Principles of Soil Testing, Interpretation, and Recommendations for Healthy Soil

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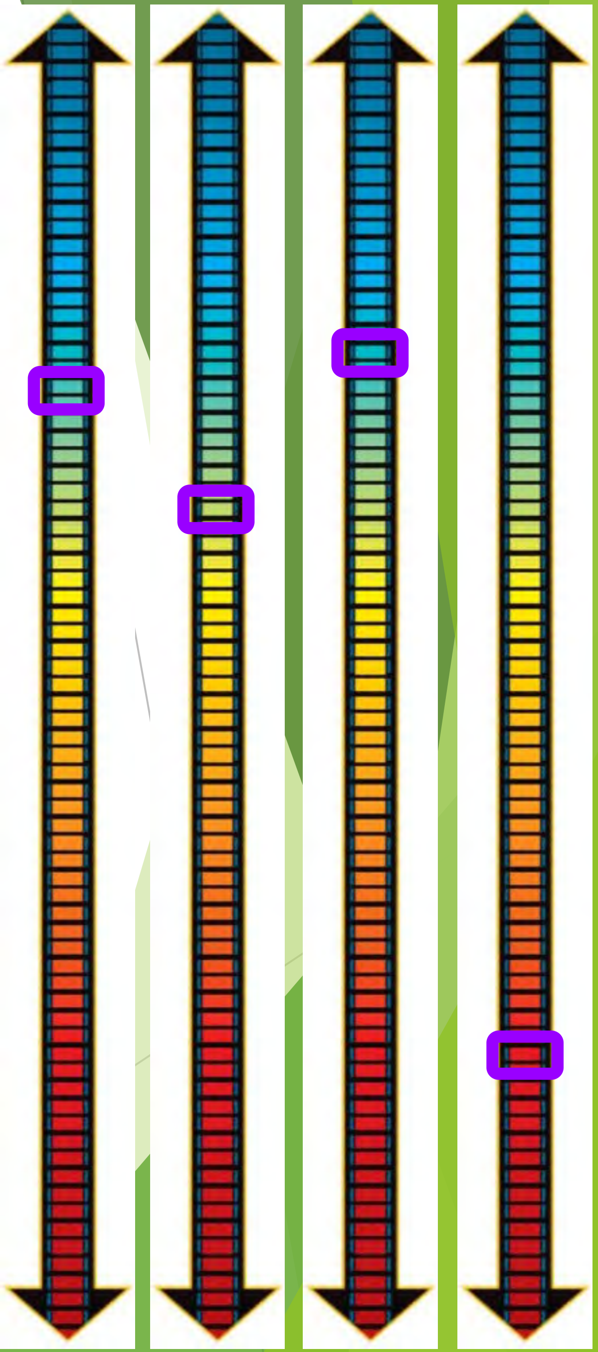
What is Healthy Soil?

- *"Soil health, also referred to as soil quality, is defined as the* ***continued*** *capacity of soil to* ***function*** *as a vital living ecosystem that sustains plants, animals, and humans"* (USDA-NRCS).
- Soil health is often used to specify the conditions of soil that are related to management practices…
  - Focus on managing soils in a way that maintains favorable properties for the foreseeable future.
  - Understand that a healthy soil serves many needs of the ecosystem, starting with plants but extending up the food chain.
- *"Only 'living' things can have health, so viewing soil as a living ecosystem reflects a fundamental shift in the way we care for our nation's soils."* (USDA-NRCS).
  - Strive to manage soils in ways that sustain (or improve) its **functions** as part of the whole ecosystem – including **habitat for organisms, geochemical cycling, water infiltration, storage, & filtering**, etc.
- Quantifying: Measure various properties as indicators of "health"

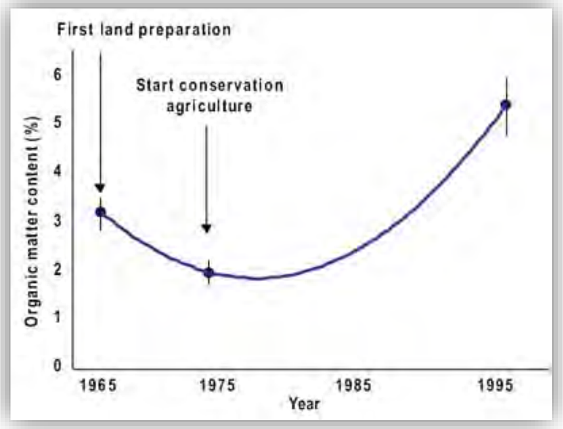


Natural Soil Variability

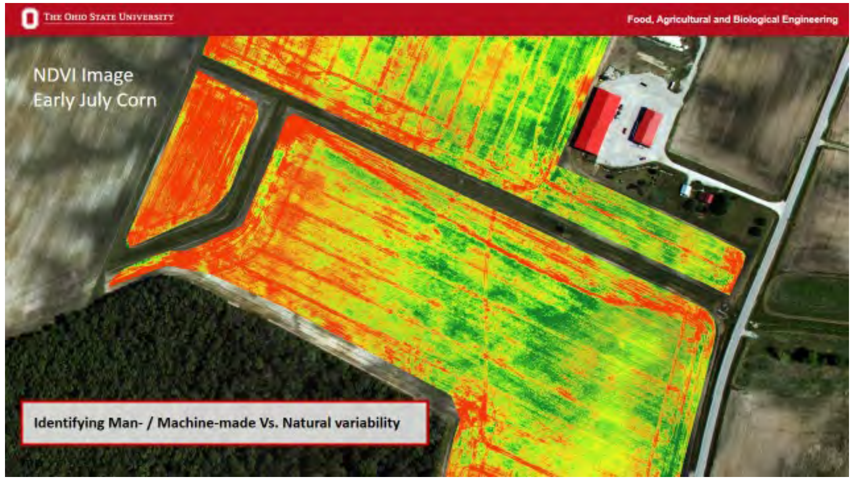
- Soil forming factors:
  - parent material
  - climate
  - prior organism activity
  - topography
  - time
- ***Inherent*** and ***dynamic*** properties of soils determine suitability or limitations for different uses
- The goal of the soil health paradigm is to **maximize each soil's functions** that support its existing or desired ecosystem with a **minimum of inputs**

Dynamic Properties: change with management (relatively short-term)

Soil Fertility Training, Nutrient Deficiency Image Collection. Crozier, 2006. North Carolina State University.



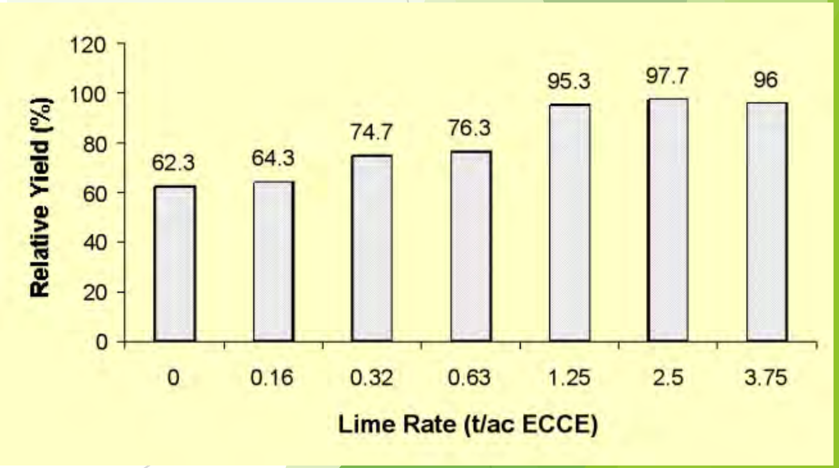
Management effect on soil organic matter. UN-FAO, Bot and Benites, 2005. adapted from Derpsch, 1997.



Tire tracks in this field are clearly visible from overhead NDVI imagery (Fulton and Shearer, OSU)

Management effect on soil surface view from air. WebSoilSurvey. In Burlington County, NJ. Accessed 2019. BuhA—Buddtown, JdrA—Jade Run, MunA—Mullica (all fine sandy loam, 0 to 2% slope).

Response of common winter wheat varieties to liming and low soil pH (photo/illustration: Gene Krenzer). Managing Acid Soils for Wheat Production. March 2017. Oklahoma State Extension.



Three-year average relative wheat forage yields with different lime application rates. Managing Acid Soils for Wheat Production. March 2017. Oklahoma State Extension.

The Soil Health Institute endorses these indicators:

SOIL HEALTH INSTITUTE

Tier 1 measures:

organic carbon,
pH,
nitrogen,
phosphorus,
potassium,
micronutrients,
cation exchange capacity,
base saturation,
electrical conductivity,
carbon mineralization,
nitrogen mineralization,
crop yield,
texture,
bulk density,
penetration resistance,
water-stable aggregation,
erosion rating,
infiltration rate,
available water holding capacity

Note focus on (dynamic) soil properties that are affected by management

Chemical
Biological
Physical

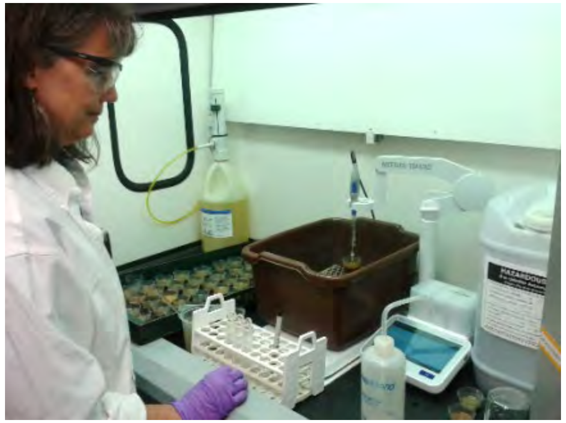
Additional (Tier 2 & Tier 3) indicators are being studied in various systems to understand regional differences in interpretation, establish thresholds, and develop management recommendations to improve soil functioning.

Field assessments

bulk density,
penetration resistance,
aggregation,
erosion,
infiltration rate,
available water holding capacity,
crop yield

Soil Testing

- "Traditional" agronomic tests (for native/mineral soils)
- Soil microbial activity
- Physical properties
- Contamination



Rutgers Soil Testing Laboratory Services
(partial list)

Soil Fertility Analysis
Soil pH, P, K, Mg, Ca, Cu, Mn, Zn, B, Fe; Recommendations

Soil pH & Lime Requirement only
Includes recommendations for selected crop/plant

Soil CO2-burst
Microbial respiration as biological indicator of soil health, with estimation of nitrogen release

Soluble Salts
Level of total dissolved ions measured by electrical conductivity

Soil Organic Matter Content
Method used for most soil samples

Loss-on-ignition Organic Matter
Method used for very high organic-content soil, or as specified

Soil particle-size analysis
Percentages of sand/silt/clay and textural class

Inorganic Nitrogen
Plant-available, nitrate-nitrogen and ammonium-nitrogen

Total Nitrogen
Includes organic-bound nitrogen and ammonium-nitrogen

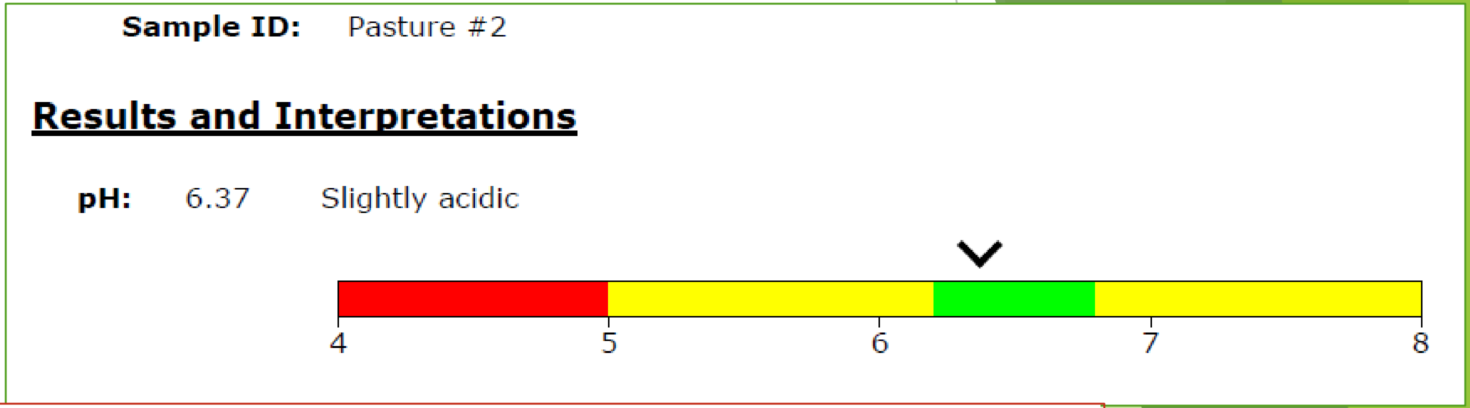
Cation Exchange Capacity & Exchangeable Cations
Cation exchange sites, and Calcium, Magnesium, Potassium, Sodium

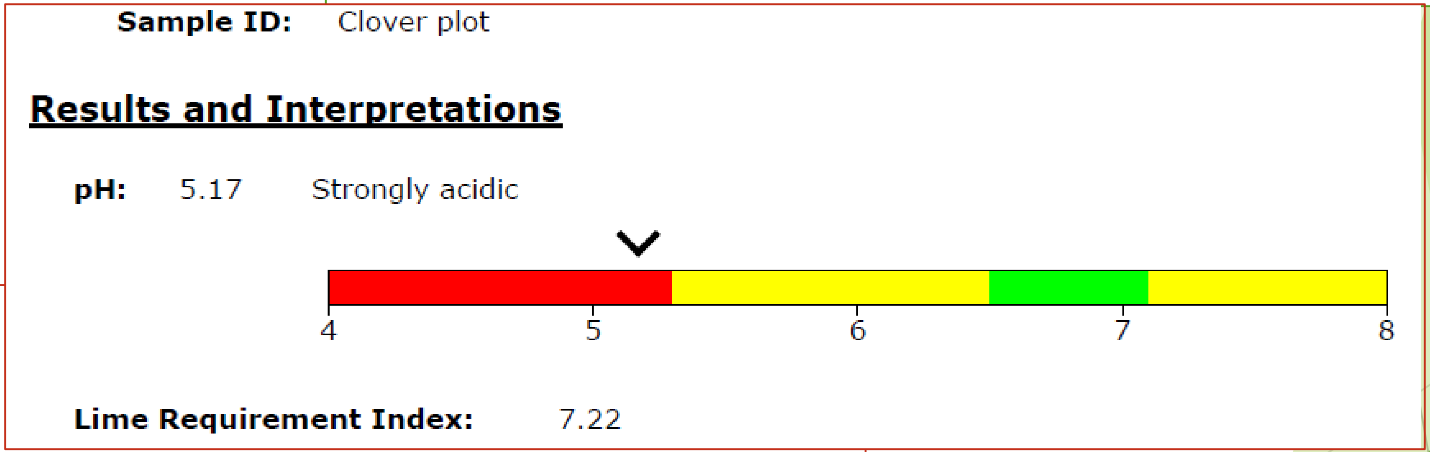
Lead Screening by Mehlich 3
Screening for Lead (Pb) contamination

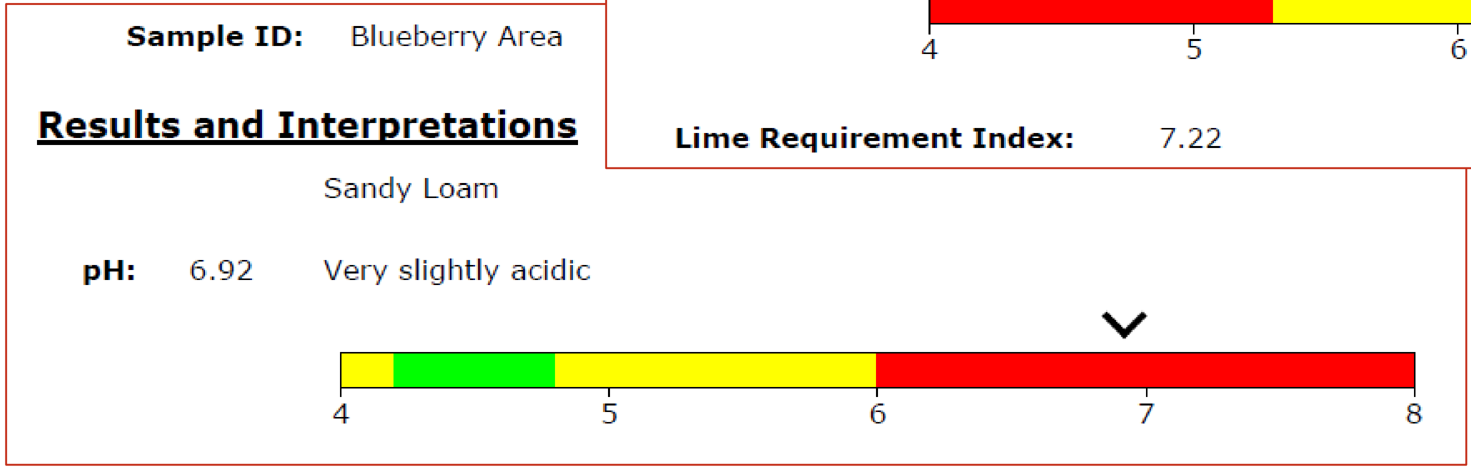
USDA Sieve Analysis of Sand
Percentages of very coarse, coarse, medium, fine and very fine sand classes, plus gravel

Soil pH Interpretation

Assuming that a "crop" is indicated by the grower, a chart is included to indicate the optimum pH range (Rutgers STL reports)







Recommendations to optimize soil pH

Limestone to neutralize acidity
- Rate of application depends on…
  - Target pH – existing pH
  - Soil's buffering capacity
  - Properties of the limestone
- Type depends on…
  - Mg soil test level

Soil pH too high? (Why?)
- Sulfur
- Aluminum sulfate(?)
- Ammonium-N fertilizers

www.agric.wa.gov.au

Surface application

Direct injection

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Soil Test Nutrient Level Interpretation

Each nutrient measured has its specific “optimum” scale (specific to extractant)

Table 1. Mehlich-3 Soil Test Values for Relative Level Categories

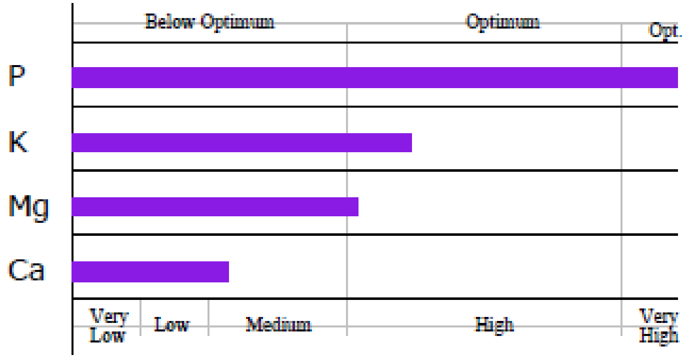
Macronutrients	Units	Very Low	Low	Medium	High	Very High
Phosphorus	pounds/acre	0-24	25-45	46-71	72-137	>137
Potassium	pounds/acre	0-40	41-81	82-145	146-277	>277
Magnesium	pounds/acre	0-45	46-83	84-143	144-295	>295
Calcium	pounds/acre	0-615	616-1007	1008-1400	1401-1790	>1790

Bar graph is used (Rutgers STL reports) to demonstrate how each macronutrient level is categorized in terms of deficiency/sufficiency

Macronutrients (pounds per acre)

by Mehlich 3 extraction

Phosphorus:	221	(Above Optimum)
Potassium:	176	(Optimum)
Magnesium:	149	(Optimum)
Calcium:	1054	(Below Optimum)



Micronutrients (parts per million)

Zinc(Zn)	Copper(Cu)	Manganese(Mn)	Boron(B)	Iron(Fe)
1.22 (Adequate)	1.69 (Adequate)	15.62 (Adequate)	0.39 (Low)	99.83 (Adequate)

Sufficiency Levels and CEC/Basic Cation Saturation Ratios

Macronutrients (pounds per acre)

by Mehlich 3 extraction

Phosphorus: 221 (Above Optimum)

Potassium: 176 (Optimum)

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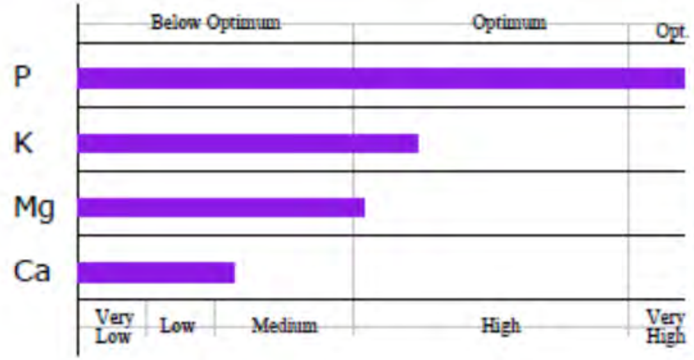

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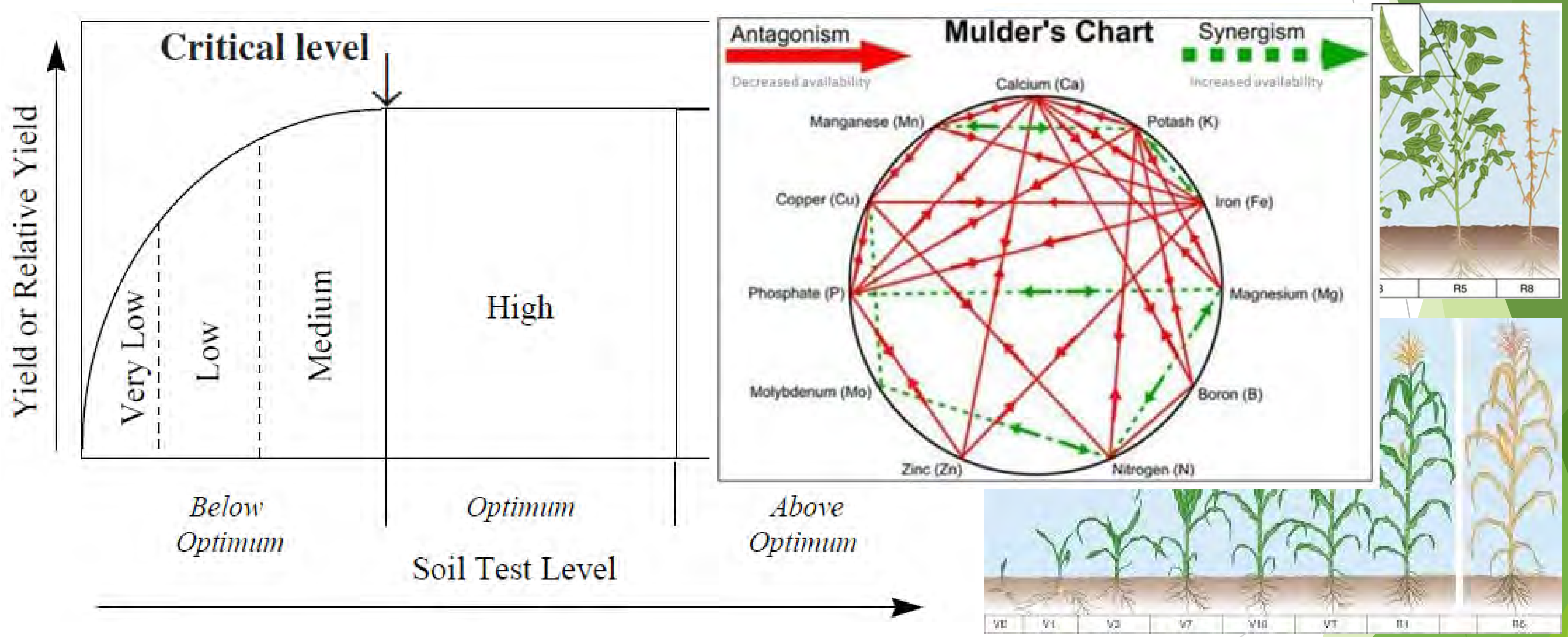
Estimated Cation Exchange Capacity and Basic Cation Saturation

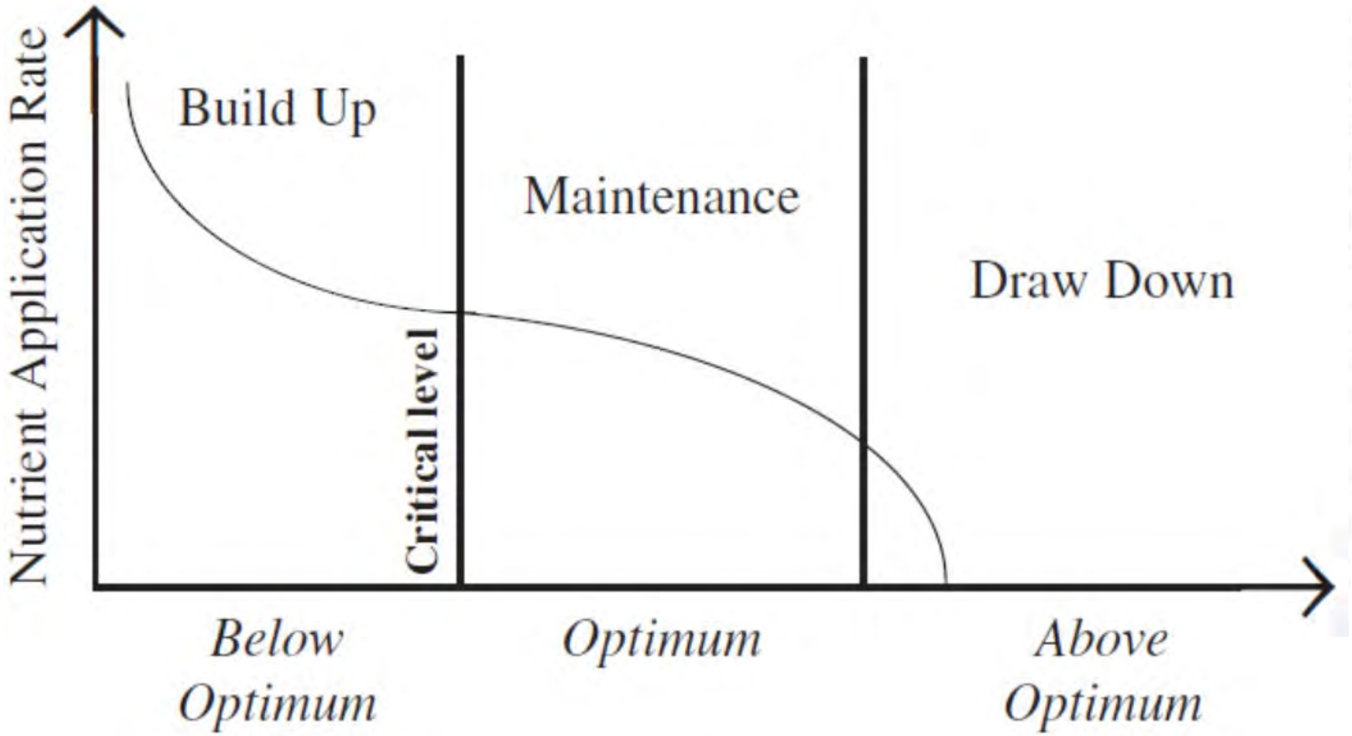
CEC	Base Saturation	Calcium	Magnesium	Potassium
5.2 meq/100g		2.6 meq/100g	0.6 meq/100g	0.2 meq/100g
(100%)	66%	50%	12%	4%
Suggested Range of Cation Saturation:		65-76%	10-15%	4-7%
		...or 65-85%?	...or 6-12%?	...or 2-5%?

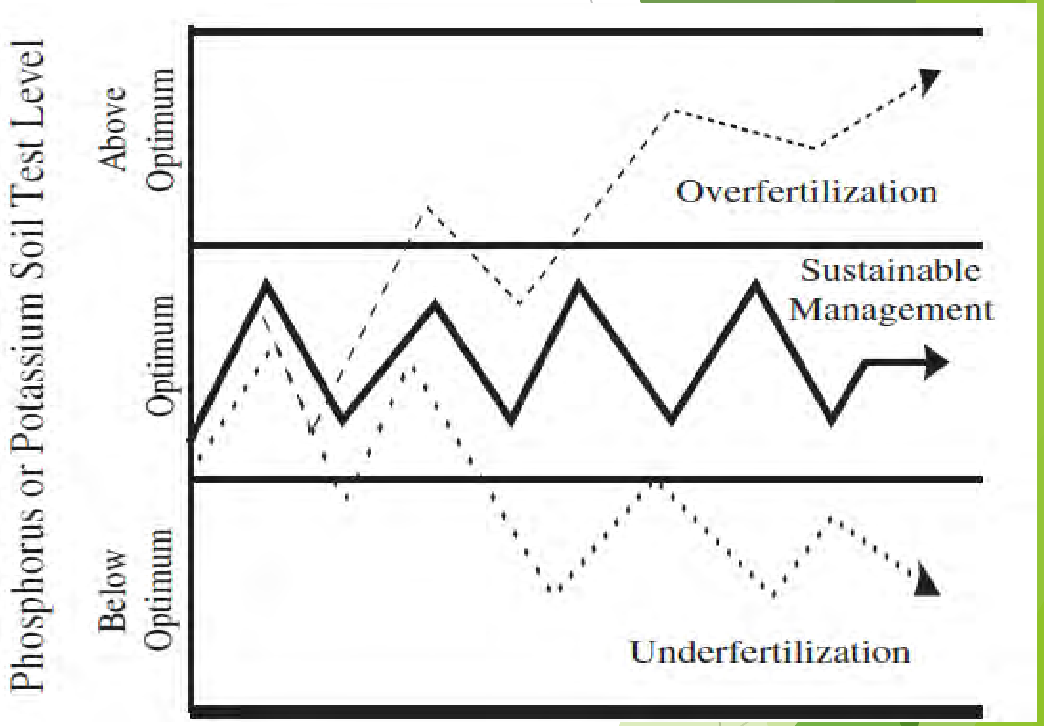
Goal: Avoid plant nutrient deficiency throughout growing season



Maximum yield may not correspond to the most economic yield (profit), and higher levels of nutrients (above the critical value) result in wasted amendment and therefore low nutrient-use efficiency.

Fertilizer Recommendations for healthy soil (sustainable, low input, economic)





Time (years) →

Micronutrient Interpretation/Recommendations

"Essential" but needed in smaller amounts than macronutrients;
ranges not as well-defined, categorized simply as "low", "adequate", or "high"

Micronutrients (parts per million)

Zinc(Zn)	Copper(Cu)	Manganese(Mn)	Boron(B)	Iron(Fe)
1.22 (Adequate)	1.69 (Adequate)	15.62 (Adequate)	0.39 (Low)	99.83 (Adequate)

Interpretive statements (Rutgers STL reports)

Zinc does not appear to be a limiting factor. For information about zinc in soil for plant nutrition, see FS721.

Copper does not appear to be a limiting factor. As with most other micronutrients, copper availability is related to soil pH. Do not over-lime. For more information about soil copper, see FS720.

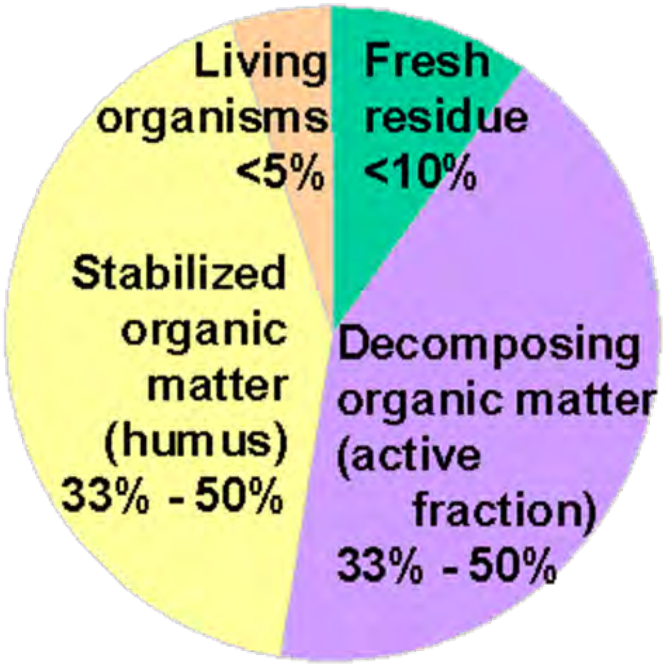
Manganese does not appear to be a limiting factor. Maintain soil pH in the optimum range, as directed in "Recommendations". See FS973 for more information about manganese in soil and plant nutrition.

Plant types differ in their susceptibility to boron deficiency; certain fruit, vegetable, and field crops are most susceptible. Symptoms include improper development or dieback of growing tips, poor flowering or fruit set, twisting and yellowing of young leaves from base to tip, and black heart of roots. Lime only as necessary, since pH above 7.0 limits boron availability. Building up organic matter content of soil will increase boron availability. Use of boron fertilizer must be done only with extreme care because of the toxicity that might occur if over-applied and the difficulty of applying the low rates necessary. See FS873 for more information and follow recommendations above.

Iron should be sufficient as long as soil pH is in the optimum range for the plant being grown. The availability of iron to plants decreases as soil pH increases. Maintain soil pH in the recommended range to assure availability of iron to plant roots. See FS971 for more information.

Organic matter or organic carbon -

- directly and indirectly linked to many other important soil properties:



pH buffering,
nitrogen,
phosphorus,
micronutrients,
cation exchange capacity,
microbial activity
- carbon mineralization,
- nitrogen mineralization,
- base of the food web

water-stable aggregation,
erosion susceptibility,
available water holding capacity

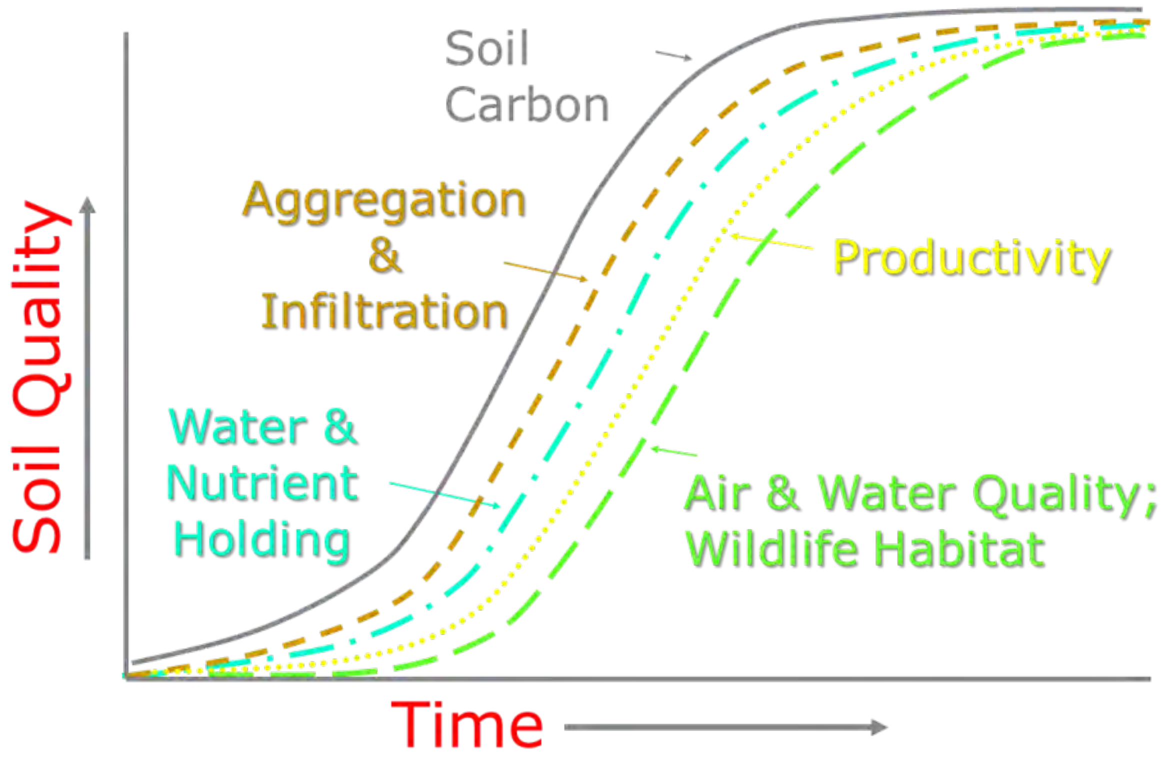
Organic matter Interpretation:

- depends on soil texture

Table 2. Interpretation of Organic Matter Levels in New Jersey Soils

Organic Matter	Soil Texture			
%	**Loamy Sand**	**Sandy Loam**	**Loam**	**Silt Loam**
Less than 0.5%	Very Low	Very Low	Very Low	Very Low
0.5 to 1.0%	Low	Very Low	Very Low	Very Low
1.0 to 1.5%	Medium	Low	Very Low	Very Low
1.5 to 2.0%	High	Medium	Low	Low
2.0 to 2.5%	Very High	High	Medium	Low
2.5 to 3.0%	Very High	Very High	Medium	Medium
3.0 to 3.5%	Very High	Very High	High	Medium
3.5 to 4.0%	Very High	Very High	High	Medium
4.0 to 5.0%	Very High	Very High	Very High	High
More than 5%	Very High	Very High	Very High	Very High

If low **organic matter content**, consider compost amendments or use of perennial vegetative cover.
Still, significant increases in %OM (and soil quality) take time.



5-10% organic matter should be maximum range

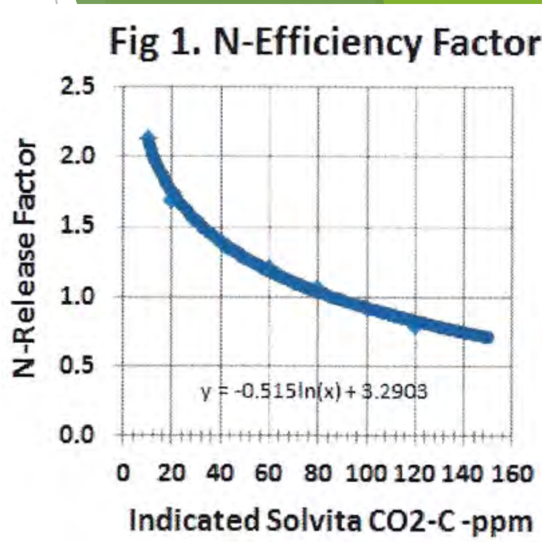
Microbiological Activity

- Can be measured by CO_2 (respiration)
- Related to nutrient release

TABLE #2 Soil CO_2-Rate Index of Fertility

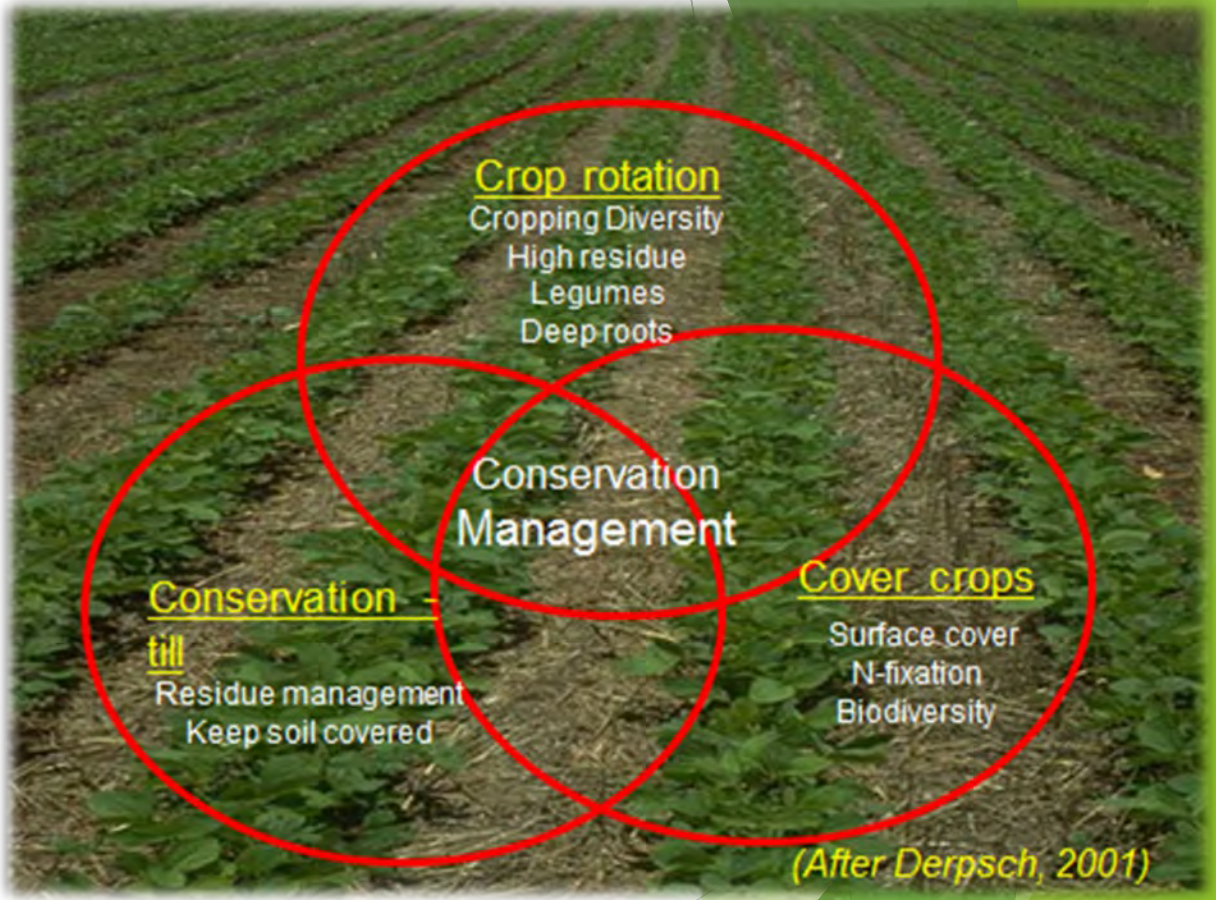
Color 0 - 1 Blue-Gray	Color 1 - 2.5 Gray-Green	Color 2.5 - 3.5 Green	Color 3.5 - 4 Green-Yellow	Color 4 - 5 Yellow
VERY LOW ACTIVITY Associated with depleted and dry sandy soils, and little or no organic matter	LOW ACTIVITY Soil is marginal in terms of biological activity and organic matter	MEDIUM ACTIVITY Soil is moderately balanced and has likely been receiving organic matter additions	IDEAL ACTIVITY Soil is well supplied with organic matter and has an active microbial population	HIGH ACTIVITY High or excessive organic matter
EMISSIONS (FLUX) OF CO_2-C as LBS / ACRE/ DAY (a)				
2 - 5 lb/acre/day	5 - 16	16 - 32	32 - 64	64 - 140
EMISSIONS (FLUX) OF CO_2 as KG / M^2 / year (b)				
0.2 - 0.5 kg/m^2	0.5 - 2.5	2.5 - 6.0	6.0 - 9.0	9 - 20
SOLVITA BASAL CO_2-C RESPIRATION RATE, mg/kg (c)				
< 2	2 - 6	6 - 14	14 - 22	22 - 55

Soil Activity



Other management recommendations for Healthy Soil

Prevent compaction
Prevent erosion
Keep soil covered: crop canopy + residue
    USDA "**Keep the Soil Covered as Much as Possible**"
Minimize tillage/disturbance
    USDA "**Manage More by Disturbing Soil Less**"
Diversify and rotate crops/soil inhabitants
    USDA "**Diversify Soil Biota with Plant Diversity**"
Return organic matter to soil: recycle nutrients
    residues
    manure
    composts
    cover crops
    USDA "**Keep a Living Root Growing Throughout the Year**"
Be conservative in amendment applications
    Soil Test & follow recommendations
    Scout and know pest thresholds



Contaminant Testing

- Lead (Pb) is most common metal contaminant
- Lead screening at Rutgers STL:
  - not an official EPA method
  - Extracted with Mehlich-3 solution and analyzed by ICP spectrometer
    - Calibration to EPA method allows estimation of total Pb
    - When values high, recommend testing at a certified environmental laboratory
- Priority Pollutant metals in soil by X-ray fluorescence:
  - 12 of 13:
    Antimony (Sb), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), Selenium (Se,) Silver (Ag), Thallium (Tl) and Zinc (Zn)
  - Does not include Beryllium (Be)
- Certified environmental laboratory for other contaminants types
  - Organics
  - Xenobiotics (man-made chemicals, foreign to biosphere)

Raised beds

- Especially useful for problem areas
  - Beneficial in limited-space situations
  - Low sites and/or poor drainage areas
  - Contaminated or otherwise poor soil
- Soil drains & warms quickly in spring
- Design precludes soil compaction issues
  - Meant to be gardened from edge
  - No traffic; paths between beds
  - Typically, "light-weight" soil is used – resists compaction
- Soils for raised beds: soil/organic blends
  - Use $^1/_3$ – $^2/_3$ mineral soil
  - Large organic component ($^1/_3$, or 4" - 6" mixed into 12" soil depth)
  - Sand, perlite, or other product (up to $^1/_3$) to improve drainage in "heavy" soil
  - Organic-only ***not*** recommended

Soil Management in Raised Beds

- Treat as a container planting
  - Typically requires close monitoring of plant-available H_2O
    - Relative retention of water compared to mineral soil
    - Drying may cause hydrophobicity
    - Layering may inhibit drainage
  - Subsidance
    - Needs seasonal replacement/supplementation
    - Can become fairly dense as it collapses upon itself
  - May require more fertilizer, different ratio

Organic growing media & Compost tests

- Mild extraction of nutrients (with water): Saturated media extract, SME
  - Compare to mineral soil nutrient extractions with acids + salts + chelating agent
- Interpretations calibrated to plant resonse in typical potting soil (sphagnum peat moss, etc.)
- Typically more analyses performed: includes available nitrogen, soluble salt level, in addition to nutrients and pH
- More labor-intensive and time-consuming…more expensive
- Physical conditions are often as important as fertility measures
  - Drainage, aeration, temperature
  - Natural compaction as organic matter continues to decompose – subsidence, slumping
  - Plant root vs. microbe competition for oxygen in soil
- Periodic replacement may be necessary with organic-only media
- All compost is not created "equal" –
  quality of raw materials and "maturity" or "curing" of compost should be accessed.

Conclusions

- Stewardship of soils in sub/urban farms will avoid many problems & minimize costs in the long run
- Monitoring and thoughtful management of soils will help develop and sustain successful yields
- In addition to producing healthy crops, soil BMPs often involve ***prevention*** of soil degradation - such as compaction and erosion – for a healthier environment.

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