Chapter 1
Understanding Soil

Lecture 3 – Soil Assessment Methods

Choose the right assessment tool

At Texas A&M, my major professor had been approached by the oyster industry in Galveston Bay.

The oysters were not growing, despite addition of every combination of fertilizer, growth promoters, and nutrient enhancement known to man. Someone suggested that the problem might be biological.

How do you approach this problem?

The consensus was to determine what microorganisms were in healthy oyster digestive systems, versus the oysters in the commercial beds.

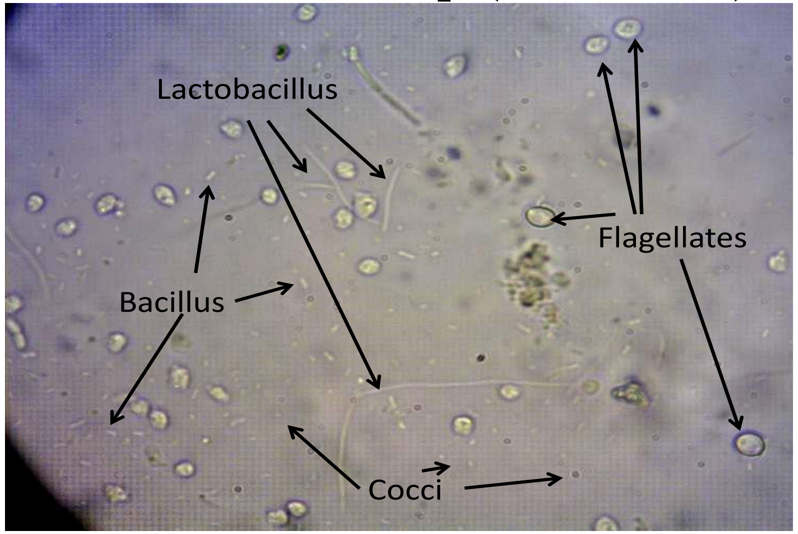
Using plate counts, no differences were observed

Direct Microscopy versus Plate Counts

Because I had microscope training, I looked at digestive system samples using a microscope, and determined the following:

Direct Microscopy

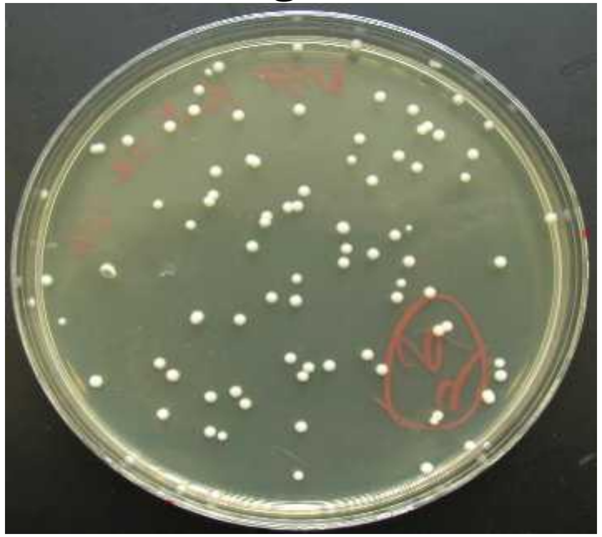
1/2000th of a drop (microliter)



1000 bacteria, 12 species; protozoa

Plate Count using TSA

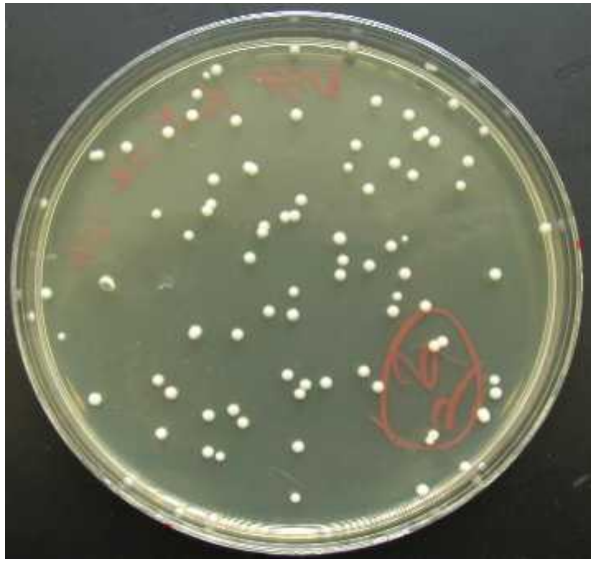
1 ml of digestive fluid



100 Bacteria CFU; 2 species

Which method is telling the truth?

Plate Counts



- A specific mix of foods in the dish
- Potato dextrose agar (PDA) for “total fungi”
- Tryptone soy agar (TSA) for “total bacteria”
- Spread sample on surface of medium
- Cover, incubate at constant temperature,
- Humidity, moisture. (Is that normal?)
- Added food allows organisms to grow rapidly from 1 to over a million individuals in 18 hours, and we see the resulting colony.
- The colonies of different species usually look different.
- Oxygen will be used up rapidly when bacteria are growing rapidly in a limited atmosphere. Reduced oxygen conditions select for pathogen growth

What was I actually learning from these assessments?

The plate count method was not telling me what I wanted to know. I wasn't asking how many anaerobic, and most likely pathogenic organisms were present in the oyster's digestive system.

Oyster digestive systems aren't typically anaerobic.

I wanted to know if the biology in healthy oysters was different from the biology in sick oysters. And I figured that out using shadowing microscopy.

When we added the right sets of microbes to the digestive systems of the oysters, the oysters grew.

Knowledge Desired	Name of Method(s)	Description of Methods: Problems with Method
Organism Biomass	Shadowing Microscopy	Measure length, with or number of individuals separated by general or specific morphological criteria. Compare values over time. Compare to desired ranges based on crops
Organism Activity	CO_2 absorption; e.g., Solvita, Haney Enzymes; e.g., Dehydrogenase, chitinase	CO_2 absorbing chemical with a pH indicator is used so color change can be related to CO_2 taken up. Other chemical reactions in soil can release CO_2. Sampling can alter soil biology. Add food, or not? Enzymes react with substrate, measure initial and final amounts of substrate. Disturbance reduces numbers and kinds of organisms.
Numbers of Individuals of one or more species or genus	Plate Counts PLFA	Can organisms grow on the medium used, at the temperature, moisture, humidity used? Useful for specific pathogens, but completely inappropriate for total species or activity. Not all species microbes produce PLFA, so results underestimate actual values.

Knowledge Desired	Name of Method(s)	Description of Methods: Problems with Method
Organism numbers	Chloroform fumigation	Fumigation is supposed to kill all the organisms in the sample, but this will not be the case unless the sample is spread very thinly, which means severe disturbance impact on the organisms. All the dead organisms are supposed to now be used by the remaining living organisms (but the chloroform killed everything, so how can living organisms still be present? How much of the total set of organisms weren't killed? Temperature, moisture, amount of organic matter will affect the results as well. Significant controls are needed and are rarely included.
Nutrient Cycling	Haney Test	Measure soluble inorganic nitrogen levels at the start and end of an incubation period. Samples incubated in a sealed jar will quite likely become anaerobic, which means inorganic N will be lost as gas when the jar is opened leading to underestimates.

Soil Quality Indicator Properties

Physical Properties	Chemical Properties	Biological Properties
Bulk density	Soil reaction of pH	Organic matter content
Rooting depth	Electrical conductivity	Microbial biomass carbon
Water infiltration rate	Cation exchange capacity	Microbial biomass nitrogen
Aggregate stability	Organic matter	Earthworms
Surface and sub-surface hardness	Mineralisable nitrogen	Enzymes
	Exchangable potassium	Disease suppressiveness
	Exchangable calcium	Active carbon
		Decomposition rate

Soil Chemistry Definitions

pH is the negative log of the H+ concentration

- Neutral pH or pH 7 occurs at [H+] = [OH-] where both are at a concentration of 10^{-7}

Cation Exchange Capacity (CEC) is a measure of the ability of sand, silt, clay and organic matter surfaces to hold and release cations.

Electrical conductivity (EC) is the ability of a volume of material to transmit electrical current.

- Expressed as Siemens per cubic meter, or milliSiemans per cubic cm (mS/cm^3). Be **VERY CAREFUL** about units!

ACIDS, ALKALIS, AND THE pH SCALE

The pH scale is a way of gauging the acidity or alkalinity of a solution. It is calculated using: $pH = -\log_{10}[H^+]$. Adding an acid to water increases the H^+ (H_3O^+) concentration, and decreases the OH^- concentration. An alkali does the opposite.

	pH	H^+ CONCENTRATION (in moles per litre)	OH^- CONCENTRATION (in moles per litre)	EVERYDAY EXAMPLE
ALKALINE (Purple)	14	1×10^{-14}	1	Drain Cleaner
	13	1×10^{-13}	0.1	Bleach
	12	1×10^{-12}	0.01	Ammonia
(Blue)	11	1×10^{-11}	0.001	Soap
	10	1×10^{-10}	1×10^{-4}	Antacid Tablets
(Turquoise)	9	1×10^{-9}	1×10^{-5}	Baking Soda
	8	1×10^{-8}	1×10^{-6}	Seawater
NEUTRAL (Green)	7	1×10^{-7}	1×10^{-7}	Pure Water
ACIDIC	6	1×10^{-6}	1×10^{-8}	Urine (average)
(Yellow)	5	1×10^{-5}	1×10^{-9}	Black Coffee
	4	1×10^{-4}	1×10^{-10}	Tomato Juice
(Orange)	3	0.001	1×10^{-11}	Soda
	2	0.01	1×10^{-12}	Lemon Juice
(Red)	1	0.1	1×10^{-13}	Stomach Acid
	0	1	1×10^{-14}	Battery Acid

Cation Exchange Capacity (CEC)

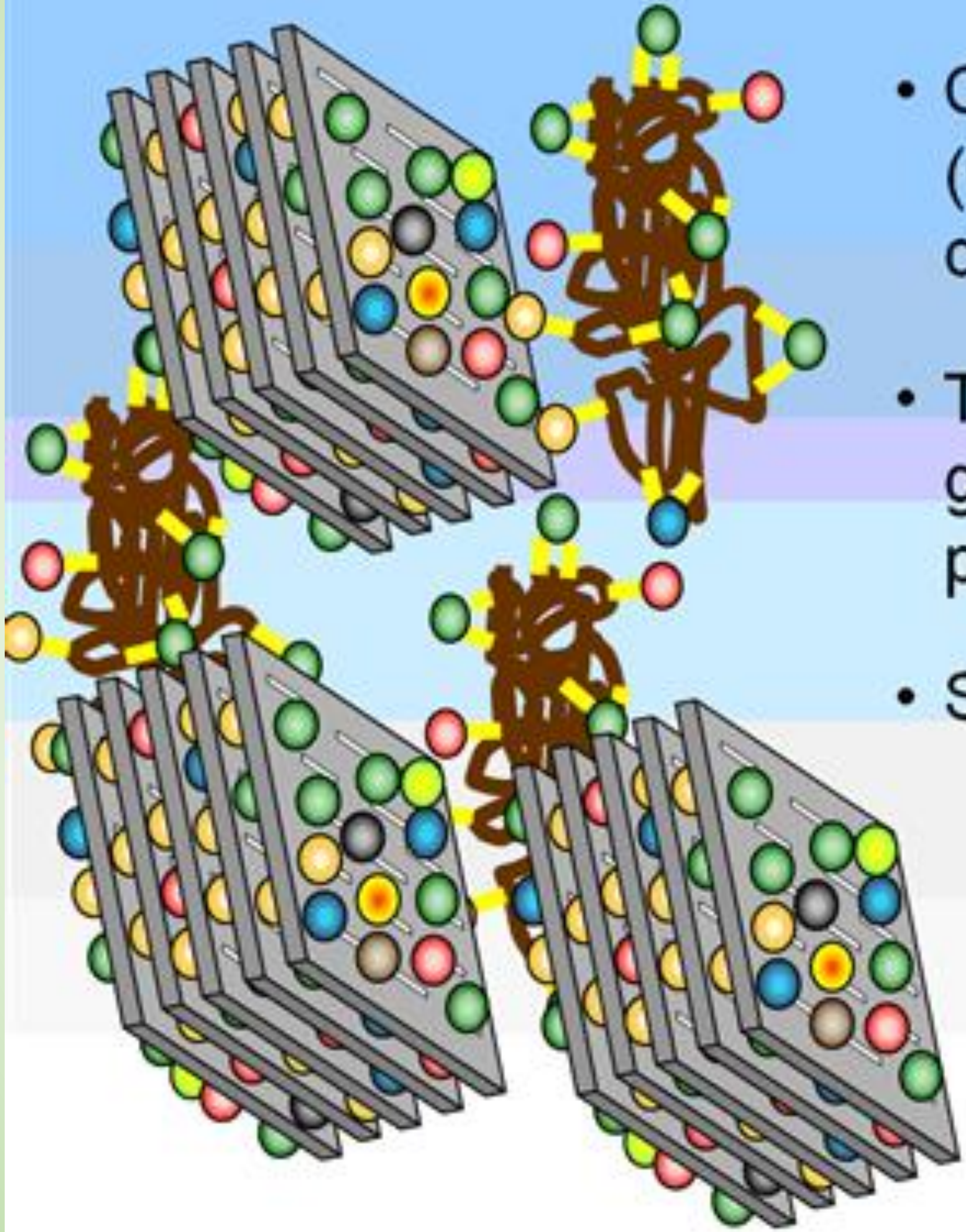
- ✓ **Ability of a soil to hold and exchange cations**
  - Ions are atoms with an electrical charge

Cations	
Ca^{2+}	Mg^{2+}
Na^{+}	K^{+}

Anions	
SO_4^{2-}	PO_4^{3-}
Cl^{-}	NO_3^{-}

- ✓ **Negatively charged colloids (organic matter and clay) attract and hold cations**

Cation Exchange Capacity



- Cation exchange capacity (CEC) is the total amount of cations that a soil can retain
- The higher the soil CEC the greater ability it has to store plant nutrients
- Soil CEC increases as
  - **The amount of clay increases**
  - **The amount of organic matter increases**
  - **The soil pH increases**

Predicting CEC

1) sum of cations : remove all cations and total the amount

2) NH_4^+ saturation: soil is saturated with NH_4^+ - the NH_4^+ is replaced by Ca^{++} and the NH_4^+ removed is measured.

3) Estimation based on texture:

Sand = 0-3 meq/100 g   LS to SL = 3-10

Loam = 10 - 15   Clay Loam = 15-30

Clay = > 30 (depends on kind of clay)

Cation Exchange Capacity

Table 1. Cation exchange capacities at pH 7.0 of different soil types, textures and soil organic matter.

Soil and Soil Components	**CEC (meq/100 g)**
Clay Type	
Kaolinite	3-15
Illite	15-40
Montmorillonite	80-100
Soil Texture	
Sand	1-5
Fine Sandy Loam	5-10
Loam	5-15
Clay Loam	15-30
Clay	>30
Organic Matter	200-400

Soil Chemistry Definitions: Base Saturation

- Base Saturation is the percentage of the soil exchange sites (CEC) occupied by cations, such as potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and sodium (Na^+).

- Ca:Mg affects the way CLAY platelets arrange themselves: collapsed, flocculated, dispersed.
  - In the early decades of the 19^{th} Century in the US, Albrecht showed that montmorillinite, a certain kind of clay, requires EXCHANGEABLE Ca:Mg to be 7:1 in order to cause the clay platelets to repel each other, opening space for oxygen, nutrients and organisms to be present between the clay silica layers. This means soil has an easier time staying aerobic.
  - A clay soil with too much Ca acts like dust, repels water.
  - A clay soil with too little Ca collapses and compacts

		Block ID:	Bedwell SFI#7623	*Desirable Level Heavy Soil*	*Desirable Level Medium Soil*
	Nutrient	Units			
Soluble Tests & Morgan 1 Extract	Calcium Ca	ppm	525	*1150*	*750*
	Magnesium Mg	ppm	593	*160*	*105*
	Potassium K	ppm	145	*113*	*75*
	Phosphorus (Morgan) P	ppm	0.5	*15*	*12*
	Phosphorus (Bray 1) P	ppm	4	*45 note 8*	*30 note 8*
Soluble Tests & Colwell + Bray 2 Phoshorus Extract	Phosphorus (Colwell) P	ppm	16	*80*	*50*
	Phosphorus (Bray 2) P	ppm	12	*90 note 8*	*60 note 8*
	Nitrate N	ppm	23.8	*15*	*13*
	Ammonium N	ppm	5.9	*20*	*18*
	Sulphate Sulphur S	ppm	12	*40*	*30*
	pH (1:5 water)	units	5.29	*6.5*	*6.5*
	Conductivity (1:5 water)	µS/cm	169	*200*	*150*
	Organic Matter	%	4.91	*5.5*	*4.5*
Ammonium Acetate Equiv. Extract	Calcium Ca	$cmol^+/Kg$	9.18	*15.6*	*10.8*
	Ca	kg/ha	4112	7000	4816
	Ca	ppm	1836	3125	2150
	Magnesium Mg	$cmol^+/Kg$	11.09	*2.4*	*1.7*
	Mg	kg/ha	2981	650	448
	Mg	ppm	1331	290	200
	Potassium K	$cmol^+/Kg$	1.28	*0.6*	*0.5*
	K	kg/ha	1117	526	426
	K	ppm	498	235	190
	Sodium Na	$cmol^+/Kg$	1.60	*0.30*	*0.26*
	Na	kg/ha	822	155	134
	Na	ppm	367	69	60
	Aluminium Al	$cmol^+/Kg$	0.13	*0.6*	*0.5*
	Al	kg/ha	26	108	90
	Al	ppm	12	54	45

Acidity Titration	Hydrogen	H^+	$cmol^+/Kg$	0.20	*0.6*	*0.5*
		H^+	kg/ha	4	12	10
		H^+	ppm	2	6	5
	Cation Exchange Capacity		$cmol^+/Kg$	23.47	*20.0*	*14.0*
Percent Base Saturation	Calcium	Ca	%	39.1	*77.0*	*76.0*
	Magnesium	Mg	%	47.3	*12.0*	*12.0*
	Potassium	K	%	5.4	*3.0*	*3.5*
	Sodium	Na	%	6.8	*1.5*	*2.0*
	Aluminium	Al	%	0.6	*6.5*	*6.5*
	Hydrogen	H+	%	0.8		
	Calcium/ Magnesium Ratio		ratio	0.83	*6.42*	*6.33*
SMP	BUFFER pH		units	6.60	*6.7*	*6.7*
Micronutrients- DTPA +Hot $CaCl_2$ Extracts	Zinc	Zn	ppm	0.7	*6.0*	*5.0*
	Manganese	Mn	ppm	19.4	*25*	*22*
	Iron	Fe	ppm	199.3	*25*	*22*
	Copper	Cu	ppm	2.8	*2.4*	*2.0*
	Boron	B	ppm	1.47	*2.0*	*1.7*
Total Nutrients	Total Carbon	C	%	2.81	*3.1*	*2.6*
	Total Nitrogen	N	%	0.22	*0.30*	*0.25*
	Carbon/ Nitrogen Ratio		ratio	12.8	*10 to 12*	*10 to 12*
	Texture	t		Clay	..	..
	Colour	c		Brown	..	..

Notes:

1: Cation Exchange Capacity = sum of the exchangeable Mg, Ca, Na, K, H and Al;   Sodium % = ESP (Exchangeable Sodiu

1a: Soluble Salts included in exchangeable Cations - NO WASHING/ REMOVAL OF SOLUBLE SALTS

2: Albrecht Methods from Rayment and Higgins, 1992. Australian Laboratory Handbook of Soil and Water Chemical Methoc

3: Reams available nutrient testing adapted from 'Science in Agriculture' and 'Non-Toxic Farming' and Lamonte Soil Handbc

4. All results as dry weight; ppm = mg/Kg air dried @ 65°C and crushed to ensure homeogenity (ie. ring mill)

Soil Biology Assessment

Organism Group	Corn Field	Desired Values	Orchard Soil	Desired Values
Bacterial Biomass (µg/g)	21,730 (1,560)	>300 1:1 balance with fungi	18,850 (1,620)	>300 10:1 balance with fungi
Actinobacterial Biomass (µg/g)	0.33 (0.66)	< 16	1.66 (2.81)	<16
Beneficial Fungal Biomass (µg/g)	49.0 (45.5)	> 300 1:1 balanced with bacteria	58.3 (58.0)	>3,000 10:1 balanced with bacteria
Oomycete Biomass (µg/g)	3.80 (5.10)	0	3.80 (7.81)	0
Protozoan Numbers		Control bacteria		Control bacteria
Flagellate	0	>10,000	0	>10,000
Amoebae	0	>10,000	0	>10,000
Ciliates	0	0	0	0
Nematode Numbers		Nutrient cycling		Nutrient cycling
Bacterial-Feeders	0	>100	0	>100
Fungal-Feeders	0	>10	0	>10
Predatory	0	>1	0	>1
Root-Feeders	0	0	0	0