

Soil Quality Test Kit

SECTION II

Background & Interpretive Guide for Individual Tests



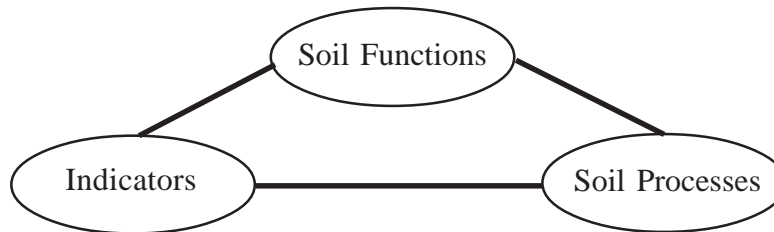
Section II

	Page
Introduction	51
Background & Interpretive Guides:	
1. Soil Respiration	52
2. Infiltration	55
3. Bulk Density	57
4. Electrical Conductivity (EC)	59
5. Soil pH	63
6. Soil Nitrate	67
7. Aggregate Stability	69
8. Soil Slaking	72
9. Earthworms	73
10. Soil Physical Observations and Estimations	75
11. Water Quality	79
Salinity of water	
Nitrate/nitrite levels in water	

INTRODUCTION

Soil quality assessment or interpretation should be considered a process through which soil resources are evaluated on the basis of soil function (what the soil does) and change in soil function in response to a specific natural or introduced stress, or management practice. Five vital soil functions have been proposed. They are: (1) sustaining biological activity, diversity, and productivity; (2) regulating and partitioning of water and solute flow; (3) filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition; (4) storing and cycling of nutrients and other elements within the Earth's biosphere; and (5) providing support of socioeconomic structures and protection for archeological treasures associated with human habitation (Karlen et al., 1997).

It is also important to emphasize that soil quality evaluations must consider biological, chemical, and physical properties and processes. For interpretation, the measurements must be evaluated with respect to their long-term trends or signs of sustainability. A general sequence of how to evaluate soil quality is to (1) define the soil functions of concern, (2) identify specific soil processes associated with those functions, and (3) identify soil properties and indicators that are sensitive enough to detect changes in the functions or soil processes of concern (Carter et al., 1997).



Section II provides background and interpretive information for each test described in Section I. Each test is considered to be an indication of the level of functioning. However, indicator data is not meaningful unless a baseline or some reference condition is available for comparison or unless relative comparisons between management systems are made.

References

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1. Soil Respiration

Introduction

Soil respiration is the production of carbon dioxide (CO₂) as a result of biological activity in the soil by microorganisms, live roots, and macroorganisms such as earthworms, nematodes, and insects (Parkin et al., 1996). Carbon dioxide emitted from soil is a colorless and odorless gas that enters the atmosphere and annually exceeds the amount emitted by all human activities (Volk, 1994). The activity of organisms in the soil is considered to be a positive attribute for soil quality.

Soil respiration is highly variable both spatially and seasonally, and is strongly affected by moisture and temperature conditions. Because this variability can complicate interpretations, certain sampling precautions must be taken.

Knowing the history of the sampling site and characteristics of nearby soils becomes very important when evaluating respiration. Soil color may provide some assistance when interpreting respiration rates. A light colored soil with a high respiration rate may be indicative of a soil being depleted of organic matter. A relatively darker soil with the same rate could be considered healthy. The dark color indicates the presence of organic matter. Tillage or cultivation can result in loss of soil carbon (C) and increases in the amount of CO₂ released. The soil is loosened, which creates better accessibility of oxygen necessary for organic matter decomposition and respiration, resulting in CO₂ release (Reicosky and Lindstrom, 1995).

Interpretations

When comparing soil respiration rates from different sites or from the same site at different times, differences in soil temperature and soil water content must be taken into account. Soil temperature corrections can be performed using the general rule that biological activity increases by a factor of 2 with each 10°C increase in temperature (Parkin et al., 1996). The following equation can be used to standardize (to 25°C) for differences in soil temperatures that are between 15 and 35°C:

$$\text{Standardized soil respiration rate} = \text{soil respiration rate} \times 2^{[(25-T) \div 10]}$$

For soil temperatures between 0 and 15°C, the following equation is used:

$$\text{Standardized soil respiration rate} = \text{soil respiration} \times 4^{[(25-T) \div 10]}$$

For example, if you had a soil respiration rate of 15 CO₂-C lbs/a/d and soil temperature of 22°C, the first equation listed above would be used, and the standardized soil respiration rate would be calculated as follows:

1. $[(25 - 22) \div 10] = 0.3$
2. $2^{0.3} = 1.2$
3. $(15 \text{ CO}_2\text{-C lbs/a/d}) \times 1.2 = 18 \text{ CO}_2\text{-C lb/a/d}$ (standardized respiration rate at 25°C)

Standardization for differences in soil water content must also be taken into account. Maximum

microbial activity generally occurs when 60% of the soil pores are filled with water (Parkin et al., 1996). The amount of water in the pore space is referred to as **water-filled pore space** (WFPS), and gives an indication of how well aerated the soil is at the time of sampling.

$$\text{Water-filled pore space (\%)} = (\text{volumetric water content} \times 100) \div [1 - (\text{soil bulk density} \div 2.65)]$$

Soil respiration can be adjusted to equivalent values at 60% WFPS through the following equation for WFPS values between 30 and 60% (Parkin et al., 1996):

$$\text{Soil respiration}_{60} = \text{soil respiration rate} \times (60 \div \text{measured \% WFPS})$$

For WFPS values between 60 and 80%, the following equation is used:

$$\text{Soil respiration}_{60} = \text{soil respiration rate} \div [(80 - \% \text{WFSP}) \times 0.03] + 0.4$$

When the soil water content or WFPS exceeds 80%, soil respiration may be restricted by the wet conditions and should not be measured. The relationship between WFPS and soil respiration has been evaluated primarily in the laboratory and remains to be tested in the field (Parkin et al., 1996).

Table 1. General soil respiration class ratings and soil condition at optimum soil temperature and moisture conditions, primarily for agricultural land uses (Woods End Research, 1997).

Soil respiration (lbs CO ₂ -C/a/d)	Class	Soil condition
0	No soil activity	Soil has no biological activity and is virtually sterile.
< 9.5	Very low soil activity	Soil is very depleted of available organic matter and has little biological activity.
9.5 - 16	Moderately low soil activity	Soil is somewhat depleted of available organic matter, and biological activity is low.
16 - 32	Medium soil activity	Soil is approaching or declining from an ideal state of biological activity.
32 - 64	Ideal soil activity	Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms.
> 64	Unusually high soil activity	Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure.

Conversion of Woods End Solvita respiration levels: (mg CO₂/kg/wk) x 0.039 x (1.2 g/cm³) x (7.6 cm depth) ÷ 10 x 0.89 = (lbs CO₂-C/acre/day). It was assumed all respiration was coming from a 7.6 cm depth with an average bulk density of 1.2 g/cm³ (Doran et al., 1997).

A high soil respiration rate, indicative of high biological activity, can be a good sign of rapid decomposition of organic residues into nutrients available for plant growth. However, decomposition of the stable organic matter is detrimental to many physical and chemical processes such as aggregation, cation exchange, and water holding capacity. Also, immediately following a tillage operation, CO₂ evolution can rise dramatically due to exposure of organic matter to organisms and oxygen. Also, soil respiration can rise dramatically after rainfall (Rochette et al., 1991). The rise in soil respiration is affected by the length of time the soil is dry before the rainfall event.

Under dry conditions, soil respiration tends to be higher in the crop row than in the interrow (Rochette et al., 1991). The higher respiration rates are attributed to the contribution from plant roots. Under wet conditions, there tends to be no difference in respiration between the row and interrow. When the soil interrow is compacted (wheel track) and the soil is wet, soil respiration tends to be lower than in the row. The lower soil porosity accounts for the lower respiration rate under compacted conditions.

Biological activity is a direct reflection of the degradation of organic matter in the soil. This degradation indicates that two processes are occurring: (1) loss of soil carbon and (2) turnover of nutrients (Parkin et al., 1996). Some optimum soil respiration rate, that balances the long-term detrimental aspects of soil carbon loss and soil nutrient turnover, must be defined .

Conversions

$$\text{kg CO}_2\text{-C/ha/d} = \text{lbs CO}_2\text{-C/a/d} \times 1.12$$

$$\text{g CO}_2\text{-C/m}^2\text{/d} = \text{lbs CO}_2\text{-C/a/d} \div 11.2$$

$$\text{kg CO}_2\text{-C/ha/d} = \text{g CO}_2\text{-C/m}^2\text{/d} \times 10$$

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2. Infiltration

Introduction

Infiltration is the process of water entering the soil. The rate at which water enters the soil is the infiltration rate, which is dependent on the soil type; soil structure, or amount of aggregation; and the soil water content (Lowery et al., 1996). The initial soil water content at time of measurement affects the ability of the soil to pull additional water into the soil. Therefore, the infiltration rate will be higher when the soil is dry than when it is wet. This factor is important when comparing infiltration measurements of different soils. The soils should have similar moisture content when taking the measurements.

Tillage will affect the infiltration rate. Immediately after tillage, improved infiltration may occur due to the loosening of surface crusts or compacted areas. Tillage fluffs up the soil. However, tillage further disrupts aggregates and soil structure, creating the potential for compaction, surface crusting, and loss of continuous surface connected pores. Compacted soils will have less pore space, resulting in lower infiltration rates. Soils that tend to form surface crusts, which seal the soil surface, can have severely reduced infiltration rates.

Interpretations

Since infiltration is affected by the initial water content at the time of measurement, it is important that the soil water content be similar when comparing infiltration rates from different sites. The infiltration test in the soil quality kit requires two 1-inch depths of water to be applied consecutively. Application of the first inch of water is used to wet the soil, and the second inch of water determines the infiltration rate. This procedure is an attempt to standardize the soils for differences in initial water content. Infiltration rates are best determined when the soil is at or near field capacity, usually 12 to 48 hours after the soil has been thoroughly wetted (i.e., soaking rain or irrigation).

The infiltration rate is sensitive to near-surface conditions and is subject to significant change with soil use, management, and time. It is affected by the development of plant roots, earthworm burrows, soil aggregation, and by overall increases in stable organic matter (Sarrantonio et al., 1996). Infiltration is rapid into large continuous pores in the surface. Infiltration is decreased when the size

Table 2. Steady infiltration rates for general soil texture groups in very deeply wetted soil (Hillel, 1982).

Soil type	Steady infiltration rate (inches per hour)
Sands	> 0.8
Sandy and silty soils	0.4 - 0.8
Loams	0.2 - 0.4
Clayey soils	0.04 - 0.2
Sodic clayey soils	< 0.04

or amount of pore space is reduced from conditions such as structure breakdown, pore clogging by lodged particles, or slower movement of deeper water as it reaches denser subsoils (Donahue et al., 1977).

Texture, or the percentage of sand, silt, and clay will affect the infiltration rate. Usually sandy soils will have rapid infiltration rates. Some typical values for steady infiltration rates (After long continuous wetting, the rate of infiltration becomes steady.) for general soil texture groups are shown in Table 2. However, the values in Table 2 can be considerably higher in well aggregated or cracked soils and during initial stages of wetting; these values can be lower if surface crusting occurs (Hillel, 1982). Soil structure greatly influences the movement of water into the soil.

Table 3 shows the infiltration rate in minutes per inch and inches per hour and the associated infiltration class. These classes are the soil permeability classes historically used in Soil Survey. Classes are estimated from soil properties and indicate a steady infiltration rate.

Table 3. Infiltration rates and classes.		
Infiltration rate (minutes per inch)	Infiltration rate (inches per hour)	Infiltration class
< 3	> 20	Very rapid
3 to 10	6 to 20	Rapid
10 to 30	2 to 6	Moderately rapid
30 to 100	0.6 to 2	Moderate
100 to 300	0.2 to 0.6	Moderately slow
300 to 1,000	0.06 to 0.2	Slow
1,000 to 40,000	0.0015 to 0.06	Very slow
> 40,000	< 0.0015	Impermeable

References

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3. Bulk Density

Introduction

Bulk density is defined as the ratio of oven-dried soil (mass) to its bulk volume, which includes the volume of particles and the pore space between the particles. It is dependent on the densities of the soil particles (sand, silt, clay, and organic matter) and their packing arrangement. Mineral particle densities usually range from 2.5 to 2.8 g/cm³, while organic particles are usually less than 1.0 g/cm³. Bulk density is a dynamic property that varies with the structural condition of the soil. This condition can be altered by cultivation; trampling by animals; agricultural machinery; and weather; i.e., raindrop impact (Arshad et al., 1996). Compacted soil layers have high bulk densities, restrict root growth, and inhibit the movement of air and water through the soil.

Interpretations

Soil bulk density can serve as an indicator of compaction and relative restrictions to root growth (See Table 4). Typical soil bulk densities range from 1.0 to 1.7 g/cm³, and generally increase with depth in the soil profile (Arshad et al., 1996). In soils containing high amounts of swelling clays, bulk densities will vary with the water content, which should be measured at the time of sampling.

Table 4. General relationship of soil bulk density to root growth based on soil texture.

Soil texture	Ideal bulk densities (g/cm ³)	Bulk densities that may affect root growth (g/cm ³)	Bulk densities that restrict root growth (g/cm ³)
sands, loamy sands	< 1.60	1.69	> 1.80
sandy loams, loams	< 1.40	1.63	> 1.80
sandy clay loams, loams, clay loams	< 1.40	1.60	> 1.75
silts, silt loams	< 1.30	1.60	> 1.75
silt loams, silty clay loams	< 1.40	1.55	> 1.65
sandy clays, silty clays, some clay loams (35-45% clay)	< 1.10	1.49	> 1.58
clays (> 45% clay)	< 1.10	1.39	> 1.47

Comments

Bulk density values are also required for converting soil water content in percent by weight (gravimetric) to percent by volume (volumetric):

$$\text{Volumetric water content (g/cm}^3\text{)} = \text{soil water content (g/g)} \times \text{bulk density (g/cm}^3\text{)}$$

and to calculate porosity, which is the amount of pore space in the soil:

$$\text{soil porosity (\%)} = 1 - (\text{soil bulk density} \div 2.65).$$

References

Arshad, M.A., B. Lowery, and B. Grossman. 1996. Physical tests for monitoring soil quality. p.123-142. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49. SSSA, Madison, WI.

4. Electrical Conductivity

Introduction

The electrical conductivity (EC) of soil-water mixtures indicates the amount of salts present in the soil. All soils contain some salts, which are essential for plant growth. However, excess salts will hinder plant growth by affecting the soil-water balance. Soils containing excess salts occur both naturally and as a result of soil use and management. Salt-affected soils are largely found in the western arid and semiarid areas of the country, where the annual rainfall is low, allowing salts to accumulate in the soil profile. The electrical conductivity measurement detects the amount of cations or anions (salts) in solution; the greater the amount of anions or cations, the greater the electrical conductivity reading. The ions generally associated with salinity are Ca^{2+} , Mg^{2+} , K^+ , Na^+ , H^+ (cations), or NO_3^- , SO_4^- , Cl^- , HCO_3^- , OH^- (anions).

Interpretations

In general, $\text{EC}_{1:1}$ values between 0 and 0.8 dS/m are acceptable for general crop growth. Site specific interpretations for soil quality will depend on specific land use and crop tolerance. Table 5 shows the soil salinity class and general crop and microbial responses for each class.

Table 5. Electrical conductivity measurement and salinity classes for a 1:1 soil:water suspension.			
Electrical Conductivity (dS m ⁻¹ at 25 C)	Salinity class	Crop response	Microbial response
0 - 0.98	Non saline	Almost negligible effects	Few organisms affected
0.98 - 1.71	Very slightly saline	Yields of very sensitive crops restricted	Selected microbial processes altered (nitrification/denitrification)
1.71 - 3.16	Slightly saline	Yields of most crops restricted	Major microbial processes influenced (respiration/ammonification)
3.16 - 6.07	Moderately saline	Only tolerant crops yield satisfactorily	Salt tolerant microorganisms predominate (fungi, actinomycetes, some bacteria)
> 6.07	Strongly saline	Only very tolerant crops yield satisfactorily	A select few halophilic organisms are active

Adapted from Soil Survey Staff (1993), Janzen (1993), and Smith and Doran (1996). Conversions from the saturation paste extract to the 1:1 soil:water suspensions were performed using the regression equation ($y = 2.75x - 0.69$) developed by Hogg and Henry (1984).

Table 6 provides general salt tolerance ratings for selected crops. These ratings apply to soils in which chloride (Cl⁻) is the predominant anion. The EC of soils containing gypsum will tolerate 1 dS/m higher than those listed in this table (Tanji, 1990). Consult a local Soil Survey to determine if gypsum is present in the soil of interest.

Table 6. Salt tolerance of selected crops (Tanji, 1990).					
Crop	Rating	Crop	Rating	Crop	Rating
Alfalfa	MS	Clover, iadino	MS	Loquat	S
Alkali grass, Nuttall	T	Clover, red	MS	Love grass	MS
Alkali sacaton	T	Clover, strawberry	MS	Mango	S
Almond	S	Clover, sweet	MT	Milkvetch, Cicer	MS
Apple	S	Clover, white Dutch	MS	Millet, foxtail	MS
Apricot	S	Corn	MS	Muskmelon	MS
Artichoke	MT	Corn (forage)	MS	Oat grass, tall	MS
Asparagus	T	Corn, sweet	MS	Oats (forage)	MS
Avocado	S	Cotton	T	Okra	S
Barley	T	Cowpea	MT	Olive	MT
Barley (forage)	MT	Cowpea (forage)	MS	Onion	S
Bean	S	Cucumber	MS	Orange	S
Beet, red	MT	Currant	T	Orchard grass	MS
Bentgrass	MS	Dallis grass	MS	Panic grass, blue	MT
Bermuda grass	T	Date palm	T	Papaya	MT
Blackberry	S	Eggplant	MS	Rape	MT
Bluestem, Angleton	MS	Fescue, tall	MT	Parsnip	S
Boysenberry	S	Fescue, meadow	MT	Passion fruit	S
Broad bean	MS	Fig	MT	Pea	S
Broccoli	MS	Flax	MS	Peach	S
Brome, mountain	MT	Foxtail, meadow	MS	Pear	S
Brome, smooth	MS	Gooseberry	S	Pepper	MS
Brussels sprouts	MS	Gramma, blue	MS	Persimmon	S
Buffelgrass	MS	Grape	MS	Pineapple	MT
Burnet	MS	Grapefruit	S	Plume, prune	S
Cabbage	MS	Guar	T	Pomegranate	MT
Canary grass, reed	MT	Guayule	T	Potato	MS
Carrot	S	Harding grass	MT	Pummelo	S
Castorbean	MS	Jojoba	T	Pumpkin	MS
Cauliflower	MS	Jujube	MT	Radish	MS
Celery	MS	Kale	MS	Rescue grass	MT
Cherimoya	S	Kaller grass	T	Raspberry	S
Cherry, sweet	S	Kenaf	MT	Rhodes grass	MT
Cherry, sand	S	Kohlrabi	MS	Rice, paddy	S
Clover, alsike	MS	Lemon	S	Rose apple	S
Clover, berseem	MS	Lettuce	MS	Rye	T
Clover, hubam	MT	Lime	S	Rye (forage)	MS

When distilled water is not available, tap or rain water can be used. Measure the conductivity of the water source, and subtract the water source EC value from the sample EC value.

The relationship between electrical conductivity and salt concentration is only approximate. General relationships that have been established are (Rhoades, 1996):

- 1) Total cation (or anion) concentration: $\text{meq/L} \approx 10 \times \text{EC (dS/m)}$.
- 2) Total dissolved solids: $\text{mg/L} \approx 640 \times \text{EC (dS/m)}$.
- 3) Osmotic pressure: $\text{kPa (at } 25^\circ\text{C)} \approx 0.36 \times \text{EC (dS/m)}$.

Where NO_3^- is the predominant ion in the soil solution, a very useful relationship has been established between the EC (in 1:1 soil to water mixture) readings and soil nitrate (NO_3^-) concentrations (Smith and Doran, 1996).

$$\text{EC (dS/m)} \times 140 \approx \text{mg NO}_3^- \text{-N/kg of soil}$$

This relationship assumes the complete extractability of NO_3^- in water and that NO_3^- is the major anion in the soil solution.

Conversions

- 1 dS/m (decisiemens per meter) = 1 mmhos/cm (millimhos per centimeter)
- 1 dS/m (decisiemens per meter) = 1000 $\mu\text{S/cm}$ (microsiemens per centimeter)
- 1000 $\mu\text{S/cm}$ (microsiemens per centimeter) = mS/cm (millisiemens per centimeter)

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5. Soil pH

Introduction

Soil pH is a measure of the acidity or alkalinity of a soil, which affects the availability of plant nutrients, activity of microorganisms, and the solubility of soil minerals. Major factors affecting soil pH are temperature and rainfall, which control the intensity of leaching and soil mineral weathering. Acidity is generally associated with leached soils; alkalinity generally occurs in drier regions. However, agricultural practices, such as liming or addition of ammonium fertilizers, can alter soil pH. The pH measurement is actually measuring the hydrogen ion activity [H⁺] in the soil solution.

Interpretations

In general, pH values between 6 and 7.5 are optimum for general crop growth. Site specific interpretations for soil quality will depend on specific land use and crop tolerance.

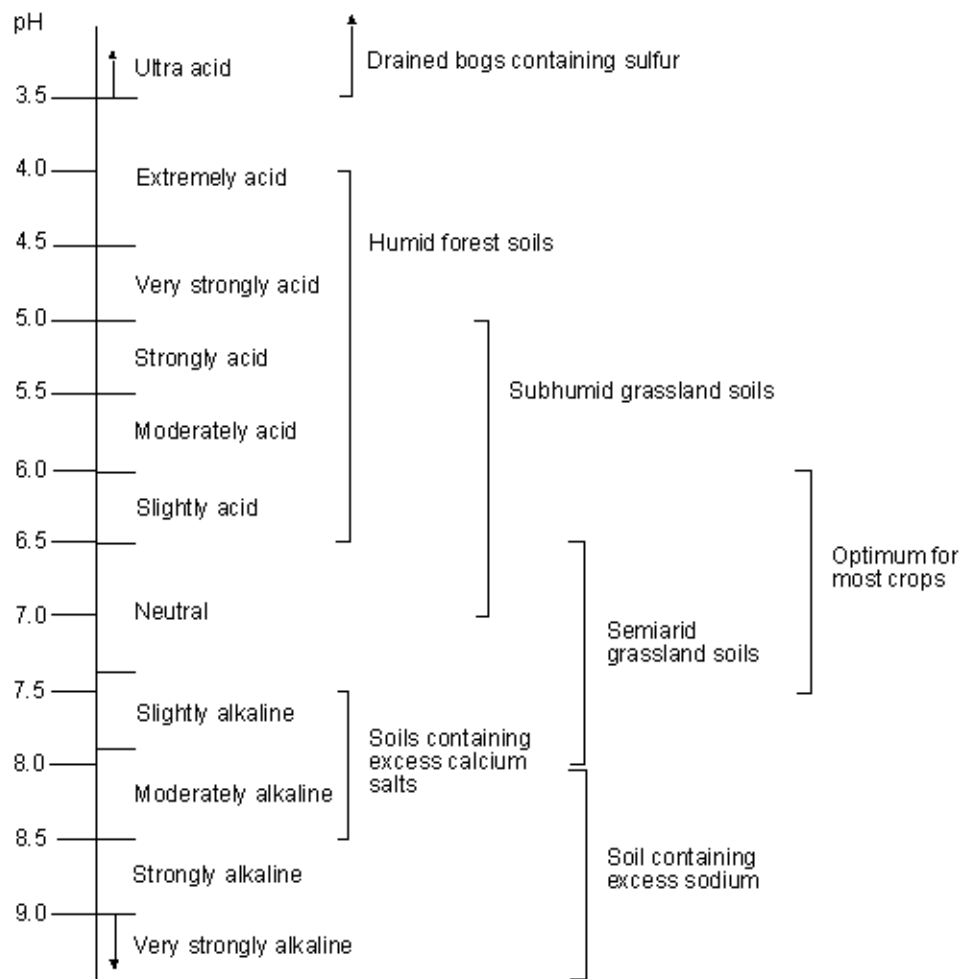


Figure 1. Soil pH, ranges for pH classes, and associated soil conditions. Adapted from the National Soil Survey Manual (1993) and Troeh and Thompson (1993).

Table 7. Suitable soil pH ranges for selected crops (Whittaker et al., 1959).

Crops	Soil pH ranges						
	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Alfalfa					■	■	■
Alsike clover		■	■	■	■	■	
Apples			■	■	■	■	
Asparagus				■	■	■	
Azalea	■	■	■				
Barley			■	■	■	■	
Beans, lima			■	■	■	■	
Beans, snap			■	■	■		
Beans, velvet			■	■	■		
Blueberries		■	■				
Buckwheat		■	■	■	■		
Cabbage			■	■	■	■	
Carrots			■	■	■	■	
Clover, crimson			■	■	■	■	
Clover, red				■	■	■	
Clover, sweet						■	■
Clover, white				■	■	■	
Corn			■	■	■	■	
Cotton			■	■	■		
Cowpeas			■	■	■	■	
Cucumber			■	■	■	■	
Grasses			■	■	■	■	
Hydrangea, blue flowered	■	■					
Iris, blueflag		■	■	■	■	■	■
Juniper, Irish		■	■	■	■		

Table 7. Continued.

Crops	Soil pH ranges						
	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Kale			■	■	■	■	
Lettuce					■	■	
Mustard			■	■	■		
Oats			■	■	■	■	
Onions					■	■	
Parsnips			■	■	■		
Peas					■	■	
Peppers			■	■	■		
Pine, longleaf	■	■					
Pine, yellow		■	■	■			
Potatoes, sweet		■	■	■			
Potatoes, white		■	■				
Radishes			■	■	■		
Rye			■	■	■	■	
Sorghum			■	■	■	■	
Soybeans			■	■	■	■	
Spinach					■	■	
Squash			■	■	■		
Strawberries		■	■	■	■		
Sudan grass			■	■	■	■	
Timothy				■	■	■	■
Tobacco		■	■	■			
Tomatoes			■	■	■	■	
Trefoil, birdsfoot		■	■	■	■	■	
Vetch			■	■	■	■	
Wheat			■	■	■	■	

Nutrient Availability

Soil pH affects the availability of nutrients to plants or crops (Figure 2). Nutrient availability is affected by changes in the solubility of soil minerals. Most minerals are more soluble in acid soils than in neutral or slightly basic soils. The greatest availability for most nutrients is between pH 6 and 7 (Figure 2). Where nutrients are shown interlocking in Figure 2, those nutrients at that pH combine to form insoluble compounds, reducing their availability. Soil pH also affects the activity of beneficial microorganisms, which affects nutrient availability. In general, fungi function at a wide pH range, but bacteria and actinomycetes function better at intermediate and higher pH.

Comments

The presence of salts affects soil pH by decreasing the reading by 0.2 to 0.3 pH units (Thomas, 1996). To mask the effects of salts, a 0.01 M CaCl_2 solution has been commonly used instead of distilled water.

Declining pH is a sign of inefficient N use where ammonia based fertilizers are used (see Smith and Doran, 1996).

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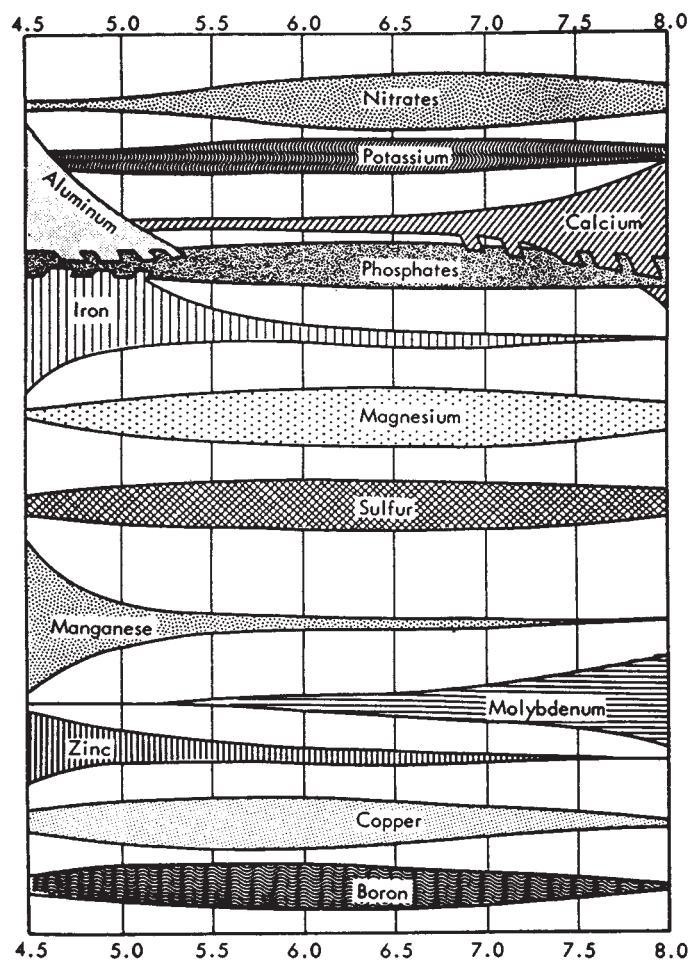


Figure 2. Nutrient availability based on pH of mineral soils (Soils Handbook, Kentucky Agr. Exp. Stn. Misc. 383, 1970, p.28).

6. Soil Nitrate

Introduction

Soil nitrate (NO_3^-) is a form of inorganic nitrogen (N) that is available for use by plants. It forms from the mineralization (by microorganisms) of organic forms of N (i.e., soil organic matter, crop residue, and manure) in the soil. The rate of N mineralization is dependent on the amount of soil organic N, water content, temperature, pH, and aeration. Crop needs are met by soil-derived mineral-N and by fertilizer-N. Efficient management of soil N requires knowledge of crop needs for N and the amount of soil-derived N. Nitrate is mobile in soil, so it can be leached with percolating water below the root zone. All soils lose a small amount of nitrate to groundwater, including soils under natural vegetation. When amounts leach that are greater than what occurs naturally, we need to be concerned. Nitrate is not a contaminant until it leaches below the root zone or is transported off-site in surface runoff. When leached to groundwater, there is a human and animal health risk. In surface water systems, nitrate can contribute to eutrophication.

Interpretations

The amount of residual nitrate-N in the soil at any one time is a function of the rate at which microorganisms decompose soil organic matter (Figure 3). This rate is dependent on temperature, moisture, aeration, type of organic residues, pH, and other factors (Dahnke and Johnson, 1990). Also, once soil nitrate has formed, it is subject to leaching, fixation, denitrification, and plant uptake (Figure 3). Therefore, it is difficult to interpret the nitrate-N content in terms of how much and when N will be available to meet crop needs. However, residual nitrate-N tests can be useful in determining fertilizer-N needs of crops in certain regions during specific times of the year and at specific crop growth stages (Dahnke and Johnson, 1996). **For interpretations of residual nitrate-N tests for crop needs, consult local or regional calibrations.**

Any amount of nitrate in the soil that is not used by the crop may potentially be leached from the root zone and become an environmental liability. Nitrate is not adsorbed on to soil particles unless they have a positive charge. Therefore, nitrate can readily move with percolating water out of the root zone and into groundwater or into surface waters through subsurface flow (Figure 3). Acidic soils of the humid tropics contain a significant amount of positively charged soil particles which can hold nitrate and keep it from leaching.

Nitrogen Cycling

In general, soil nitrate levels will change significantly during the course of the year and from week to week. Soil nitrogen is continuously cycling, moving from one form to another (Figure 3). It is derived primarily from atmospheric nitrogen gas (N_2). Soil microorganisms fix N_2 to produce organic nitrogen, which becomes part of the soil organic matter. The decomposition of organic matter converts some organic nitrogen into mineral nitrogen (mineralization). Ammonium (NH_4^+) produced by mineralization (an intermediate step) can be converted to nitrate by specific microorganisms (nitrification). The nitrate formed is then available for uptake by plants or microorganisms and is converted to organic forms of nitrogen (immobilization). Under water logged or anaerobic conditions, nitrate may be substituted for oxygen and ultimately released to the atmo

sphere as elemental nitrogen or nitrous oxide gas (N_2 or N_2O) [denitrification]. Each N transformation depends on the activity and abundance of a specific population of microorganisms that require different sets of optimal environmental conditions.

Primary *sources* of nitrates:

- addition of fertilizers containing nitrate,
- microbial conversion of ammonium fertilizers to nitrate-N,
- microbial conversion of organic N (i.e., soil organic matter and manures) to nitrate-N.

Primary *fates* of nitrates:

- utilization by microorganisms or plant roots (immobilization)
- leached below the root zone
- moved off-site in surface runoff
- microbial conversion of nitrate-N to nitrogen gas

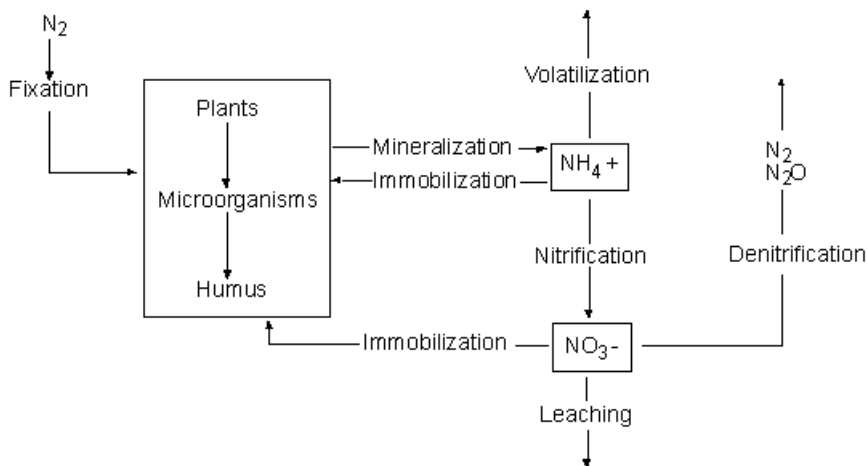


Figure 3. Generalized soil nitrogen cycle.

Comments

The nitrate/nitrite test strips can determine both nitrate and nitrite concentrations (two test pads on each test strip). Nitrite levels in soils are usually not detectable (in a transition state); therefore, its measurement is not warranted. The nitrate test pad on the test strip measures the sum of both nitrate-N and nitrite-N present in the sample. If nitrite is detected in the sample, the amount can be subtracted from the nitrate reading to get the actual amount of nitrate-N in the sample.

Spring soil nitrate-N tests can be used to assess the effectiveness of soil and cropping management practices in providing sufficient N for optimal crop yields. For example, for corn in the Midwest, values of 20-25 ppm nitrate-N in top foot (30 cm) of soil are needed (14-16 ppm is the threshold for soils receiving manure or having alfalfa or soybeans as the previous crop) [Allan et al., 1996; page 196].

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7. Aggregate Stability

Introduction

Aggregate stability is a measure of the vulnerability of soil aggregates to external destructive forces (Hillel, 1982). An aggregate consists of several soil particles bound together. The destructive force in this test is flowing water. Aggregates that stand up to the forces of water are called water stable aggregates (WSA). In general, the greater the percentage of stable aggregates, the less erodible the soil will be. Soil aggregates are a product of the soil microbial community, the soil organic and mineral components, the nature of the above-ground plant community, and ecosystem history. They are important in the movement and storage of soil water and in soil aeration, erosion, root development, and microbial community activity (Tate, 1995). Breakdown of aggregates is the first step to crust development and surface sealing, which impedes water infiltration and increases erosion. Soil aggregation can change over a period of time, such as in a season or year. Aggregates can form, disintegrate, and reform periodically (Hillel, 1982).

Interpretations

The percentage of water stable aggregates indicates the amount resistant to disturbance by flowing water. **In general, greater amounts of stable aggregates are better for soil quality.**

Aggregates improve soil quality by:

- protecting soil organic matter entrapped in the aggregates from exposure to air and microbial decomposition,
- decreasing soil erodibility,
- improving water and air movement (Aggregates increase the amount of large pore spaces.),
- improving the physical environment for root growth,
- improving soil organism habitat.

Aggregate stability is affected by the amount and type of the following soil constituents (Kemper, 1966):

Soil Organic Matter content:

Aggregate stability generally increases with organic matter content (Table 1). The effect is more pronounced in soils containing small amounts of clay. Generally, increases in organic matter above 2% do not increase aggregate stability appreciably.

Soil Clay content:

Aggregate stability is affected by the amount and type of clay in the soil and generally increases with clay content (Table 1). This effect decreases at higher clay contents (Table 1). In general, high surface-area clays (i.e., montmorillonite) tend to cause greater aggregation than low surface-area clays (i.e., kaolinite).

Aluminum and Iron Oxide content:

Aggregate stability generally increases with free iron oxide content. In general, free aluminum oxides do not appreciably increase aggregate stability.

Calcium Carbonate content:

The calcium carbonate content generally does not appreciably affect aggregate stability.

Exchangeable Sodium content:

Aggregate stability decreases with increasing amounts of exchangeable sodium. In general, water stable aggregates are nonexistent in soils with greater than 20% exchangeable Na⁺.

Table 8 contains suitable values for aggregate stability based on soil organic matter and clay content. A suitable range of values could be developed for a soil using the aggregate stability values for the organic matter content and clay content as end members to the range. For example, for a soil with 2% organic matter and 10% clay, the suitable aggregate stability range (taken from Table 8) would be 65 to 75% water stable aggregates.

Table 8. Suitable values for % water stable aggregates based on clay and organic matter content (Kemper, 1966). Water stable aggregates for % clay should be read independently of % organic matter in this table.

Organic Matter (%)	Water Stable Aggregates (%)		Clay (%)	Water Stable Aggregates (%)
0.4	53		5	60
0.8	66		10	65
1.2	70		20	70
2	75		30	74
4	77		40	78
8	81		60	82
12	85		80	86

Aggregate stability values are based on 519 soil samples from the arid, semiarid, and subhumid regions of the United States and Canada. The majority of the samples were from cultivated areas, but a large number were taken from virgin or replanted grasslands (Kemper, 1966).

Soil aggregates are divided into two general groups based on aggregate size (diameter):

- **Microaggregates** (less than 250 μm) consist of primary soil particles and smaller microaggregates bound together. Binding agents include:
 - humified organic matter (organic polymers)
 - polyvalent metals or cations
 - roots and fungal hyphae
 - polysaccharides
 - plant and microbial debris (encrusted)
 - iron and aluminum amorphous oxides
- **Macroaggregates** (> 250 μm) consist of microaggregates bound together. Major binding agents are:
 - fungal hyphae
 - fibrous roots
 - polysaccharides

iron and aluminum oxides (soils that contain more than 10% iron and aluminum oxides)
The size of the water stable aggregates measured in the soil quality kit are macroaggregates.

Macroaggregates form readily under the following conditions:

- under pasture or forage grasses (dense, fibrous root mass),
- where organic residues have been added,
- where large amounts of microaggregates ($< 250 \mu\text{m}$ diameter) are present.

Differences between micro- and macroaggregates include the following:

- Macroaggregates are more sensitive to changes in management than microaggregates and thus, are considered a better indicator of changes in soil quality. Macroaggregate stability depends on management because of the transient nature of the binding agents.
- Macroaggregates form more rapidly than microaggregates.
- Carbon is more stable in microaggregates than in macroaggregates.
- Microaggregates are more water stable than macroaggregates.
- When the proportion of macro- to microaggregates increases, soil quality increases.

Considerations and Comments

The temperature of the water used to sieve the soils should be maintained within the range of 22 to 25°C (71.5 to 77°F). At higher water temperatures, aggregate stability tends to decrease.

To make observational estimations of aggregate stability or relative comparisons, weighing and drying of the aggregates are not necessary.

When dry aggregates are wetted up too quickly at atmospheric pressure, disintegration and slaking can result. Upon rapid wetting, capillary water entering the pores causes air entrapped inside the aggregate pores to increase in pressure causing them to rupture (Kemper and Rosenau, 1986).

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8. Soil Slaking

Introduction

Slaking is the process of fragmentation that occurs when aggregates are suddenly immersed in water (Chan and Mullins, 1994). Slaking occurs because the aggregates are not strong enough to withstand the stresses of rapid water uptake. At fast rates of wetting, internal stresses arise from differential swelling and air entrapment in the soil aggregate (Kay, 1998). These stresses may be released through the creation of an increasingly extensive network of failure zones in the soil fragments or aggregates. The differences between tests of aggregate stability and slaking are the type of stress applied and the size of aggregates or soil fragments used. The slake test is a qualitative and simpler test to perform. The two tests may not necessarily yield the same results.

Interpretations

The slake test in the kit yields a stability rating of 0 to 6 (Herrick, 1998). Soil fragments or aggregates which fall into classes 0 to 3 are relatively unstable. Class 4 indicates some stability, but very little strength. Classes 5 and 6 represent relatively stable soil fragments or aggregates. Soil strength relates to the ability of the soil to resist loss of its structure.

Stability ratings of soil surface crust fragments are interpreted differently. Soil crust formation in agricultural systems reduces the capacity of the soil to function (i.e., soil crusts can reduce air and water movement into the soil and can inhibit seedling germination). In general, weakly formed or unstable crusts are better than very strong or stable crusts, which have a greater potential to lower soil quality. The subsurface fragments or aggregates directly beneath the crust are tested to provide an indication of the potential for future slaking and crusting of the soil (potential of crust formation).

Slaking is affected by:

- the soil water content,
- rate of wetting,
- texture,
- clay mineralogy, and
- organic matter content.

Slaking is more severe when the soil is initially dry than when it is moist. For loamy soils, the pressure of entrapped air has been shown to be more important. For clayey soils, differential swelling was shown as the more important process (Chan and Mullins, 1994). In general, organic matter can influence both the rate of wetting and the resistance to stress generated during wetting (Kay, 1998). The stability of aggregates is strongly dependant on the rate of wetting; therefore, aggregate stability declines as the rate of wetting increases.

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9. Earthworms

Introduction

Earthworm populations may vary with site characteristics (food availability and soil conditions), season, and species. Populations are highly variable in space and time, which can range from less than 10 to greater than 10,000 individuals per square meter (Curry, 1998). However, not all areas or soils support earthworms. Either they were not introduced, or environmental conditions are not favorable. Earthworms generally increase soil microbial activity and soil chemical fertility and enhance soil physical properties.

Interpretations

About 10 earthworms per square foot of soil (100 worms/m^2) is generally considered a good population in agricultural systems. Populations generally do not exceed 20 per square foot of soil (200 worms/m^2) in cultivated systems (Edwards, 1983). In grassland systems, populations can generally range up to about 50 per square foot of soil (500 worms/m^2) [Edwards, 1983]. The hand digging method does not capture certain deep-burrowing or fast moving earthworm species. However, hand digging is one of the best methods available.

Earthworms improve soil quality by:

- increasing the availability of nutrients. (Available plant nutrients (N, P, & K) tend to be higher in fresh earthworm casts than in the bulk soil.) [Edwards et al., 1995];
- accelerating the decomposition of organic matter by incorporating litter into the soil and activating both mineralization and humification processes;
- improving soil physical properties, such as aggregation and soil porosity;
- suppressing certain pests or disease organisms; and
- enhancing beneficial microorganisms.

Earthworms and soil aggregation processes:

- Fresh earthworm casts are often highly dispersed, nearly saturated masses of soil, which are unstable and susceptible to erosion (Edwards et al., 1995). As earthworm casts age, they can become more stable. The organic matter content, wet-dry cycles, and fungal hyphae and other microbial products help to stabilize casts over time and improve the aggregation of soil.
- In general, the more sensitive the soil is to physical disturbance, the more effective casting is for stable aggregation but less effective for tensile strength (Schrader and Zhang, 1997).

Factors affecting earthworm populations include the following (Curry, 1998):

Tillage

- Tillage generally kills about 25% of the earthworm population. The indirect effects of tillage affects the remaining population. These indirect effects include increases in surface temperature, decreased soil moisture regimes, reduced litter input, and more rapid oxidation (decomposition) of crop residues.
- Earthworm populations are often greater under no-till than under conventional tillage. Large populations of both surface-dwelling and deep-burrowing earthworms are often

associated with improved soil physical conditions. Higher infiltration rates often occur in no-till than in conventional tillage systems due to (in part) the large number of macropores from earthworm activity.

Temperature

The optimum temperature range for earthworms is between 10 and 20°C. The upper lethal range is 25 to 35°C. Few species can tolerate temperatures below 0°C. Many species have behavioral and/or physiological adaptations that enable them to survive unfavorable conditions.

Soil Properties

- Medium textured soils are more favorable for earthworms than sandy or clayey soils.
- Depth of aeration in soils affects the deep-burrowing species.
- Soil pH affects earthworm populations. Earthworms are usually absent in soils with pH less than 3.5 and are scarce in soils with pH between 3.5 and 4.5. The majority of the earthworms live in soils with pH between 5.0 and 7.4.
- Quality and amount of food (organic matter) affect earthworm distribution and abundance.

Food Source

Litter, or organic, residue on the soil surface is the primary food source for earthworms in most ecosystems. However, dead roots and root exudates can also be important food sources. If the physical and chemical environments are not limiting, the quality and quantity of litter input frequently determines earthworm abundance.

Soil Disturbance

- Earthworm populations are generally higher in undisturbed soil systems.
- Population size depends on the severity and frequency of soil disturbance.
- If the soil disturbance is not repeated, earthworm populations can recover fairly rapidly (within a few years).

Soil Moisture

Soil moisture restrictions generally determine earthworm distributions and their activity.

Agrochemicals

- Pesticides, especially insecticides, can affect earthworm populations. The majority of triazine herbicides (i.e., atrazine, simazine, and cyanazine) are slightly toxic. Carbamate-based fungicides (i.e., carbendazim, benomyl, and thiophanate-methyl) are very toxic. Organophosphates (i.e., phorate, isozophos, chlorpyrifos, and ethoprophos) and most of the carbamate-based insecticides (i.e., carbaryl, carbofuran, methomy, and methiocarb) are toxic. Most of the nematicides (i.e., D-D, metham-sodium, and methyl bromide) have been reported to be toxic to earthworms (Edwards et al., 1995).
- Regular use of ammonium sulfate and anhydrous ammonia and sulfate coated urea has been shown to decrease earthworm populations (Edwards et al., 1995).

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10. Soil Physical Observations and Estimations

Topsoil Depth

Topsoil depth is important for water storage and nutrient supply for plant growth. Generally, removal of the topsoil will result in loss of soil fertility, water-holding capacity, soil organic carbon content, and productivity. Measurements of topsoil depth over time provide a good estimate of soil loss (erosion).

Interpretations

Change in topsoil thickness is usually a result of wind erosion, water erosion, deposition of material, or land leveling. Eroded soils will commonly have a reduced Ap horizon (plow layer) or topsoil thickness. Natural erosion occurs in the absence of human disturbances. However, it is the accelerated erosion caused by plowing, burning, overgrazing, and other management practices that remove the protective vegetative cover and results in loss of soil quality.

Root Growth

Depth of soil to a layer that would restrict root growth strongly affects crop production. Factors that influence rooting depth include high salt content and depth to bedrock, stone layer, hard pan, frozen layer, and water table (Arshad et al., 1996).

When continuous pores are present in the soil, roots will grow through these pores as a result of the low mechanical impedance. The distribution of roots in the soil profile is a function of soil depth, thickness, and mechanical resistance of the root-impeding soil layers (Bennie, 1996).

Interpretations

Roots growing through restrictive soil layers undergo morphological changes, particularly root stunting and thickening (Bennie, 1996). Impeded roots are generally shorter, thicker, and more irregularly shaped. The shorter root system will exploit a smaller soil volume for plant nutrients and water, causing the plant to maintain a higher than normal uptake rate of nutrients and water per unit of root length. Also, more photosynthetic energy is needed to sustain root length increases that do occur. All of these factors can result in plant stress, which may eventually result in reduced crop growth and productivity.

Penetration Resistance

Penetration resistance is a measure of the ease with which an object can be pushed into the soil (Bradford, 1986). It gives an indication of root-impeding layers in the soil and can be used in comparing relative strengths among similar soil types. It can also be used for determining hard-pans, zones of compaction, or dense soil layers.

Interpretations

Soil compaction that results in severely restricted root growth is caused mainly by trampling of animals, use of farm and tillage equipment, and vehicular traffic. The type of root system will

determine the ability of a root to penetrate the soil. Figure 4 shows typical locations of compaction zones in cultivated soils.

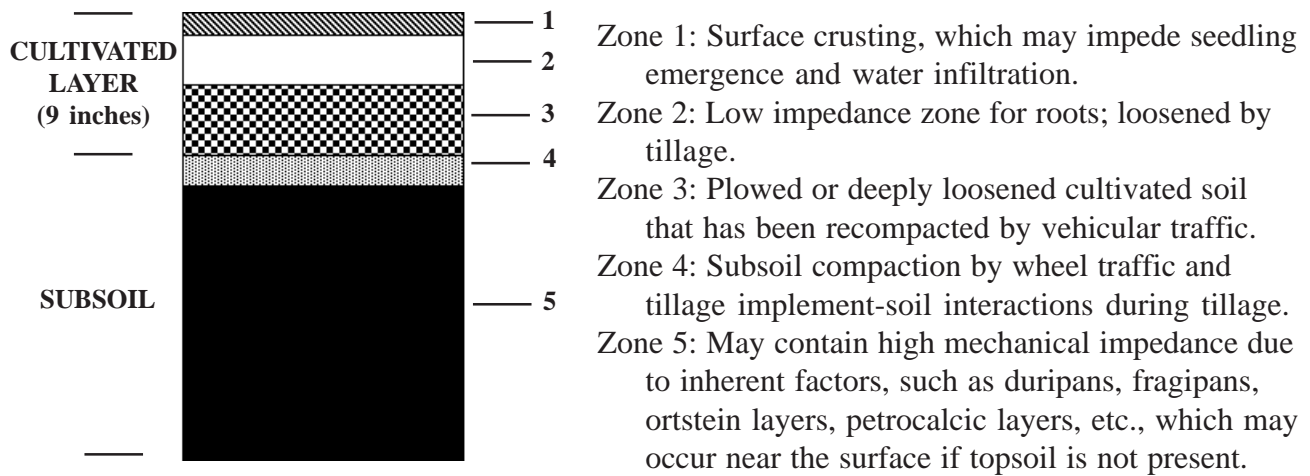


Figure 4. General position of soil compaction zones in cultivated systems (Bennie, 1996)

Penetration resistance depends strongly on the soil water content: the dryer the soil, the greater the resistance to penetration. Therefore, the water content of the soil should be noted when taking a measurement. Penetration resistance is best determined when the soil is at field capacity, which is a uniform condition that can be reproduced from season to season.

Soil Structure

Soil structure is the arrangement and organization of particles in the soil. It is strongly affected by changes in climate, biological activity, and soil management practices. Soil structure affects the retention and transmission of water and air in the soil as well as the mechanical properties of the soil. Observing and describing soil structure in the field is subjective and qualitative.

Interpretations

For plant growth it is desirable to have a physical condition in which the soil is an optimally loose, friable, and porous assemblage of aggregates permitting free movement of water and air, easy cultivation and planting, and unobstructed germination and root growth (Hillel, 1982). The soil structure index is a general quality placement that indicates the closeness to the condition described above. In general, the higher the index value the better the soil's capacity to transmit water and air and to promote root growth and development.

Soil processes involved in the development of soil structure are as follows (Rowell, 1994):

- drying and wetting, which cause shrinking and swelling, creating cracks and channels;
- freezing and thawing, which creates spaces as ice is formed;
- the action of roots (removal of water, release of exudates (organic materials), and formation of root channels);
- the action of soil animals (moving soil material around, creating burrows, and bringing soil

mineral and organic materials into close association); and

- the action of microorganisms (breaking down plant and animal residues and creating soil organic matter and humus as a binding material).

Soil Texture

Soil texture refers to the distribution of sand, silt, and clay sized mineral particles in the soil. Texture is one of the most stable attributes of the soil, being modified only slightly by cultivation and other practices that cause mixing of the different soil layers.

Interpretations

This test is routinely used by soil scientists and provides reliable estimates of soil texture. The textural class places the soil in one area of the triangular diagram based on the distribution of sand, silt and clay in the soil (Figure 5). Texture is an important characteristic, because it influences fertility and helps determine water intake rates, water storage in the soil, ease of tillage, and amounts of aeration. For example, clay soils will retain more water and nutrients than a sandy soil.

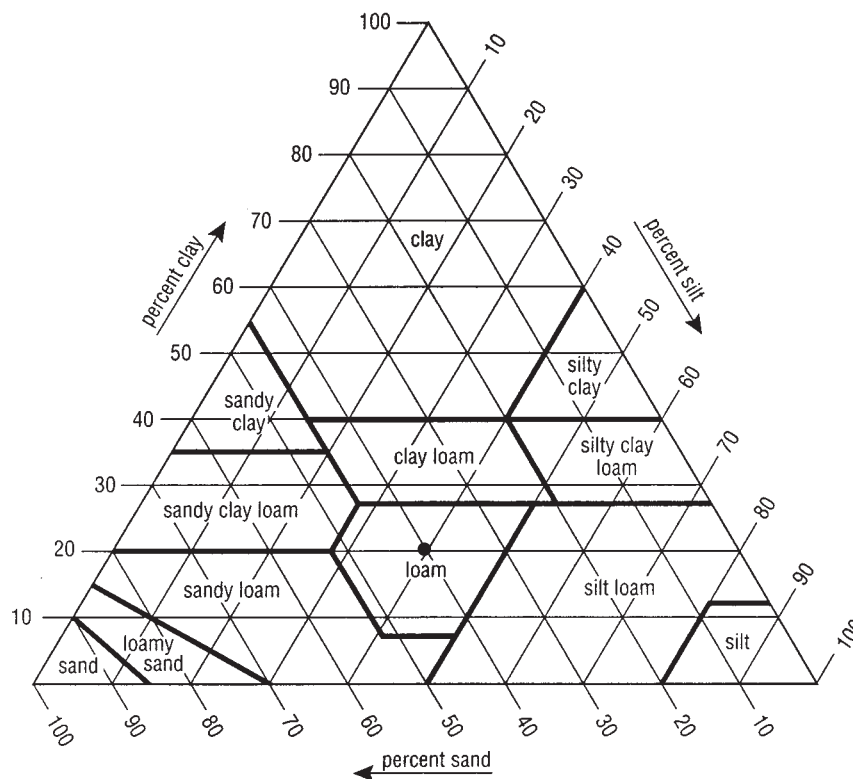


Figure 5. Soil textural triangle showing the percentages of clay, silt, and sand in the textural classes.

Mineral Particles Soil is composed of mineral particles that vary in size. There are three general classifications (or soil separates) of mineral particles:

- *sand* particles - 2.0 mm (very coarse) to .05 mm (very fine);
- *silt* particles - .05 mm to .002 mm;
- *clay* particles - smaller than .002 mm.

Twelve Soil Textural Classes. Definitions of the 12 textural classes are based on the relative proportion, or weight, of these three particle classifications. Sandy soil, for example, has a greater proportion of sand particles than silt or clay. In reading the textural triangle (Figure 5), any two particle size percentages will locate the textural class. For example, a soil containing 20% clay and 40% sand is located in the *loam* textural class (Figure 5).

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11. Water Quality

The quality of water is relative to the purpose for which the water is used; therefore, specific use conditions will determine the suitability of a water body (James et al., 1982).

Water Electrical Conductivity

Introduction

Water salinity levels, as measured by electrical conductivity, can be used to assess irrigation water quality. Other water quality concerns about saline waters include possible physiological effects on humans and animals and mineral taste. Also, high concentrations of certain mineral salts can cause corrosion damage in water systems. The measurement of electrical conductivity is an indicator of the total dissolved solids (TDS) in water. The relationship of EC to TDS will vary depending upon the distribution of major constituent elements present in the water.

Interpretations

Tables 9 and 10 contain safe salinity limits for human and livestock drinking water. Table 11 contains general guidelines for salinity in irrigation waters. For aquatic plant growth, salinity levels should be kept as close to natural conditions as possible (US EPA, 1973).

Table 9. Safe limits for drinking water (US EPA) and average salinity levels for river waters of the world (James et al., 1982)		
Water	EC ² (dS/m 25°C)	Total Dissolved Solids (mg/L)
Drinking water		
SMCL ¹	0.78	500
Livestock and poultry		
US EPA recommendation	4.7	3000
Average salinity levels in river waters		
North America	0.23	146
Europe	0.28	182
Australia	0.09	59
World	0.19	120

¹ SMCL = secondary maximum contaminant levels are unenforceable Federal guidelines regarding taste, odor, color, and other non-aesthetic effects in drinking water.

² EC estimated from total dissolved solids (TDS); EC = TDS/640

Table 10. Use of saline waters for livestock and poultry (US EPA, 1973)

Comment	EC ¹ (dS/m 25°C)	Total Dissolved Solids (mg/L)
Relatively low level of salinity. Excellent for all classes of livestock and poultry.	< 1.6	< 1,000
Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.	1.6 - 4.7	1,000 - 3,000
Satisfactory for livestock, but may cause temporary diarrhea or be refused first by animals not accustomed to them. Poor waters for poultry, often causing watery feces, increased mortality, and decreased growth, especially in turkeys.	4.7 - 7.8	3,000 - 5,000
Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Unfit for poultry and probably for swine.	7.8 - 10.9	5,000 - 7,000
Considerable risk in using for pregnant or lactating cows, horses, or sheep, or the young of these animals. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.	10.9 - 15.6	7,000 - 10,000
Risks are too great and are not recommended for use under any conditions.	>15.6	> 10,000

¹ EC estimated from total dissolved solids (TDS); EC = TDS/640

Table 11. General purpose guidelines for salinity in irrigation water for arid and semi-arid regions (US EPA, 1973).

Classification	EC dS/m	TDS mg/L
Water for which no effects are usually noticed	0.75	500
Water that can have detrimental effects on sensitive crops	0.75-1.50	500-1,000
Water that can have adverse effects on many crops: requires careful management	1.50-3.00	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management	3.0-7.50	2,000-5,000

Water Nitrate and Nitrite Levels

Introduction

Nitrate in water is of concern in regards to human and animal health and to environmental quality of ground and surface waters. Nitrate in drinking water can cause methemoglobinemia (“blue baby syndrome”) in infants under six months of age and can have toxic effects in livestock and poultry. The toxicity occurs with the conversion of nitrate to nitrite after it has been consumed. Nitrite has a more rapid and pronounced toxicity effect than nitrate in drinking water. Fortunately, nitrite concentrations in water sources are usually very low. Nitrate in surface waters can cause accelerated growth of algae and aquatic plants, causing depletion of dissolved oxygen and general degradation of the water body (eutrophication). Eutrophication jeopardizes the use of water for recreation, sport and commercial fishing, agriculture, industry, and municipal supply. Also, nitrates can adversely impact aquatic ecosystems. Nitrate entering surface and groundwater is from non-point sources; both urban and agricultural runoff and leachate are recognized as contributors.

Interpretations

The levels of N required to induce eutrophication will vary depending on the nitrogen to phosphorous ratio. Excesses of either or both N and P can lead to eutrophication. Excessive growth of algae has been shown to occur when total phosphorus (mostly phosphate) levels exceed 0.10 ppm. Table 12 shows commonly used values for total nitrogen (mostly nitrate or ammonia). Eutrophication is defined as an increase in the nutrient status of natural waters that causes accelerated growth of algae or water plants, depletion of dissolved oxygen, increased turbidity, and general degradation of water quality (Pierzynski et al., 1994).

Table 12. Human, animal, and environmental limits of nitrate and nitrite in water (Pierzynski et al., 1994; US EPA, 1973).	
Description	Limit or threshold
US EPA maximum contaminant level for nitrate-N in public drinking water	10 mg NO ₃ -N L ⁻¹
US EPA maximum contaminant level for nitrite-N in public drinking water	1 mg NO ₂ -N L ⁻¹
Recommended safe level for livestock and poultry drinking water	40 mg NO ₃ -N + NO ₂ -N L ⁻¹
Recommended safe level for Nitrite-N alone in livestock and poultry drinking water	10 mg NO ₂ -N L ⁻¹
Threshold for eutrophication in fresh water environments	0.5-1.0 mg N L ⁻¹
Threshold for eutrophication in marine environments	> 0.6 mg N L ⁻¹

Comments

The nitrate/nitrite test strips can determine both nitrate and nitrite concentrations (two test pads on each test strip). The nitrate test pad on the test strip measures the sum of both nitrate-N and nitrite-N present in the sample. If nitrite is detected in the sample, the amount can be subtracted from the nitrate reading to get the actual amount of nitrate-N in the sample. However, nitrite is rarely found in drinking waters at levels above 0.1 mg L⁻¹ (Manahan, 1993).

1 ppm (parts per million) = 1 mg L⁻¹ (milligram per liter)

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