000 Mn: .300 Cu: .020 B: .500 Zn: .050 Mo:

Resh Tropical Formula Lettuce Date:1984 Component:Dry Summer Basis:ppm
N:230 P: 60 K:200 Ca:250 Mg: 36 S:129 Fe:5.000 Mn: .500 Cu: .030 B: .500 Zn: .050 Mo: .020

Resh Tropical Formula Lettuce Date:1984 Component:Wet Summer Basis:ppm
N:147 P: 50 K:150 Ca:150 Mg: 50 S: 52 Fe:5.000 Mn: .500 Cu: .030 B: .500 Zn: .050 Mo: .020

Robbins Date:1946 Component:all Basis:ppm
N:196 P: 31 K:195 Ca:200 Mg: 48 S: 64 Fe: .500 Mn: .250 Cu: .020 B: .250 Zn: .250 Mo: .010
Fe as reqd

Saanichton Formula Date: Component:A Basis:ppm
N:126 P: 37 K:209 Ca:131 Mg: 22 S: 30 Fe:1.700 Mn: .800 Cu: .035 B: .460 Zn: .094 Mo: .027

Saanichton Formula Date: Component:B Basis:ppm
N:168 P: 37 K:209 Ca:146 Mg: 22 S: 30 Fe:1.700 Mn: .800 Cu: .035 B: .460 Zn: .094 Mo: .027

Saanichton Formula Date: Component:C Basis:ppm
N:210 P: 37 K:209 Ca:146 Mg: 22 S: 30 Fe:1.700 Mn: .800 Cu: .035 B: .460 Zn: .094 Mo: .027

Schwartz - Israel Date: Component:all Basis:ppm
N: 98 P: 93 K:312 Ca:124 Mg: 43 S:160 Fe: Mn: Cu: B: Zn: Mo:

Shive Date:1915 Component:all Basis:ppm
N:148 P:448 K:562 Ca:208 Mg:484 S:640 Fe: .200 Mn: Cu: B: Zn: Mo:

Shive & Robbins Date:1942 Component:all Basis:ppm
N: 56 P: 46 K:117 Ca: 60 Mg: 53 S: 70 Fe:0.000 Mn: .150 Cu: B: .100 Zn: .150 Mo:

South Africa Date: Component:all Basis:ppm
N:200 P: 65 K:300 Ca:320 Mg: 50 S: Fe: Mn: Cu: B: Zn: Mo:

Tumanov Date:1960 Component:all Basis:ppm
N:100 P: 80 K:150 Ca:300 Mg: 50 S: 64 Fe:2.000 Mn: .500 Cu: .050 B: .500 Zn: .100 Mo: .020

White Date:1943 Component:all Basis:ppm
N: 47 P: 4 K: 65 Ca: 50 Mg: 72 S:140 Fe:1.000 Mn:1.670 Cu: .005 B: .260 Zn: .590 Mo: .001

Carnations

Hydro-Chronicle/Hydro-Gro Date:1991 Component:all Basis:ppm
N:190 P: 35 K:237 Ca:152 Mg: 39 S: 52 Fe:3.600 Mn: Cu: .050 B: .230 Zn: .090 Mo: .010
Mn not listed ?????

Lettuce

Hydro-Chronicle/Hydro-Gro Date:1991 Component:all Basis:ppm
N:127 P: 32 K:208 Ca: 86 Mg: 30 S: 40 Fe:3.100 Mn: Cu: .040 B: .200 Zn: .080 Mo: .010
Mn not listed ?????

Sample Commercial Pre-mixed Powders

Mix 1 Top Australia formulas Date:1991 Component:all Basis:ppm
N:239 P: 45 K:243 Ca:166 Mg: 44 S: 59 Fe:4.360 Mn:1.100 Cu: .065 B: .270 Zn: .110 Mo: .010
Mix 2 Top Australia formulas Date:1991 Component:all Basis:ppm
N:219 P: 41 K:223 Ca:152 Mg: 41 S: 54 Fe:4.000 Mn:1.000 Cu: .060 B: .250 Zn: .100 Mo: .010
Mix 3 Top Australia formulas Date:1991 Component:all Basis:ppm
N:210 P: 34 K:297 Ca:114 Mg: 33 S: 44 Fe:3.200 Mn: .800 Cu: .050 B: .210 Zn: .080 Mo: .010
Mix 4 Top Australia formulas Date:1991 Component:all Basis:ppm
N:204 P: 41 K:284 Ca:152 Mg: 47 S: 62 Fe:4.400 Mn:1.100 Cu: .065 B: .320 Zn: .110 Mo: .010
Mix 5 Top Australia formulas Date:1991 Component:all Basis:ppm
N:197 P: 38 K:261 Ca:152 Mg: 43 S: 57 Fe:4.000 Mn: .990 Cu: .060 B: .250 Zn: .100 Mo: .010
Mix 6 Top Australia formulas Date:1991 Component:all Basis:ppm
N:192 P: 31 K:327 Ca:114 Mg: 35 S: 47 Fe:3.200 Mn: .800 Cu: .050 B: .210 Zn: .080 Mo: .010

Strawberries

Hydro-Chronicle/Hydro-Gro Date:1991 Component:all Basis:ppm
N:169 P: 34 K:221 Ca:133 Mg: 32 S: 42 Fe:3.200 Mn: Cu: .050 B: .210 Zn: .090 Mo: .010
Mn not listed ?????

Tomatoes

Hydro-Chronicle/Hydro-Gro Date:1991 Component:all Basis:ppm
N:210 P: 38 K:247 Ca:133 Mg: 33 S: 44 Fe:4.000 Mn: Cu: .060 B: .250 Zn: .110 Mo: .010
Mn not listed ?????
Hydro-Chronicle/Hydro-Gro Date:1991 Component:all Basis:ppm
N:196 P: 49 K:319 Ca:133 Mg: 46 S: 61 Fe:4.700 Mn: Cu: .070 B: .300 Zn: .130 Mo: .020
Mn not listed ?????

Appendix 1.

CONVERSION TABLES FOR IMPERIAL, US AND METRIC UNITS

Weight Conversions

1 ounce = 0.063 pound = 0.028 kilogram
1 kilogram = 2.2 pounds = 35.28 ounces
1 pound = 0.454 kilogram = 16 ounces
1 kilogram = 1,000 grams = 1,000,000 milligrams

Volume Conversions

1 litre = 1,000 millitres
= 1,000 cm^3
= 0.028 m^3
= 0.035 ft^3
= 1.06 qt
= 0.263 gal US
= 0.219976 gal imp.
= 33.80 oz
= 200 tsp

1 foot^3 = 28.3161 litres
= 0.037 yd^3
= 29.95 qt
= 7.447 gal US
= 6.229 gal Imperial
= 957.3 ounces

1 yard^3 = 764.534 liters
= 27 foot^3
= 21.71 bushels

1 bushel = 0.035 meter^3
= 35.24 liters
= 1.24 foot^3
= 0.046 yard^3
= 32.0 quarts
= 9.3 gallons US

1 quart = 0.947 liters
= 0.033 foot^3
= 32 ounces
= 192 teaspoons

1 gallon US = 3.785 liters
= 0.8327 gallons Imperial
= 0.134 foot^3
= 4 quarts
= 128 ounces
= 768 teaspoons

1 gallon Imperial = 4.5454 liters
= 1.2009 gallons US

1 ounce (Av.)= 0.029 liters
= 0.00104 foot3
= 0.031 quart
= 0.0078 gallons US
= 6 teaspoons
= 28.3495 grams

Appendix 2

CALCULATIONS OF FERTILIZER CONCENTRATIONS IN MILLIEQUIVALENTS (meq/l)

1 equivalent (eq) = molecular weight of ion/valence

1 equivalent = 1,000 milliequivalent (meq)

1 eq/l = 1 equivalent weight of fertilizer in 1 liter

1 eq/l NO_3^{-1} = (62.0/1)/l = 62 g/l

1 eq/l SO_4^{-2} = (96/2)/l = 48.0 g/l

or

1 meq/l NO_3^{-1} = 0.062 g/l = 62 mg/l

1 meq/l SO_4^{-2} = 0.048 g/l = 48 mg/l

Appendix 3

QUICK PPM CALCULATIONS USING WEIGHTS AND PERCENTAGES

A: One gram of any fertilizer or salt in 1 litre of water yields a concentration of 1,000 ppm

B: One ounce of any fertilizer or salt in 100 gallons US of water yields a total concentration of 65 ppm.

C: One ounce of any fertilizer or salt in 100 gallons US of water yields a total concentration of 78 ppm.

If you know what percentage of a specific element or ion a fertilizer or salt contains calculating the ppm of the salt or ion is simple. (*If the salt you are working with is not listed in Chapter 14 simply divide the molecular weight of the element or ion by the molecular weight of the salt or fertilizer you are using as a source.*)

1. Determine what ppm of the ion or element is required.

e.g. 100 ppm N from $Ca(NO_3)_2*4H_2O$

2. Determine what volume of feed solution you will be making up.

e.g.

A. 50 liters

B. 50 gallons imperial

C. 50 gallons US

3. Multiply the % of the salt the ion or element is by the ppm yield of either of the above to determine the ppm of the ion or element.

e.g. N = 15% of $Ca(NO_3)_2*4H_2O$

A. 1,000 x .15 (15%) = 150 ppm of N @ 1 gm/l

B: 65 x .15 = 9.75 ppm of N @ 1 oz/100 gal

C. 78 x .15 = 11.7 ppm of N @ 1 oz/100 gal

4. Determine what multiplier is required to convert the ppm yield of the ion or compound to the required ppm of the ion or salt on the basis of either A or B by dividing the requirement by the yield.

e.g.

A. 100/150 = .6667

B: 100/9.75 = 10.256

C: 100/11.7 = 8.547

5. Determine what multiplier is required to convert the volume of solution as a standard to the volume of solution required by dividing the solution volume by the standard volume of either A, B or C.

e.g.

A. 50/1 = 50

B. 50/100 = .5

C. 50/100 = .5

6. Perform the following calculation to determine the weight of salt required for the volume of solution you want to create.

A. Metric

1 gram x ppm multiplier (step 4)
x multiplier for volume of solution (step 5)
= required weight of salt or fertilizer in ounces.

1 x 0.6667 x 50 = 33.335 grams

So 33.335 grams of calcium nitrate would be added to 50 liters of water to yield a 100 ppm concentration of nitrogen.

B. (Imperial)

1 oz x ppm multiplier (step 4)
x multiplier for volume of solution (step 5)
= required weight of salt or fertilizer in ounces.

1 x 10.256 x .5 = 5.128 ounces

So 5.128 ounces of calcium nitrate would be added to 50 gallons of water to yield a 100 ppm concentration of nitrogen.

C. (US)

I oz x ppm multiplier (step 4)
x multiplier for volume of solution (step 5)
= required weight of salt or fertilizer in ounces.

1 x 8.547 x .5 = 4.2735 ounces

So 4.2735 ounces of calcium nitrate would be added to 50 gallons of water to yield a 100 ppm concentration of nitrogen.

Exactly the same procedure is used to do calculations for any salt you are using to provide any element or compound for a nutrient solution.

FORMULATION WORKSHEET

DATE ____________________

CROP ________________________

SALT	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
TARGET PPM												
WATER PPM **TDS**												
NEEDED PPM												
				MACRO SOURCE SALTS								
$Ca(NO_3)_2$ * $4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4$ * $7H_20$ gm												
				CHELATES & TRACE SALTS								
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$

FORMULATION WORKSHEET

DATE ____________________ **CROP** ________________________

SALT	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
TARGET PPM												
WATER PPM **TDS** ____												
NEEDED PPM												
MACRO SOURCE SALTS												
$Ca(NO_3)_2 * 4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4 * 7H_20$ gm												
CHELATES & TRACE SALTS												
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$

FORMULATION WORKSHEET

DATE ____________________ **CROP** ________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGET PPM												
WATER PPM **TDS**______												
NEEDED PPM												
				MACRO SOURCE SALTS								
$Ca(NO_3)_2 * 4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4 * 7H_20$ gm												
				CHELATES & TRACE SALTS								
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$

FORMULATION WORKSHEET

DATE ____________________ **CROP** ________________________

SALT	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
TARGET PPM												
WATER PPM TDS												
NEEDED PPM												
				MACRO SOURCE SALTS								
$Ca(NO_3)_2 * 4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4 * 7H_20$ gm												
				CHELATES & TRACE SALTS								
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$

FORMULATION WORKSHEET

DATE ____________________ **CROP** ________________________

SALT **TARGET PPM**	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
WATER PPM **TDS**												
NEEDED PPM												
MACRO SOURCE SALTS												
$Ca(NO_3)_2 * 4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4 * 7H_20$ gm												
CHELATES & TRACE SALTS												
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$

FORMULATION WORKSHEET

DATE ____________________ **CROP** ____________________

SALT	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**
TARGET PPM												
WATER PPM **TDS** ______												
NEEDED PPM												
MACRO SOURCE SALTS												
$Ca(NO_3)_2$ * $4H_20$ gm												
KNO_3 gm												
KH_2PO_4 gm												
K_2SO_4 gm												
$MgSO_4$ * $7H_20$ gm												
CHELATES & TRACE SALTS												
TRACE MIX 7% Fe gm												
TOTALS												

(T)__________ total gm all salts incl. TDS in water

(B)__________ total gm all salts excl. $Ca(NO_3)_2$