From Minerals to Microbes:

Connecting Soil Health to Plant Nutrition

by
Mary Lucero, PhD

End-O-Fite
Enterprises LLC

NM STATE
ALAMOGORDO

How do *you* define a healthy soil?

End-O-Fite
Enterprises LLC

NM STATE
ALAMOGORDO

What do *you* consider the benefits of a healthy soil?

Widely agreed upon benefits of healthy soil :

Benefits For the Grower

Higher crop yield
More infiltration
More plant available water
Lower irrigation costs
More nutrient dense crops
Fewer pests, less disease
Reduced need for inputs

Benefits for the Rest of Us

Water management (less runoff, erosion. Potential to recharge water table)
Improved air and water quality
Cleaner environment (fewer chemicals needed, more chemicals degraded
Climate mitigation
Biodiversity
Stronger economy

What is a nutrient dense plant?

Possible benefits of nutrient dense plants

Benefits For the Grower

- Higher yields
- Fewer pests
- Less disease
- Less need for costly pesticides
- Higher premiums

Benefits for the Rest of Us

- More nutrition
- Better consumer health
  - Lower health care costs
  - Improved productivity
- Better flavor
- Satiety – Eat less. Enjoy it more.
- Longer shelf life (Less food waste).

This presentation will:

- Define soil health and the five principles for maintaining it.
- Describe the roles of the local environment and native biology in building healthy soil
- Explore the relationship between soil health, plant productivity, and nutrition

Participants will learn:

- when to conduct popular soil, plant, and microbial tests
- how to interpret lab results
- how to use data to optimize fertility and plant performance

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

First, what *is* soil?

- ***A vital living ecosystem***
  - *Soil consists of:*
    - Air
    - Water
    - Parent material (Rocks and minerals)
      - Mineral nutrients
    - Organic matter (Hydrocarbon based compounds)
      - Food (energy) for living systems
    - Life. Biology. Critters.
      - There is no such thing as a *lifeless* ecosystem.

All life comes from the soil.

- **What about aquatic life?**
- **Soil is:**
  - Air
  - Water
  - Parent material (Rocks and minerals)
  - Organic matter (Hydrocarbon based compounds)
  - Life. Biology. Critters.
- Oceans, lakes, rivers and other natural bodies of water are just *wet soil*.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Knowledge that *life* comes from the soil pre-dates modern science, transcends religion and culture

The LORD God *formed man out of the clay* of the ground and blew into his nostrils the breath of life, and so man became a living being. — Book of Genesis 2:7

To forget how to dig the earth and to tend the soil *is to forget ourselves.* — Mahatma Gandhi

"*We are part of the earth and it is part of us ...* " — Chief Seattle

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

If life itself is sacred, so is soil.

NRCS Definition of Soil Health

- the continued capacity of soil to function as a *vital living ecosystem* that *sustains* plants, animals, and humans.

Interpretation:

Healthy soil is not just about carrying you through the next harvest…

It is about building capacity for future generations.

Why should kids come back to work on a farm that is not producing?

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Principles are guidelines. They don't guarantee success, but they improve the odds. In human health, we follow these principles to live longer

- Eat well
- Stay hydrated
- Exercise
- Avoid 3 "land mines" of:
    - Toxic behavior
    - Toxic substances
    - Toxic people
- Think positively/be happy

- Embracing these principles won't keep you well all the time, but clearly:
- increase longevity for most
- reduce health care costs

Following 5 principles for soil health will improve the odds of longevity for your farm and reduce your input costs.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Five soil health principles

1. Cover it up
2. Minimize disturbance
3. Maximize biodiversity
4. Maintain living roots
5. Integrate livestock

Integrating native plants may improve soil health.

End-O-Fite
Enterprises LLC

NM STATE
ALAMOGORDO

All soils were built by local ecosystems.

- **Rocks and minerals were not evenly distributed across the earth.**
  - Biogeochemistry differs locally. (Temperature, rainfall, slope, parent material…)
  - Indigenous soil microbes, native plants evolved by building local soil.
  - Native plants often have deeper roots.
  - These organisms have enzymes that excel at extracting nutrients and removing toxins *under local conditions*.

Are local biota more effective at extracting nutrients from local soil?

- Many plant and microbial species are adapted to dry climates.
  - Halophytes
  - Alkaliphiles
  - Thermophiles
  - Xerophiles
- Research into how local biota may support crop production is limited.
  - 2014 study showed species dependence associated with additions of local microbes[1].
  - Support/funding for similar studies will always be limited.
  - Local observations, citizen science initiatives are encouraged.

[1]Nelson C, Unc A, Lombard K, Lucero M, Perkins, S. 2014. Impact of seed exposure to plant material on plant growth and development on remediated arid lands. American Society of Mining and Reclamation Journal. 3(1):41-69.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Ways to integrate native biology into agriculture and soil health initiatives

- Minimize tillage and "-cidal" practices.
  - Wind and water will deliver all the microbes you need.
    - Just let them live
- Build sufficient soil carbon.
  - Soil carbon = food for microbes.
- Include native plants in border plantings and cover crops
  - Reduce wind and water erosion
  - Deep-rooted native plants can capture water that trickles below the agronomic root zone.
  - Unique microbial inoculum.
  - Start slow. Observe results before expanding.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Personal experience: native plants in flood irrigated agriculture and on rangelands

- Grama grass (*Bouteloua sp.*)
  - Good forage
  - Difficult to establish
  - Prolific one established
- Indian Ricegrass (*Achnatherum hymenoides)*
  - Good forage
  - ~~Difficult~~ *Extremely* difficult to establish
- Yellow coneflower (*Ratibida columnifera*)
  - Easy to establish
  - Integrates well with cover crop
  - Not incredibly palatable
  - Supports beneficial mycorrizal fungi

Results will differ with location, management, and crop species

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Side note: Pros and cons for commercial microbial formula (the so-called bug-in-a-jug)

- Pros:
  - Convenience
  - You are not raising "native" plants, so why native microbes?
  - A diverse mix of plant-growth promoting microbes may boost crops after disturbance or neglect.

- Cons:
  - Likely non-native
  - May not survive in your soil
  - Price

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Summary so far:

- Soil health reflects its ability to sustain life
- To maintain soil health:
  - Keep it covered
  - Minimize disturbance
  - Maximize biodiversity
  - Maintain living roots
  - Integrate livestock
- Native plants and microbes add biodiversity that is adapted to your environment.
  - On site research and critical observation will determine how this benefits your crop.

Let's explore the relationship between soil health, plant productivity, and nutrition

Characteristics of healthy soil

- **Structure and physical properties**
  - **Good tilth**
  - **Air and water balance**
  - **High organic matter -**
    - Soils with >3% organic matter are "regenerative." Assuming minimal disturbance, soil repairs itself, OM increases with time.
- **Resilience** – bounce back following disturbance
- **Biodiverse** – A teaspoon of soil should contain 6 kingdoms
- **Low pest and disease pressure**– built in biotic controls
- **Nutrient rich-**Soil biota chelate minerals, improve uptake
- **pH balance (pH 6-7)** - Natural biotic buffering
- **Capable of removing or sequestering toxins** - Bioremediation

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

How healthy soil supports plant productivity

- Structure and physical properties - More water between irrigations. Less flooding.
- Resilience - Less compaction. Plants are also more resilient to stress.
- Biodiverse - Biochemical capacity to build soil, cycle nutrients, detoxify.
- Low pest/disease pressure- Natural enemies eliminate common pests and disease.
- Sufficient nutrients- Microbes dissolve parent material, make nutrients bioavailable.
- pH balance (pH 6-7) - Microbes create weak acids>buffer soil pH.
- Removing or sequestering toxins - Enzymes bind, sequester, &/or transform toxins.

End-O-Fite
Enterprises LLC

NM STATE
ALAMOGORDO

Plant nutrition basics – The macronutrients

Macronutrients are used for anabolism (building materials), fuel (energy production) osmotic balance and cellular signaling (electrolytes)

Macronutrient	%[1]	Source	Examples of how it is used
Hydrogen	6	H_2O	Photosynthesis, osmotic balance, Turgor, Temperature and pH homeostasis, redox biochemistry, anabolism (building material)
Oxygen	45	Air	Cellular respiration/catabolism (energy), anabolism
Carbon	45	Air, Soil	Cellular respiration/catabolism (energy), anabolism
Nitrogen	2	Microbes	Anabolism – amino acids, proteins, DNA, RNA, ATP, alkaloids, polyamines...
Potassium	1	Soil	Osmotic/electrolyte balance, fluid regulation, cellular signaling.
Phosphorus	<1	Microbes	Anabolism – Cell membranes, DNA, RNA, ATP...
Calcium	<1	Soil	Anabolism-Cell wall structure, cell membrane function, signalling/stress mitigation, cofactor
Magnesium	<1	Soil	Photosynthesis, cofactor for >300 enzymes, stabilizes membranes, P transport
Sulfur	<1	Soil/SOM	Photosynthesis, Protein synthesis, vitamins, coenzymes, glutathione (detox), defense

[1]Smith, K. T. (2007). American Nurseryman [Review of *American Nurseryman*]. *American Nurseryman*, *206*(10), 10–

Plant nutrition basics – The micronutrients

Micronutrients are used in small amounts. Important for catalyzing metabolic reactions

Micronutrient	%	Source	Examples of how it is used
Chlorine	<1[1]	microbes	Nutrient transport, photosynthesis, stomatal regulation, osmotic balance...
Boron	<<1[1]	microbes	Cell wall synthesis, reproduction (fruit production), cell division, hormone regulation.
Iron	<<1[1]	microbes	Photosynthesis/chlorophyll synthesis, cellular respiration, nitrogen fixation, defense
Manganese	<<1[1]	microbes	Photosynthesis, enzyme function, nitrogen assimilation, lignin synthesis
Zinc	<<1[1]	microbes	Cofactor for >300 enzymes. Gene regulation, defense, reproduction
Copper	<<1[1]	microbes	Photosynthesis, respiration, structural integrity, reproduction, quality and color.
Molybdenum	<<1[1]	microbes	Nitrogen and sulfur metabolism, including nitrate reductase and nitrogenase, stress resistance, pigment production
Nickel	<<1[1]	microbes	Nitrogen metabolism (urease) defense, detox (including detox of urea)
Selenium	varies	microbes	Abiotic stress tolerance (Can accumulate toxic levels)
Silica	varies	microbes	Structural support, pest and disease resistance, drought resistance, facilitates nutrient uptake.

Soils lacking SOM, microbes will not deliver adequate nutrition to plants.

Nutrients compete with one another.

- High levels of nitrogen may reduce availability of **boron, potash, copper**
- **Excess nitrogen may increase crop yield, but…**
  - **decrease nutrient density**
  - **decrease pest resistance**
  - **decrease disease resistance**
  - **decrease shelf life**
- **Nitrogen dependence and "drug-addicted" soil:**
  - **Excess nitrogen reduces microbial capacity to fix nitrogen**
  - **Excess nitrogen increases soil population of denitrifying bacteria**
    - **More nitrogen becomes necessary, because more is being lost.**

Testing for nutrients

- **Many kinds of tests are available**
- **Standard soil chemistry tests have the longest history of informing growers.**
- **Leaf tissue tests and sap tests show what the plant is obtaining from the soil.**
  - Applied nutrients may not reach your plant.
  - Plants may store nutrients in the leaves
  - Sap analysis offers best view of what plant is using.
- **Microbial testing – Offers promise and insight**
  - Much to be learned about best methods and interpretation

Soil Testing (ie: Soil Chemistry) – Suggested Practices

- Find a good lab and stick with them.
  - Labs that participate in NAPT offer science-based testing guided by the Soil Science Society of America.
- Follow your laboratory's instructions for sampling and submitting samples.
- Test annually at the same time each year.

Soil chemistry tests should include

- **pH:** Measures the soil's acidity or alkalinity.
- **Organic matter (SOM):** Indicates the amount of organic material in the soil.
  - **About 50% of SOM is carbon.**
  - **Correllates with microbial abundance.**
- **Nitrogen:** Look for total *and* nitrogen-nitrogen.
- **Other Macronutrients: Phosphorus, Potassium, Calcium, Magnesium, Sulfur** (If your soil has moisture, H and O are present)
- **Cation Exchange Capacity (CEC):** Measures the soil's ability to hold positively charged nutrients.
- **Soluble salts:** Checks the overall salt concentration in the soil.
- **Base saturation:** Shows the percentage of cation exchange sites occupied by base cations like calcium, magnesium, and potassium

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Importance of SOM, pH, and CEC

- **SOM – Should exceed 3%. - Build with cover crops.**
  - **Most important amendment in semi-arid and arid lands.**
  - **Feeds and shelters soil microbes.**
  - **Builds CEC, Water Holding Capacity.**
- **pH - Nutrient availability is optimal at pH 6.5 -7.**
  - **Manage chemically by adding sulfur (expensive).**
  - **Manage with SOM and microbial abundance (multifaceted benefits).**
- **CEC – how many sites are available to bind nutrient cations.**
  - **Depends on soil texture and SOM**
  - **CEC by soil type**
    - **Sandy soils:** Low CEC, typically **3 to 10 meq/100 g**. Poor nutrient retention. Apply less nutrient, apply often.
    - **Clay and clay loam soils:** High CEC, ranging from **15 to 30+ meq/100 g**.
    - **Organic soils:** Very high CEC, up to **100 meq/100 g** or more. -Soil can retain more nutrients! - may not need to add. Test to be sure.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Importance of Base Saturation

- Ideal base saturation levels for alkaline soils
  - Calcium (Ca^{2+}): 80–85%
  - Magnesium (Mg^{2+}): 8-10%
  - Potassium (K^{+}): 4-6%
  - Sodium (Na^{+}): Below 2%
  - Hydrogen (H^{+}): Below 10% (rarely an issue in Western US)

Chemical mitigation expensive.
SOM mitigation practical.

End-O-Fite Enterprises LLC

Astera, M., & Agricola. (2015). *The ideal soil v2.0 : a handbook for the new agriculture.* Soilminerals.com.

NM STATE ALAMOGORDO

Salinity

- < 2 deciSiemens per meter (dS/m) is desired
- When too high:
  - Plant tolerant crops
  - Increase SOM
  - Improve drainage

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Adjusting Macronutrients and Micronutrients in Soil

- Testing labs often recommend as if *all* added nutrients are plant available.
- Many commercial fertilizers become bound to soil, volatilize, or run off.
- Labs often ignore microbial activity.
  - Ex. Phosphorus may be present, insoluble. However, microbes are transporting it to plants through rhizophagy
- May get more milage applying foliar nutrients in smaller amounts.
- Use soil test to explore soil health trends (OM, CEC, salinity...)

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Sample Soil Test

-personal info and lab details removed.

[redacted] Depth : 0 - 6

1:1 Soil pH	8.4
Soluble Salts 1:1, mmho/cm	0.16
Excess Lime Rating	LOW
Organic Matter LOI, %	1.1
Nitrate-N KCl, ppm N	4.0
Nitrate-N, lbs N / Acre	7
Phosphorus Olsen P, ppm P	7.0
Potassium NH_4OAc, ppm K	342
Sulfate M-3, ppm S	41.0
Zinc DTPA, ppm Zn	0.27
Iron DTPA, ppm Fe	2.3
Manganese DTPA, ppm Mn	1.2
Copper DTPA, ppm Cu	0.31
Calcium NH_4OAc, ppm Ca	3809
Magnesium NH_4OAc, ppm Mg	565
Sodium NH_4OAc, ppm Na	110
Total Carbon, % C	0.457

Sum of Cations, me/100g	% Saturation				
	H	K	Ca	Mg	Na
25.1	0	3	76	19	2

Available Water g H2O / g soil	0.08
Available Water inch H2O / inch of soil	0.10
Total Available Water inches / sample	0.62
Field Capacity, % (vol)	15.90
Permanent Wilting Point, % (vol)	8.10

Adapted from Bagnall et al. SSSAJ 2022

Soil Texture	Sand, %	Silt, %	Clay, %
Sandy Loam	74	10	16

Recommendations
In Actual Pounds of Plant Nutrients per Acre

(Ward) Cotton lbs/A

1,500
130
65
Potassium K_2O 0
0
0
0
0
Potential Iron Chlorosis
6
Copper Cu 0

pH 8.4-HIGH

Salts 0.1 mmho/cm

OM 1.1%

Sum of Cations me/100 g 25.1

How is ... g
nutrie...
Melich...
Acetat...
available nutrients.

Base Saturation:
H-0
K-3
Ca – 76
Mg – 19
Na -2

End-O-Fite Enterprises LLC

Amendment Strategy:

Increase cover crop mowing height.

Look for soil test's nutrient levels to improve with soil health.

Confirm nutrient application recommendations with sap testing.

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Plant sap testing/petiole testing reveals the nutrients the plant is using “now”.

Look for a lab that tests, at a minimum, the widely recognized macronutrients and micronutrients (you can ignore C, H, O).

Macronutrients	Micronutrients	Not commonly tested.
Nitrogen	Chlorine	Nickel
Potassium	Boron	Selenium
Phosphorus	Iron	Silica
Calcium	Manganese	
Magnesium	Zinc	
Sulfur	Copper	
	Molybdenum	

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Historical Plant Sap Analysis

Lab No.	Sample ID	Type	Sample Date (Plant Date:)	Ammonium NH_4 ppm	Nitrogen N %	Phosphorous P %	Potassium K %	Sulfur S %	Sodium Na %	Calcium Ca %	Magnesium Mg %
77471	Orch	L	05/07/25	615	2.81	0.47	2.36	0.20	0.04	1.02	0.32

Lab No.	Zinc Zn ppm	Iron Fe ppm	Manganese Mn ppm	Copper Cu ppm	Boron B ppm	Silicon Si ppm	Cobalt Co ppm	Molybdenum Mo ppm	Selenium Se ppm	Nickel Ni ppm	Chloride Cl ppm	Proline µmol/g
77471	26	54	101	16	39	35	2.64	5.49	11.44	0.47		

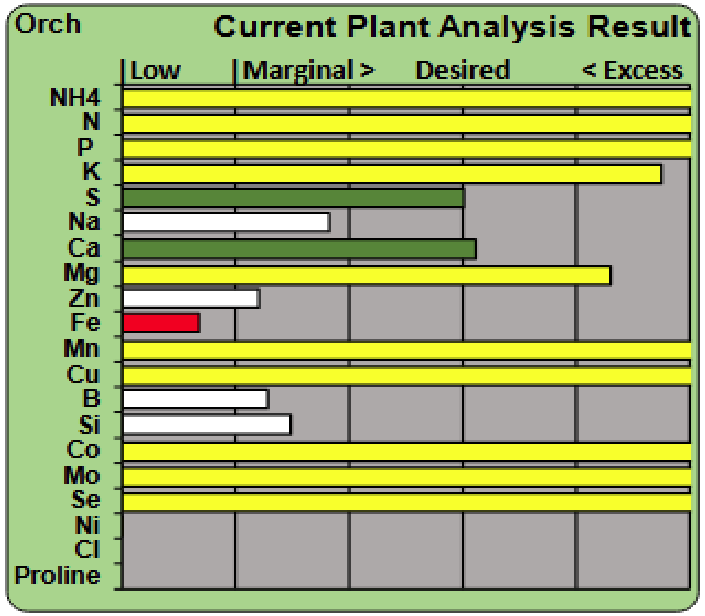
Type: Petiole - Leaf - Seed - Root - Whole Plant

Low | Marginal | Desired | Excess

Recommendations

N	P_2O_5	K_2O	S	Na	Ca	Mg	Zn	Fe	Mn	Cu	B	Si	Co	Mo	Se	Ni	Cl
lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	lbs/ac	oz/ac	oz/ac	oz/ac	oz/ac	oz/ac
0	0	0	0		0	0	0.10	0.30	0	0	0.10	0.10	0	0	0	10	

Above trace element recommendations (oz) are for a liquid 5% actual concentrate. Adjust based on %.



Interpretations:

Excessive nitrogen leads to high vegtative growth and less fruit set. Low Zinc & Boron do not promote good pollen formation & pollination. Most the nitrogen is required during fruit stage. Keep initial N to a bare minimum till July & Aug.
Ammonium-N favorably high - provide more Nitrogen in the next 20 days.
N in excessive range.
P & K in excessive range.
S on target.
Na in marginal range.
Ca & mg on target.
Boost Zinc - Iron - Boron - Silicon.

Plant Date:		T y p e		Ammonium	Nitrogen	Phosphorous	Potassium	Sulfur	Sodium	Calcium	Magnesium
Lab No.	Sample ID		Sample Date	NH_4	N	P	K	S	Na	Ca	Mg
				ppm	%	%	%	%	%	%	%
77471	Orch	L	05/07/25	615	2.81	0.47	2.36	0.20	0.04	1.02	0.32

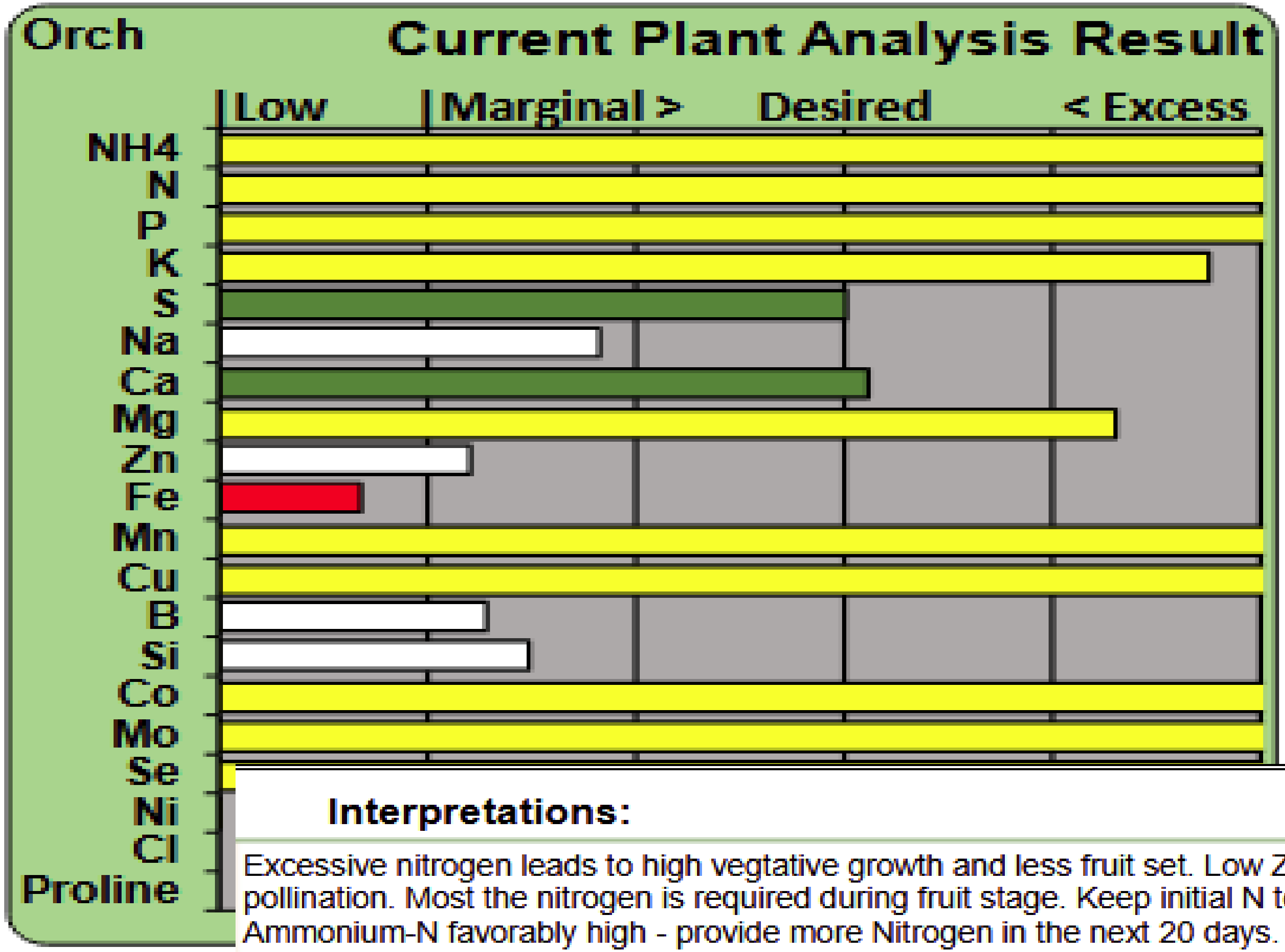
Low	Marginal	Desired	Excess

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO

Zinc	Iron	Manganese	Copper	Boron	Silicon	Cobalt	Molybdenum	Selenium	Nickel	Chloride	
Zn	Fe	Mn	Cu	B	Si	Co	Mo	Se	Ni	Cl	Proline
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	µmol/g
26	54	101	16	39	35	2.64	5.49	11.44	0.47		

Low	Marginal	Desired	Excess



Above trace element recommendations (oz) are for a liquid 5% actual concentrate. Adjust based on %.

Interpretations:

Excessive nitrogen leads to high vegtative growth and less fruit set. Low Zinc & Boron do not promote good pollen formation & pollination. Most the nitrogen is required during fruit stage. Keep initial N to a bare minimum till July & Aug.
Ammonium-N favorably high - provide more Nitrogen in the next 20 days.
N in excessive range.
P & K in excessive range.
S on target.
Na in marginal range.
Ca & mg on target.
Boost Zinc - Iron - Boron - Silicon.

Summary: the best way to ensure you are applying the right nutrients: test often.

- **Sap testing – Throughout Season**
  - Excellent guide for nutrient-based management
  - Detects plant deficiencies *before* pests and disease arrive.
  - More labs needed
  - Will spectroscopy get there?
- **Soil testing - Annually**
  - Guides general soil health
  - Test should include:
    - Soil Organic Matter
    - pH
    - Base Saturation
    - Cation Exchange Capacity
    - Macronutrients
    - Micronutrients
- **Microbial Testing - Occassional**
  - DIY-Low cost, rapid results
  - Lab based - $$$, information packed, challenging to interpret.
  - Promises rapid response

End-O-Fite Enterprises LLC

NM STATE ALAMOGORDO