Successful Landscape Planting Techniques in Difficult Clayey Soils: Soil Amendments & Fertility

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You have probably had at least one of those sites from hell. In fact you may frequently get jobs on these kinds of sites in your local area. Some of the most difficult soil problems involve dealing with heavy clay soils. After construction the clayey subsoils are on top of the ground. You have clayey subsoils that had never before seen the light of day. So what do you do now?

This workshop will explain some new alternative fertility techniques found to be successful in amending the clayey subsoils and significantly improving the ability of the plants to grow in these soil materials. The alternative techniques are normally not very expensive, and are frequently less expensive than hauling in topsoil to hide the underlying problems.

Do you know how to determine the fertility value of organic matter amendments? Do you know when you can use organic matter to change the pH of clayey soils? We will present alternative testing procedures for use of organic matter.

Did you know that fertilizer recommendations made by soil testing laboratories often do not work for clayey subsoils? They can accurately determine the available nutrients in the soil sample, but the calculation to determine the fertilization rates are based upon topsoil and therefore do not apply to clayey soils. Therefore, some recommended fertilizer rates are frequently grossly inadequate for clayey soils.

We will examine five soil based strategies that work on clayey soils; these are: (1) determining the amount and type of clay minerals, (2) best approach to soil fertility testing for clayey soils, (3) solutions for low pH acidic clays, (4) solutions for high pH alkaline clays, and (5) solutions for high pH alkaline/saline clays. The goal is to introduce new approaches that will allow you to achieve deep rooting of healthy plants and robust soil biota in clayey soils.

Definitions

1. Acidic Soils – These are soils that have low pH and are typically found in humid regions.
2. Alkaline Soils – These are soils that have high pH and are typically found in semi-arid to arid regions.
3. CEC, Cation Exchange Capacity – This is a measure of the amount of nutrient retention and exchange that can occur; it is measured as milliequivalents per 100 grams of soil (meq/100g).
    - Non-Expansive Clay Minerals - Kaolinite and halloysite clay minerals (and other 1:1 clay lattice minerals) are dominant in these soils; CEC is less than 16 meq/100 g of clay.
    - Slightly Expansive Clay Minerals – Non-expansive clay minerals (1:1 clay lattice minerals) dominant, but sufficient other clay minerals are present so that the CEC is 16 to 35 meq/100g of clay.
    - Expansive Clay Minerals – Illite, montmorillonitic, or vermiculite clay minerals (and other 2:1 clay lattice minerals) are dominant in these soils; the CEC is greater than 35 meq/100g of clay.
    - Organic Matter – Highly decomposed colloidal humic substances can have CEC of 80 to 200 meq/100g of organic matter. Sufficient quantities of highly decomposed colloidal humic substances will lower pH of alkaline soils.
4. Clayey Soils – These are soils that contain 35% or more clay; these are typically problem soils. These soils use the “fine” term in their scientific name to indicate 35 to 59% clay in the subsoil and use the “very fine” term to indicate > 60% clay in the subsoil. For clayey soils, the term “halloysitic” or “kaolinitic” in the scientific name indicates that it has non-expansive clay minerals; “chloritic” or “mixed” indicates that it has slightly expansive clay minerals; “illitic”, “montmorillonitic”, or “vermiculite” indicates that it has expansive clay minerals.
5. Fine-Loamy Soils – These are soils that contain 18 to 35% clay; these may be problem soils.
6. Fine-Silty Soils – These are soils that contain 18 to 35% clay; these may be problem soils.
7. Lime – Agricultural lime which has been finely ground is useful to raise the pH in acidic soils; the lime contains calcium carbonate.
8. pH – This is a measure of the proportion of hydrogen ions vs. hydroxyl ions. Greater concentration of hydrogen ions creates low pH and greater concentration of hydroxyl ions creates high pH. pH scale is logarithmic, so that pH 5 is ten times more acid than pH 6.
    - High pH Soils – These alkaline soils have pH greater than 7; greater than pH 8.5 is very high, pH 7.5 to 8.5 is moderately high, and pH 7 to 7.5 is slightly high.
    - Low pH Soils – These acidic soils have pH less than 7; less than pH 5.5 is very low, pH 5.5 to 6.5 is moderately low, and pH 6.5 to 7 is slightly low pH.
    - Neutral pH Soils – These soils have pH of 7, which is neither acidic nor alkaline.
9. Saline Soils – These are soils that contain sodium on more than 15% of CEC; these are problem soils.
10. Sulfur – Sulfur which has been finely ground is useful to raise lower the pH in alkaline soils.

11. Super Phosphate – Phosphorus oxide which has been finely ground is useful to the overcome phosphorus fixation capacity of clayey soils high in kaolinite.

Soil-Based Strategies

Appropriate soil-based strategies require correctly identifying the nature of the soil problems and selecting a strategy to adequately improve the soil resources on the site. Appropriate soil strategies avoid importing topsoil materials to the site. Sustainable strategies normally involve using the soil material that is present on the site. Therefore, soil-based strategies are not necessarily expensive. You should also avoid disturbance of soil profiles by retaining areas with existing trees and root systems intact.

When grading activities involve disturbance of the soil profiles and you end up with clayey soils at the ground surface, you will want to examine the following principles to improve the soil conditions. The principles will allow you to judge the severity of the soil problems and determine an appropriate corrective action plan. Corrective actions are quite different depending upon (1) the percent of clay in the soil, (2) the type of clay minerals that are present, (3) the soil pH, and (4) the plant species you want to use on the site.

Principle 1 - Determine the nature of the subsoils on the site

The Soil Survey of your county will give you a good approximation of the nature of the subsoils in the area of your site. Many landscape architects assume that a soil name such as Cecil sandy loam means that the subsoil is sandy loam. However, Cecil series soils have clayey subsoils. The sandy loam is referring to the topsoil. So, it is important to review the soil profile description in the Soil Survey to determine the subsoil texture. The Soil Survey will also have estimated data for each of the soils mapped in your county. The Soil Survey may also have actual laboratory data for some of the soils mapped.

Soils are classified by the percent of clay in the subsoil. Clayey soils have > 35% clay, while fine-loamy and fine-silty soils have 18 to 35% clay in the subsoils. The clay minerals are classified using the CEC of clay and are (1) non-expansive, (2) slightly expansive, or (3) expansive clay minerals. Expansive clay minerals are the most difficult to successfully amend.

If the landscape has deep cuts (usually more than 4 feet) the Soil Survey probably will not adequately describe the deeper soil materials. Subsoil often vary extensively with depth on a given site, therefore these sites will need more detailed evaluations.

The parent material (geology) and climate are important soil forming factors. Light colored (acid crystalline) igneous and metamorphic rocks in humid climates generally develop acidic (low pH) soils. Dark colored (mafic) igneous and metamorphic rocks in humid climates generally develop acidic (low pH) soils and basic (high pH) soils in dry climates. Sedimentary rocks in humid climates generally develop acidic soils, while in dry climates they generally form basic (high pH) calcareous soils.

Clay subsoils frequently form by the process of illuviation, whereby clay particles move downward and over time concentrate to form clay layers in the soil. Humid climates tend to accelerate the process. Clay subsoils also form by the weathering of shale and mudstone parent materials in both humid and dry climates.

Principle 2 - Determine the best approach to soil fertility testing

Agricultural research has led to major advances in soil fertility testing in the last 25 years. The results of these accurate soil testing procedures are used to determine fertilizer recommendations. The fertilizer recommendations are based upon plant growth response curve developed for agricultural topsoil. As landscape architects, we deal frequently with subsoil at the surface of the ground. If we sample the subsoil, we can get accurate test results. However, the fertilizer recommendation may be highly inaccurate since the response curves are not based upon subsoil conditions. This problem has led some to develop alternative procedures for testing subsoil and especially clayey subsoils. The alternative testing procedures are also useful for testing the fertility of various mixes of decomposed organic matter in the soil.

2A. Method 1 – Submit standard soil fertility testing

This approach relies upon standard procedures for collecting soil samples, submitting to the testing laboratory, and receiving fertility recommendations. This is a good starting point, but may be insufficient for subsoil samples.

2B. Method 2 - Amend soil samples prior to submittal

This approach involves collecting bulk soil samples, but prior to submitting to the testing laboratory samples are weighed and fertilizer and, or organic matter is added to the samples. The samples are then allowed to equilibrate for two to three months before they are sent to the testing laboratory. This approach is referred to as “incubation study”. With this approach you want to know which samples require no additional fertilization; and the fertility recommendation is based upon the amount of fertilizer and, or organic material that you actually added to the sample.

2C. Method 3 - Amend test plots prior to collecting soil samples

This approach involves selecting some small plots on the site, physically amending the soil and mixing fertilizer and, or organic matter to the plots, and then allowing three to six months for equilibration prior to collecting samples. The samples are sent to the testing laboratory. This approach is referred to as “incubation study”. With this approach you want to know which plots require no additional fertilization; and the fertility recommendation is based upon the amount of fertilizer and, or organic material that you actually added to the plot.

2D. Conduct incubation study

- Organic Amendments – In clayey soils, prepare samples or plots by mixing finely ground decomposed humic substances into pulverized soil in various proportions; use soil mixtures with 1 to 10 tons/acre of organic matter. You might want to try blends of different types of organic material.
- Chemical Amendments - In clayey low pH soils, prepare samples or plots by mixing finely ground agricultural lime into pulverized soil in various proportions; use lime rates of 2, 4, 6, 8, 10, and 12 tons per acre (tons/acre/6-inch depth). Also, mix finely ground 50% super phosphate into pulverized soil in various proportions; use super phosphate rates of 0.5, 1, 1.5, and 2 tons per acre.

Principle 3 – Identify solutions for acidic (low pH) clayey subsoils

Soil acidity or low pH is one of the largest factors limiting growth of plants and soil biota throughout North America. Low pH soils have increased solubility of aluminum, cooper, iron, manganese, and zinc. The concentration of aluminum and manganese can reach toxic levels and thereby inhibit root growth. Clayey acidic subsoils frequently have either toxic levels of aluminum or manganese. Some clayey acidic subsoils fix and immobilize phosphorous so that it is not available for plant growth. Many clayey acidic subsoils are deficient in phosphorous or potassium.

3A. Make physical amendments

Clayey low pH soils must be thoroughly pulverized. This is necessary in order to properly mix soil amendments. Special tillage equipment or grinding equipment will be necessary to adequately pulverize the soil. The pulverization should be accomplished to the desired rooting depth. The degree of pulverization in clayey soil is very dependent upon the moisture content of the soil material. If the soil is too dry or too moist, pulverization will not be effective.

3B. Make organic amendments

If you use highly decomposed organic matter, you need to understand that it will lower the pH. Therefore, you need to use the incubation approach in paragraph 2D and you should mix both organic matter and lime amendments into the soil samples.

3C. Make liming amendments

Acidic clayey subsoil normally needs to have the pH adjusted to about 6.0 to 6.5. This is a huge change if you start with a pH of 4.5 to 5.5. Agricultural limestone in a finely ground powder form is best to amend these subsoils. The lime must be added to the soil after it has been already pulverized. Immediately mix the lime thoroughly into the soil. The lime will only be effective when the individual particles are coated with the lime. The lime will not move in the soil, so it must reach each soil particle. Research has shown that many clayey subsoils require significant amount of lime to adequately raise the pH.

3D. Make phosphorus amendments

Many acidic clays have a very high phosphorous fixation rate. This means that the soil will fix phosphorous where it is not available for plants. Therefore, the phosphorus content must be raised above the fixation rate of the given soil, before any is available for the plants. Just like lime, phosphorus will not move in the soil, so it must be thoroughly mixed into the pulverized soil material.

3D. Make potassium amendments

Potassium levels are easier to amend in clayey soils, than lime and phosphorus amendments. Potassium levels in clayey subsoils will vary, but are frequently reasonably high in many acidic clays.

3E. Address micro nutrients

Micro nutrients will generally have adequate concentrations in most acidic soils if the pH has been successfully adjusted to 6.0 to 6.5.

3F. Address toxic elements

Acidic clayey soils typically have significant toxicity problems. Low pH levels can create iron and aluminum toxicity in many soils. The concentration of aluminum in many of these soils can inhibit root growth. If the pH is adjusted by liming for a 9-inch depth, root growth will stop when the roots reach the unamended soils below 9 inches.

Principle 4 – Identify solutions for alkaline (high pH) clayey subsoils

Soil alkalinity or high pH is one of the largest factors limiting growth of plants and soil biota throughout North America. High pH (greater than 7.5) soils typically have copper, iron, and, or zinc deficiencies. These deficiencies are most pronounced in clayey alkaline subsoils. Clayey alkaline subsoils are deficient in essential nutrients, due to the excessive amount of calcium in the soil.

4A. Make physical amendments

Just as in acidic soils, clayey soil material must be thoroughly pulverized. This is necessary to properly mix soil amendments. Special tillage equipment or grinding equipment is necessary to adequately pulverize the soil. The pulverization should be accomplished to the desired rooting depth. The degree of pulverization in clayey soil is dependent upon the moisture content of the soil material. If the soil is too dry or too moist pulverization will not be effective.

4B. Make organic amendments

Highly decomposed organic matter can be used to lower the pH. Therefore, you need to use the incubation approach in paragraph 2D and you should mix some samples with organic matter and others with sulfur amendments. The results will tell you using organic matter will adequately lower pH or whether some sulfur amendments may be needed.

4C. Make sulfur amendments

Basic clayey subsoil normally needs to have the pH adjusted to about 7.0 to 7.5. This is a huge change if you start with a pH of 8.5. Various forms of sulfur can be applied to lower the pH. Sulfur in a finely ground powder form is one approach to amend these subsoils. The sulfur must be added to the soil after it has already been pulverized. Immediately mix the sulfur into the soil. The sulfur is effective only when the individual particles are coated with the sulfur. The sulfur will not move in the soil, so it must reach each soil particle. Research has shown that many clayey subsoils require significant amount of sulfur to adequately lower the pH.

4C. Address micro nutrients

Micro nutrients will generally have adequate concentrations in most acidic soils if the pH has been successfully adjusted to 7.0 to 7.5.

4D. Address toxic elements

Sodium may be at toxic levels in high pH soils. Therefore, soil test should include a salinity test.

Principle 5 – Identify solutions for alkaline (high pH) saline subsoils

Soil salinity occurs when excessive amounts of salts are present in the soil. Sodium salinity occurs typically in soils with pH less than 8.5 and when the exchangeable sodium is greater than 15% of the cation exchange capacity. Salinity is most pronounced in clayey alkaline subsoils. Clayey alkaline subsoils are deficient in essential nutrients, because of the excessive amount of sodium and calcium in the soil. Corrective actions include improving drainage, leaching excess salts, reducing evaporation, removal of sodium, or combination of these actions.

5A. Improve drainage

Most saline soils on construction sites have poor drainage because of compaction. Also, drainage may be inadequate due to loss of soil structure by the process of dispersion of soil particles caused by the high sodium levels. Drainage is typically improved by tillage of the soil.

5B. Leach excess salts

After adequate internal drainage has been established in the soil, the soil is irrigated with low sodium water. This process can take considerable time and may not be very effective on clayey subsoils.

5E. Remove sodium

Sodium can be chemically removed by adding calcium in a soluble form such as gypsum. Soil testing will help establish the correct amount of gypsum to add to the soil. Just as with acidic clayey soils, the normal soil test provides you reliable rates of gypsum. Therefore, you should determine application rate using one of the above alternative testing procedures. Although gypsum is soluble, it is still best to mix gypsum into a thoroughly pulverized soil down to the desired rooting depth.

5D. Reduce evaporation

After completion of landscape improvements, heavy mulching will reduce the amount of evaporation of the soil water. This will reduce the future reconcentration of sodium in the soil.

Principle 6 - Evaluating your success in amending clayey soils

An essential part of amending difficult soils is evaluating the relative success of your methods. Evaluations should be conducted one, two, and three years after completion of the improvements.

6A. Examine post construction soil

Examine the depth of the improved soil structure. Also, examine the depth of rooting, which corresponds to the effective depth of physical and chemical amendments.

6B. Test post construction soil

Collect soil samples at varying depths to determine the effective depth of chemical amendments. If you determined the fertilization rates based upon 3.B. or 3.C. above, you may be able to adequately evaluate your success by following 3.A.

6C. Document and evaluate to improve success

Keep accurate records of all of your procedures, amendments, testing data, etc. for all of your projects. Evaluate all of your data for similar soils by grouping data based upon the dominant NRCS soil series on each site. Study results and fine tune your methods for continuing success.

Related Literature

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Hargett, David L. 1979. Soil Variability, Seedbed Preparation, and Fertility Considerations for Erosion Control Vegetation on Roadside Cut-Slopes in the Piedmont of North Carolina. Master Thesis, Department of Soil Science, North Carolina State University, Raleigh, NC.

Horton, Maurice L., et al. 1995. Recommended Soil Testing Procedures for the Northeastern United States. Northeast Regional Publication No. 493. Soil Science Society of America, North America

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Miller, Robert O., et al. 2003. Western States Laboratory Plant, Soil and Water Analysis Manual. Western States Regional Publication. Soil Science Society of America, North America Proficiency Testing Program (NAPT) for Western Coordinating Region (NCR-13).

State Soil Testing Laboratories in United States

Alabama – Soil Testing Laboratory, Auburn University.
Alaska – Soil Testing Laboratory, University of Alaska.
Arkansas – Soil Testing & Research Laboratory, University of Arkansas.
Colorado – Soil, Water, & Plant Testing Laboratory, Colorado State University.
Connecticut – Soil Nutrient Analysis Laboratory, University of Connecticut.
Delaware – Soil Testing Laboratory, University of Delaware.
Florida – Soil Testing Laboratory, University of Florida.
Georgia – Soil, Plant, & Water Laboratory, University of Georgia.
Hawaii – Soil Testing Laboratory, State of Hawaii.
Iowa – ISU Soil Testing Laboratory, Iowa State University.
Kansas – Soil Testing Laboratory, Kansas State University.
Kentucky – Soil Testing Laboratory, University of Kentucky.
Louisiana – Soil Testing & Plant Analysis Lab, Louisiana State University.
Maine – Maine Soil Testing Service, University of Maine.
Massachusetts – Soil & Plant Tissue Testing Laboratory, University of Massachusetts.
Michigan – MSU Soil & Plant Nutrient Laboratory, Michigan State University.
Minnesota – Soil Testing Laboratory, University of Minnesota.
Mississippi – Soil Testing Laboratory, Mississippi State University.
Missouri – Soil & Plant Testing Laboratory, University of Missouri.
Nebraska – Soil & Plant Analytical Laboratory, University of Nebraska.
New Hampshire – UNH Cooperative Extension Soil Testing, University of New Hampshire.
New Jersey – Soil Testing Laboratory, Rutgers University.
New Mexico – SWAT Laboratory, New Mexico State University.
New York – Cornell Nutrient Analysis Laboratories, Cornell University.
North Carolina – Soil Testing Laboratory, Agronomic Division, North Carolina Department of Agriculture.
North Dakota – Soil Testing Laboratory, North Dakota State University.
Oklahoma – SWFAL, Oklahoma State University.
Oregon – Central Analytical Laboratory, Oregon State University.
Pennsylvania – Ag. Analytical Ser. Laboratory, Pennsylvania State University.
Rhode Island – Send samples to University of Massachusetts.
South Carolina – Agricultural Service Laboratory, Clemson University.
South Dakota – Soil Testing Laboratory, South Dakota State University.
Tennessee – Soil & Forage Testing Laboratory, University of Tennessee.
Texas – Soil, Water, and Forage Testing Laboratory, Texas A&M University.
Utah – Soil Testing Laboratory, Utah State University.
Vermont – Agricultural & Environmental Testing Lab, University of Vermont.
Virginia – Virginia Tech Soil Testing, Virginia Tech University.
West Virginia – Soil Testing Laboratory, West Virginia University.
Wisconsin – Soil & Plant Analysis Laboratory, University of Wisconsin.
Wyoming – Soil Testing Laboratory, University of Wyoming.

Provincial Soil Testing Laboratories in Canada

Alberta – Soils & Animal Nutrient Laboratory, Edmonton.
British Columbia –
Manitoba – Provincial Soil Testing Laboratory, University of Manitoba.
New Brunswick – NB Agricultural Laboratory, Fredericton.
Newfoundland & Labrador – Soil Plant & Feed Laboratory, St. John's.
Nova Scotia – Soils & Crops Branch, Truro.
Ontario – Soil & Nutrient Laboratory, University of Guelph.
Prince Edward Island – PEI Soil & Feed Testing Laboratory, Charlottetown.
Quebec – Soil Test Laboratory, McGill University.