USDA-ARS Temple Texas 2012
Corn yield attributable to fertilizer and lime: 1955-2000
Morrow plots (U. of Illinois)

Outlier in 1956 reduced average for 1955-59.

Source: IPNI.net
Wheat yield attributable to fertilizer: 1930-2000
Magruder plots (OSU)

Wheat yield attributable to N and P fertilizer, %

Year

Average= 40%

Upward trend due to depletion of native N and P through crop removal.

Source: IPNI.net
Traditional NPK

• Soil is not simply a chemical system
• Soil chemistry is much easier to measure than soil biology
• Due to a lack of technology and innovation we have largely ignored soil biology
• We now have both the technology and innovation we need to improve soil testing
How it’s tested: Soil NPK

- Treat the soil as a non-living non-integrated system
- Focus on physical and chemical
- Ignore the biological
- Extract soil with chemistry that soil never sees
- Measure the house and not the food
Lab Chemistry

- Sulfuric acid
- Hydrochloric acid
- Nitric acid
- Acetic acid
- Phosphoric acid
- KCl
- Ammonium acetate
- Diethylene triamine pentaacetic acid
- Ethylenediaminetetraacetic acid
- Ammonium nitrate

- Water
- Naturally occurring organic acids (H3A)
Soil Extraction H3A and Water

What does the plant root really see?

• WATER and a complex mixture of plant root exudates along with microbial derived enzymes and nutrients
• The below ground root system flows with elegance and complexity
• We extract soil with highly disruptive acidic or alkali solutions and call it “plant available”
Nitrogen

• **Current labs**
  1. NO3-N
  2. 2 M KCl (1965)
  3. None

• **Soil Health Tool**
  1. NH4-N
  2. NO3-N
  3. WETN
  4. Solvita
  5. Org N
  6. Org C:N
  7. MAC WEON
  8. N min
  9. Water
Molecular Structure

The general formula of amino acids.
(Stevenson 1982)

β-D-Glucosamine
β-D-Galactosamine
β-Muramic acid
(3-O-(1-carboxyethyl)-β-D-glucosamine)

NO$_3$-N

H$_3^{13}$CSTEMCHEM

O-linked glycan of N. meningitidis pilin

Zwitterionic polysaccharide A1 repeating unit of B. fragilis

O-Polysaccharide repeating unit of P. aeruginosa

O-linked glycan of P. aeruginosa

Polysaccharide repeating unit of B. cereus strains ATCC and 14579
Since 1965* we have been missing half of the N

*2M KCl 1965 Bremer

“If plants could not take up organic compounds herbicides would not work”

Plants eat: Inorganic N
And Organic N from soil organic matter

Water Extractable Total Nitrogen
Average of 6227 soil samples

Inorganic N
Organic N
34 lbs N
36 lbs N
Phosphate

• Current labs
  1. ICP P or PO4-P using 7 different extractants

• Soil Health
  1. ICP P
  2. PO4-P
  3. H3A (mimics plant root exudates)
  4. Solvita
  5. Org C:N
  6. P min
  7. % water P/ H3A P
  8. % P/ FeAl
  9. Ca/FeAl
H3A

2D Graph 2

$y = -3.3 + 0.98x$

$r^2 = 0.96$
Mehlich 3

\[ y = 33.7 + 1.5x \]
\[ r^2 = 0.83 \]
What is healthy soil?

- Plentiful food and energy for soil microbes
- Living roots
- Sunlight
- Water
- Diversity in cropping systems or pastures
- Feed them and they will come and make things better
- How do you measure this? Observation
Soil Health

• Current labs
  1. Permanganate: active carbon (not what soil microbes “see”, they see water soluble carbon)
  2. Organic matter (the house, not the food)
  3. Anaerobic 7 day Nmin (40 C, anaerobic, not what happens in the field, can’t measure N immobilization)

• Soil Health Tool
  1. Solvita (microbial respiration/activity)
  2. Water soluble Organic C (microbial food)
  3. Water soluble Organic N
  4. Org C:N
  5. Soil health score
  6. Cover crop suggestion
Soil Health Methods

The SHT relies on information gleaned from newly developed soil-testing methods geared towards soil microbial activity and the readily available substrate that they act upon. In other words, we assess the soil as a doctor might assess a living being, using many measurements of health viewed collectively to attain an overall picture of soil vigor.

The measurements include:

- water extractable organic C (WEOC)
- water extractable nitrogen (WEN)
- water extractable organic N (WEON)
- C: N ratio of the two
- 1-day CO$_2$-C microbial activity test
- inorganic N and P and K
- H3A extractable aluminum, iron, and phosphate.
Soil Organic Matter is the “House” microbes live in, Water Extractable Organic Carbon is the “Food” they eat.

2% SOM, 12,000 ppm C

100-1000 ppm C from water extract = microbial food
Soil Organic C vs. Water Extractable Organic C

A soil with 2 % soil organic matter (SOM) would have 12,000 ppm C. When we analyze the water extract from the same soil, that number could be from 100-300 ppm C. The organic C in the soil water extract reflects the carbon in your soil that is highly related to the microbial activity. % SOM is about the quantity of organic C, water extractable organic C is about quality.
Microbial activity vs. SOC

1-day CO$_2$-C
mg C kg$^{-1}$ soil

Soil organic C
mg C kg$^{-1}$ soil

$y = 2306 + 265x$
$r^2 = 0.43$
Microbial activity vs. WEOC

Water extractable organic C (mg C kg\(^{-1}\) soil) vs. 1-day CO\(_2\)-C (mg C kg\(^{-1}\) soil)

Regression equation: \(y = 123 + 7x\)

Coefficient of determination: \(r^2 = 0.83\)
Microbial activity vs. SON

\[ y = 189 + 22x \]
\[ r^2 = 0.38 \]
Microbial activity vs. WEON

![Graph showing the relationship between 1-day CO$_2$-C mg C kg$^{-1}$ soil and water extractable organic N mg C kg$^{-1}$ soil. The equation y = 1.5 + 0.62x and the coefficient of determination $r^2 = 0.83$ is provided.]
Soil Health Calculation

Water Extraction for C and N

1 day CO$_2$-C

WEON

NH$_4^-$-N + NO$_3^-$-N

Soil Health Calculation

WEOC

WEN
After shaking for 10 minutes
4 grams soil 40 mls (1) H3A,
(2) water

After 5 minute centrifuge
(1) H3A (2) water

Filtration
1 day \( \text{CO}_2 \)-C

15 ml water, 40 grams soil

Capillary action rewets soil to field capacity
Soil Respiration 1 day CO$_2$-C D/R
<table>
<thead>
<tr>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
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</thead>
<tbody>
<tr>
<td>N lbs per acre</td>
<td>P2O5 lbs per acre</td>
<td>K2O lbs per acre</td>
<td>Nutrient value per acre</td>
<td>Crop</td>
<td>Yield Goal</td>
<td>lbs N needed</td>
<td>lbs P2O5 needed</td>
<td>lbs K2O needed</td>
<td>NO3-N Only lbs per acre</td>
<td>Additional N lbs per acre</td>
<td>E nitrogen saved per acre</td>
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<tr>
<td>71.7</td>
<td>59.3</td>
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<td>$111.8</td>
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<td>41</td>
<td>29</td>
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<tr>
<td>77.5</td>
<td>60.5</td>
<td>61.6</td>
<td>$125.7</td>
<td>corn</td>
<td>200</td>
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<td>39</td>
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<td>$46.8</td>
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</tr>
<tr>
<td>31.8</td>
<td>47.8</td>
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<td>$71.5</td>
<td>corn</td>
<td>200</td>
<td>158</td>
<td>52</td>
<td>44</td>
<td>15.8</td>
<td>16.0</td>
<td>$11.2</td>
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<td>45.6</td>
<td>$31.9</td>
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<td>15.8</td>
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<td>30.4</td>
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</table>
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Next a
Sheets("npk").Select
Range("A2:U5000").ClearContents
Range("A2").Select
For a = 2 To count
    Cells(a, 1) = Sample_ID(a)
    Cells(a, 2) = Lab.ID(a)
    Cells(a, 3) = NH4_water(a) * 2 + NO3_water(a) * 1.4 + MAC_WEOC(a)
    Cells(a, 4) = PO4_H3A(a) * 2.3 + Pmin(a) * 2.3
    Cells(a, 5) = K_H3A(a) * 1.2
    Cells(a, 6) = Cells(a, 3) * 0.6 + Cells(a, 4) * 0.85 + Cells(a, 5) * 0.45
    Cells(a, 13) = ((NO3_water(a) * 2)) * 0.7
    Cells(a, 14) = Cells(a, 3) - Cells(a, 13)
    Cells(a, 15) = Cells(a, 14) * 0.7
    Cells(a, 17) = one_day_C(a)
    Cells(a, 18) = WEOC(a)
    Cells(a, 19) = WEON(a)
    Cells(a, 20) = WEOC_N(a)
    Cells(a, 21) = SHC(a)
    Cells(a, 22) = Soil_input(a)
    Cells(a, 23) = WEN(a) * 2
    Cells(a, 24) = In_N_water(a) * 2
    Cells(a, 25) = Cells(a, 23) - Cells(a, 24)
    Cells(a, 26) = P.H3A(a) * 2.3
    Cells(a, 27) = PO4_H3A(a) * 2.3
    Cells(a, 28) = Cells(a, 26) - Cells(a, 27)
    Cells(a, 30) = Al_H3A(a)
    Cells(a, 31) = Fe_H3A(a)
    Cells(a, 32) = Ca_H3A(a)
    Cells(a, 34) = MAC_WEOC(a)
If Cells(a, 34) > Cells(a, 25) Then Cells(a, 34) = Cells(a, 25)
    Cells(a, 35) = Cells(a, 19) * 2 - Cells(a, 34)
    Cells(a, 36) = Pmin(a) * 2.3
If Cells(a, 36) < 0 Then Cells(a, 36) = 0
    Cells(a, 37) = Cells(a, 26) - Cells(a, 27) - Pmin(a) * 2.3
    Cells(a, 38) = P_H3A(a) / (Al_H3A(a) + Fe_H3A(a)) * 100
    Cells(a, 39) = Ca_H3A(a) / (Al_H3A(a) + Fe_H3A(a))
    Cells(a, 41) = Cells(a, 21)
    Cells(a, 42) = Cells(a, 15)
```
<table>
<thead>
<tr>
<th></th>
<th>1-day CO2-C</th>
<th>Organic C</th>
<th>Organic N</th>
<th>Organic C:N</th>
<th>Soil Health Calculation</th>
<th>Cover crop mix</th>
<th>Total Nitrogen lbs/acre</th>
<th>Inorganic N</th>
<th>Organic N</th>
<th>Total</th>
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<tr>
<td>2</td>
<td>63.4</td>
<td>273.3</td>
<td>32.3</td>
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<td>12.3</td>
<td>40% Legume 60% Grass</td>
<td>81.4</td>
<td>16.7</td>
<td>64.6</td>
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<tr>
<td>3</td>
<td>238.6</td>
<td>345.4</td>
<td>33.3</td>
<td>10.4</td>
<td>29.8</td>
<td>20% Legume 80% Grass</td>
<td>82.1</td>
<td>15.5</td>
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<tr>
<td>4</td>
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<td>50% Legume 50% Grass</td>
<td>74.7</td>
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<td>22.6</td>
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<td>8.7</td>
<td>50% Legume 50% Grass</td>
<td>58.2</td>
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<td>60% Legume 40% Grass</td>
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<td>47.8</td>
<td>8.6</td>
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</tbody>
</table>
Example: Yield Goal of 200 bushel corn

<table>
<thead>
<tr>
<th>Soil 1</th>
<th>Soil 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate nitrogen 10 lbs</td>
<td>Nitrate nitrogen 10 lbs</td>
</tr>
<tr>
<td>Soil respiration 15 ppm</td>
<td>Soil respiration 100 ppm</td>
</tr>
<tr>
<td>WEOC 100 ppm</td>
<td>WEOC 400 ppm</td>
</tr>
<tr>
<td>WEON 10 ppm</td>
<td>WEON 40 ppm</td>
</tr>
<tr>
<td>N recommendation 183 lbs</td>
<td>N recommendation 123 lbs</td>
</tr>
<tr>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Soil health Score 3.5</td>
<td>Soil health score 18.0</td>
</tr>
</tbody>
</table>
Frankenbreather
Houston Black
mean of 3 reps

Time in Hours
2 4 6 8 10 12 14 16 18 20 22 24 26 28

CO$_2$-C
mg C kg$^{-1}$ soil
0
5
10
15
20
Con avg
20 avg
10 avg
5 avg
2 avg

Graph showing the decline of CO$_2$-C (mg C kg$^{-1}$ soil) over time in Houston Black soil for different averages (Con avg, 20 avg, 10 avg, 5 avg, and 2 avg).
Missouri PMC
mean of 3 reps

CO$_2$-C
mg C kg$^{-1}$ soil

Con avg
Oxalic acg
Malic avg
Citric avg
Glycine avg
Arg avg

Time in Hours
2 4 6 8 10 12 14 16 18 20 22 24 26 28
Western Oklahoma
mean of 3 reps

Time in Hours
2 4 6 8 10 12 14 16 18 20 22 24 26 28

CO$_2$-C
mg C kg$^{-1}$ soil
0.0
0.5
1.0
1.5
2.0
2.5

Con
Oxalic
Malic
Citric
Gly
Arg

Time in Hours
Another Texas Pasture

Time in hours
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28

CO\textsubscript{2}-C
mg C kg\textsuperscript{-1} soil
0 5 10 15 20 25

Con avg
Oxalic acg
Malic avg
Citric avg
Glycine avg
Arg avg
166 Producer’s responded from 18 states. The majority from Iowa, Indiana, Minnesota and South Dakota.

Total acres: 8143, average field size 49 acres

Average Yield: 174

Average N / Yield: 1.27 (lbs. N to grow 1 bushel of corn)

Average Soil Health Score: 10

Average Soil Test lbs. N: 59
Average Soil Test lbs. P2O5: 90
Average Soil Test lbs. K2O: 127

Average lbs. N applied: 154
Average lbs. P2O5 applied: 44
Average lbs. K2O applied: 51

Average $ NPK found from soil test: $141

Average NPK $ per acre applied: $130

118 no-till, average yield 173

34 reduced till, average yield 181

14 conventional till, average yield 170

87 used cover crops, average yield 180

79 without cover crops, average yield 168
Soil test N + N applied/ Yield (lbs. N to grow a bushel of corn)

Soil Health Score
Corn Yield (bu per acre) vs. $ NPK applied per acre

Regression equation: $y = 153 + 0.15x$

Coefficient of determination: $r^2 = 0.06$
Buddy (ARS) and Chris (NRCS)
The End