An APLD Guide to

Sustainable Soils

Association of Professional Landscape Designers

APLD

We Define Landscape Design

www.apld.org

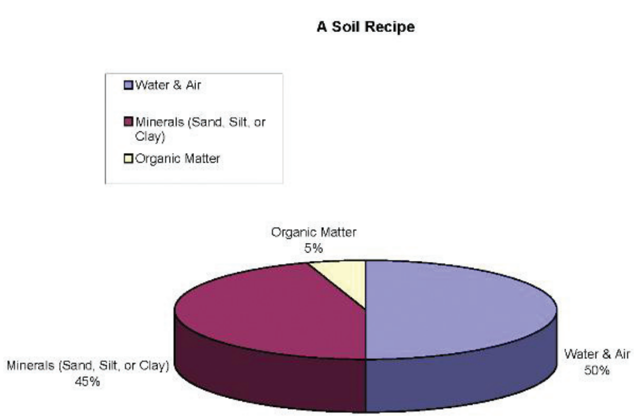
APLD is committed to the principles of sustainability as the foundation for our collective landscape design practice. Healthy, appropriate soils, sustainably generated and maintained, are key to a strong, diverse ecosystem and are essential for a successful planting design.

The Properties of Soil

Soil has physical, chemical and biological properties, all combining to provide exquisite complexity for supporting plant life.

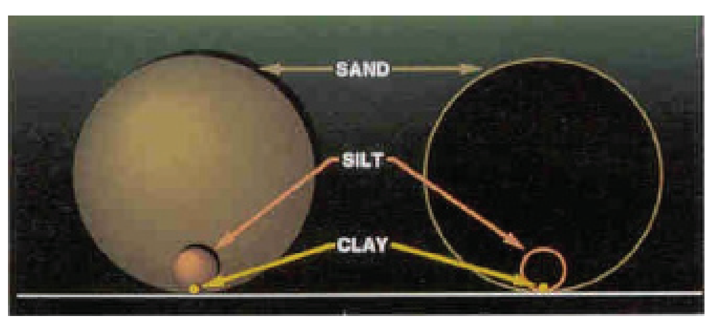
Physical Properties of Soil

The physical components of soil include liquids, gases, and mineral and organic solids.



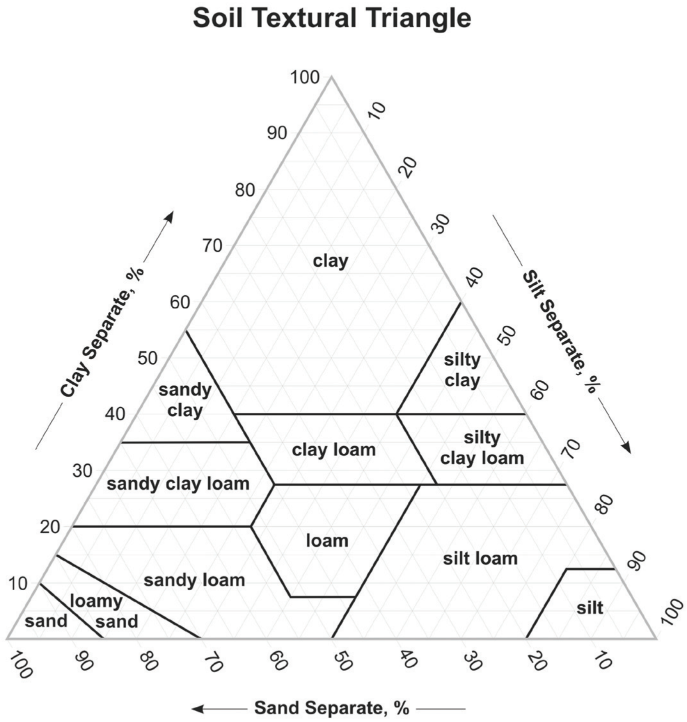
U.S. Dept. of Agriculture National Resources Conservation Service

The mineral solids are sand, silt, and clay, usually mixed in varying concentrations that define the texture of the soil. The largest particles are sand, followed by silt and clay, in that order. The comparative sizes of the particles are shown below.



U.S. Dept. of Agriculture National Resources Conservation Service

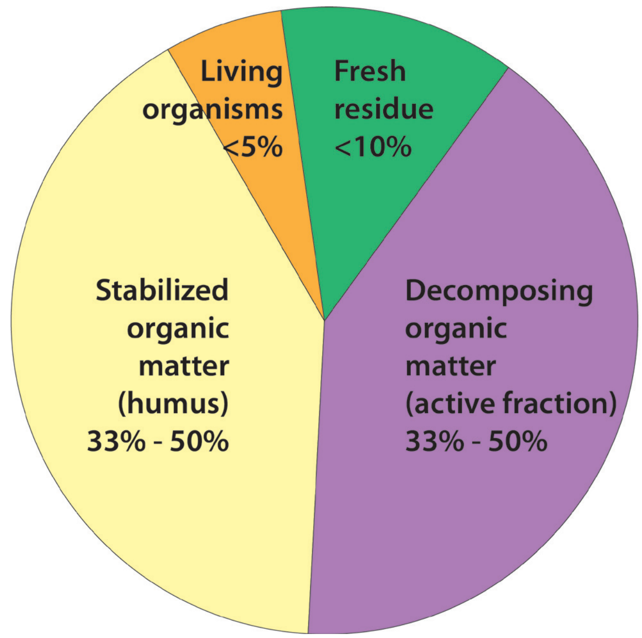
There are twelve main classes of soil texture, ranging from blends of the mineral solids, with a combination of approximately equal parts silt and sand, no more than 20% clay, and some organic solids being among the best types of soils. The diagram below illustrates the 12 main soil textures.



U.S. Dept. of Agriculture National Resources Conservation Service

The arrangement of the particles of sand, silt, and clay contribute to soil structure, another very important physical attribute of soil. The particles form larger bundles called aggregates. The aggregates are held together by clay and organic matter, which have sticky qualities that bind the aggregates. The actions of soil organisms including earthworms also contribute to aggregate formation. This structure, or grouping of aggregates, creates pore spaces in the soil where water and air are held. Plant root growth and soil structure work together to build these pore spaces, which are essential for movement of water – the liquid in the soil – and air. A soil structure with a mix of large and small pore spaces is ideal for plant growth. Air fills the larger pore spaces and water fills the smaller ones.

The organic solids are carbon-based and derive from the decaying remains of plant and animal life in the soil. They contribute to the structure of the soil by working with clay to encourage the development of soil aggregates and cement the particles, thus stabilizing soil structure. Organic solids also improve the ability of the soil to hold water. A simple way to determine the presence of organic matter is by color: if the top layer of soil is dark, it may contain organic matter.



Components of Soil Organic Matter *The Soil Biology Primer,*
U.S. Dept. of Agriculture National Resources Conservation Service

Soil air is the gaseous component of soil. Without it, few plants can survive because it is necessary for making nutrients available to plants. Air is critical for other life in the soil as well, such as microbes. Soil air is mostly carbon dioxide since the oxygen is constantly taken up; therefore, in addition to being present in plant material, carbon is also stored in the soil. Soil air fills whatever space is not occupied by water. It is also important to understand the exchange of air which occurs at the soil surface between the atmosphere and the soil air. A compacted soil surface which impedes air flow will contribute to poor growing conditions.

Chemical Properties of Soil

Plants require a variety of elements from the soil for nutrition. However, because much of the soil is sand and/or silt, which are chemically inert, the nutrients contained in those particles are unavailable to plants. Clay and organic matter retain or provide the bulk of nutrients that form a mixture, or solution, and become available for plants.

Required plant nutrients can be divided into three categories: primary (nitrogen, phosphorus, and potassium), secondary (calcium, magnesium, and sulfur), and trace, or micronutrients (copper, iron, boron, manganese, zinc, molybdenum, and chlorine). Most secondary and trace deficiencies are easily corrected by adjusting the soil pH and adding organic matter. Of the primary nutrients, nitrogen supplies strong leaf growth and dark green color; phosphorus aids roots, early plant growth, and seed formation; potassium contributes to plant vigor, disease and stress resistance, flavor and color enhancement. The role which each nutrient plays in plant growth is complex and often inter-related with and dependent on the adequate supply of all nutrients.

Soil reaction, also known as pH, is the most important chemical feature of soils. An indicator of the acidity of the soil, the pH affects nutrient availability. pH is expressed in numbers on a scale of 0 to 14, with 7 as neutral. Numbers below 7 are acidic and numbers above 7 are alkaline. Preferences for acidity and alkalinity vary from plant to plant, so it's important to know the pH level of the soil when deciding what to plant. A soil test is a reliable tool for understanding the chemical makeup of a particular soil. pH is possibly the single most important feature of soils because pH affects not just the availability of nutrients but the life processes of soil organisms. Since soil organisms contribute to the breakdown of organic matter and the creation of aggregates, the influence of pH covers all aspects of soil management.

Soil Tests

Standard soil chemical analysis, done by university soils labs, will give you a report as to how much nitrogen (N), phosphorus (P) or potassium (K) you should add to have a vigorous lawn or garden. That information is only the beginning of what you need to know about your soil. It is also important to request the percentage of organic matter, pH and any heavy metal pollution that could be a problem when growing food crops. Some soils labs now include the ability to analyze soil health from an ecosystem perspective. These labs will give you a report on the food web present. The food web is the variety of small creatures that live on decaying plants in the top few inches of the soil column. While these food web tests are expensive compared with chemical analysis, you are able to have a greater understanding of what steps you should include prior to planting a garden to ensure the best soil environment to support those plants with the least care.

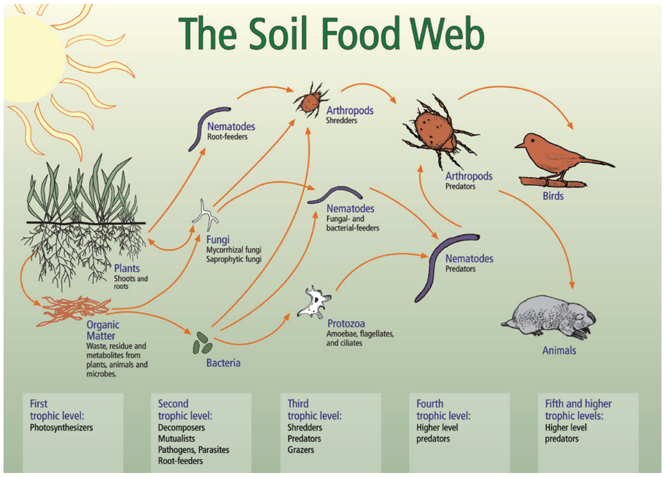
Douglas Owens-Pike, Professional Member
EnergyScapes, Inc., St. Paul, MN

Although it is common to add fertilizers to feed plants, the most sustainable and beneficial soil additive is organic matter. Not only does organic matter provide essential nutrients (including secondary and micronutrients in addition to the primary nutrients of nitrogen, phosphorus, and potassium), it supports soil structure and water retention[1], something synthetic fertilizers are unable to accomplish. At the same time, one should understand that organic matter can vary greatly in its plant nutrient content. Knowing the source of the material is important. For instance, compost from municipal waste is normally rich in plant nutrients but may contain undesirable levels of heavy metals. This is of most concern where garden crops are to be grown or where applied near water bodies and some runoff may occur. Preferably, only use compost or other organic material from a known source that provides the nitrogen-phosphorus-potassium analysis.

---

[1] There are occasions when adding organic matter to an extremely poorly drained soil with a large percentage of clay may exacerbate the drainage problem. Compaction lower down in the soil may be a contributing factor. A remedy for this is adding a drain tube to facilitate the movement of the water through the soil.

Biological Properties of Soil



The Soil Biology Primer, U.S. Dept. of Agriculture, National Resources Conservation Service

The Soil Food Web

There are essentially two components of the biological properties of the soil: (1) decomposing plant and animal residues and (2) the community of living organisms known as the soil food web. Building and maintaining an appropriate soil food web of microorganisms are fundamental for a healthy soil. The soil food web consists of multitudes of bacteria, fungi, protozoa, nematodes, arthropods and more that all work together to break down organic matter to supply basic nutrients for the growth of plants. The soil food web and the organic processes utilized are essential to the sustainable growth and maintenance of plant communities wherever they are found.

Healthy soils have 50% porosity, which should be evenly divided between air and water. Lower soil porosities prevent good soil food web interaction (an aerobic, or oxygen-requiring process) and diminish the returns of the soil food web. Low porosity soils are anaerobic (without oxygen) creating incomplete decomposition, foul odors and chemical production that damages plant root cells and are breeding grounds for pathogenic organisms.

The synthetic fertilizer approach to plant growth, though effective, short circuits the natural soil food web in order to provide nutrients directly to plants. Synthetic fertilizers, unsustainably made from natural gas and other ingredients supplied from around the globe, kill off many if not most of the soil food web microbes. These synthetic fertilizers are provided as salts, causing osmotic shock and death to bacteria, fungi and other food web organisms, effectively breaking down soil food web activity. Natural feeding stops, further increasing reliance on artificial fertility. Pesticides can add to the strain and breakdown of the soil food web.

APLD's Sustainability Committee recommends reliance on organic fertilizers as the best practice for plant nutrition and soil preservation; however, if circumstances make it necessary to use synthetic fertilizers, these should be applied in conjunction with soil testing and application instructions should be carefully observed.

To build, restore or maintain a healthy soil food web community, soil additives can be used to accelerate and supplement the process. There are several types of additives that can be utilized.

Soil Additives

Compost:

- Compost, a decomposed mix of organic matter and high concentration of soil organisms, is a great way to foster the proper soil biology. Compost uses recycled organic matter as the starting media for producing a rich spread of soil organisms.
- Know which type of compost your soil requires. Aged, brown organic materials favor fungi growth. Fresh, green organic materials favor bacterial growth.

Compost Teas:
There is a difference of opinion as to whether compost tea is effective. APLD's Sustainability Committee advises further study when considering its use.

- Compost teas, containing compost organisms in a water suspension, are another way to build soil organism populations. Again, use the proper raw materials to build the right biology for your soil.
- Compost teas are very sensitive to chlorine and preservatives in its brewing water and added ingredients. Clean water is essential for creating healthy compost teas, strong soil biology and thriving plant communities.

Mulch:

- Mulch is another way, though slower, to help build the right biology in your soils.
- Mulch that is made from green (herbaceous) materials favors bacterial growth; mulch that is made from brown materials (bark, woody branches, etc.) favors fungal growth. Note that brown mulch may contribute to temporary nitrogen deficiency unless care is taken to add a nitrogen source when the brown mulch is applied.
- Mulch that is surface applied tends to support fungi growth; mulch worked into the soil tends to support bacterial growth.
- Mulch that is wet and ground fine supports bacterial growth. Coarse, dryer mulch supports fungal growth.
- Be careful not to over-mulch and destabilize the soil composition. Heavy mulch applications can draw up organic activity out of the soil and into the mulch. Repeated, unnecessary mulch applications can alter the soil type from its intended composition.

More on Soil Additives

In addition to specific plant requirements, the following factors should be considered in determining the type, quantity and frequency of organic amendments and natural fertilizers used:

- Soil nutrient deficiencies
- The nutrients in the additive and how quickly these nutrients will be available for plant uptake
- Length of time the additive will last in the soil
- Soil texture and organic content
- Soil salinity and plant sensitivities to salts
- The salt or heavy metal content and pH of the additive
- Whether amendment is “fungal” or “bacterial” dominated

Sabrena Schweyer, APLD
Salsbury-Schweyer, Inc, Akron, OH

Mycorrhizal Fungi:

An important microorganism for plant growth is *mycorrhizal fungi*. This symbiotic microbe links itself to the roots of plants and effectively doubles the root reach through the soil. Mycorrhizal fungi may or may not be present in sufficient numbers in any given soil, and the addition of mycorrhizae can quickly boost the soil biology effectiveness at processing nutrients for plants.

- Ectomycorrhizal fungi are favored by conifers and hardwood trees.
- Endomycorrhizal fungi are favored by vegetables, annuals, grasses, perennials, shrubs, and softwood trees.
- Add mycorrhizal fungi spores in the following situations: (1) to the seeds of annuals and vegetables and to the roots of all transplants at the time of planting; (2) to soils previously treated with fungicides and heavy concentrations of chemical fertilizations; (3) to soils damaged by construction activities.

Composition and Performance of Soil Additives:

Laboratory tests can determine the nutrient levels, bacteria & fungi counts, salt content, organic content and pH of organic amendments as well as those of existing soils. The longevity of soil additives can vary considerably:

- If you are trying to improve soil physical properties quickly, choose an additive that decomposes rapidly. (However, soil improvement is best maintained by a long-term approach.)
- For quick uptake of nutrients by plants, select a fast release fertilizer, often available as a foliar spray. These will require frequent reapplication.
- If you want a long-lasting improvement to your soil or nutrients for plants that will slowly become available, choose an amendment or fertilizer that decomposes slowly.
- For a quick improvement that lasts a long time, choose a combination of amendments.

Recommendations For Designers

Recognizing that only organic soil approaches and methods are sustainable, APLD recommends the following practices concerning landscape design and maintenance:

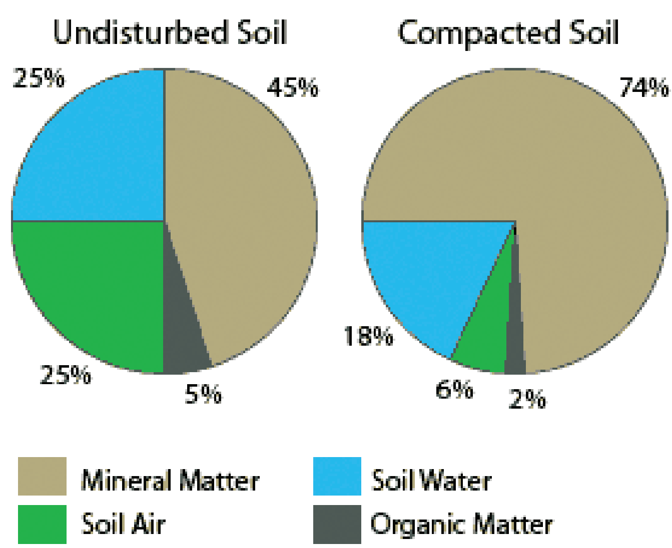
- Design for your soils. Aim to restore the site's soil back to its native composition. In most cases, avoid overbuilding soils into something beyond what is natural for your area.
- Know the *biology* of your soils by sampling and testing the soil using a competent soil *biology* lab.
- Wherever possible, use chlorine-free water for watering plants, by using chlorine filters or rainwater harvesting. Chlorine damages the soil food web.
- Understand the difference between bacterial and fungal soils and build and maintain each soil type with the proper selection of soil amendments. Bacteria dominate soils that favor vegetables, annuals and grasses; fungi dominate soils that favor perennials, shrubs and trees.

Soils and Compaction

All too often we encounter soils that are extremely difficult for roots to penetrate. This can be a result of vehicle or other traffic compacting the soil. Planting the right plants that can tolerate these low oxygen conditions can build soil health, but that is a slow process with heavy clay soil. Adding organic matter speeds it up, but working that organic matter into the soil is the fastest way to have a beautiful garden or trees and shrubs that prosper. Using machinery to till compost into the soil can severely damage existing root systems of trees, shrubs and even perennials. The best technique is to vertical mulch. This requires boring holes of approximately 3" in diameter (bulb augers on a powerful drill do a great job). The holes should be as deep as your drill will go, set 12-18" apart, depending on the severity of the compaction. Backfill those holes with a mixture of parent soil and compost. It is fine if a great deal of compost remains on the surface when you are finished.

Douglas Owens-Pike, Professional Member
EnergyScapes, Inc., St. Paul, MN

- Encourage composting of all yard waste (free from pesticides, chemical fertilizers and pet eliminations), garden and kitchen waste by your clients. Adding compost supplements the natural processes within the soil.
- Do not till or physically disturb a healthy, mature soil. Physical disruption severely damages or destroys the mature soil food web. The shallow mixing of additives at the soil surface does little damage.
- Do not add fertilizers that have high (>10) NPK numbers, except in cases where a soil is extremely deficient and would require the use of a higher analysis fertilizer. A soil test is a reliable guide for this.
- Consider using soil additives as tools for maximizing the soil food web.
- Physical soil compaction during construction has a long-term damaging effect on soils and is difficult to remedy after the fact. All efforts should be made to protect soils prior to and during any construction phase. Fencing or other restrictions on construction-related vehicular traffic should be used to eliminate soil compaction around existing trees, shrubs and all soils to be utilized for planting purposes.



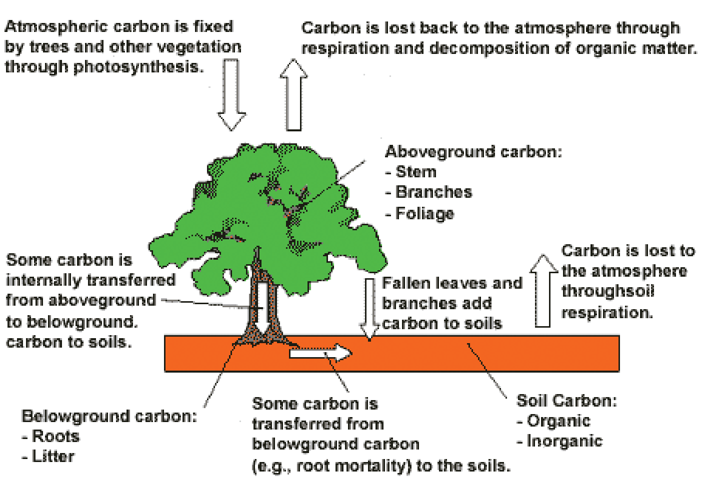
U.S. Dept. of Agriculture, National Resources Conservation Service

Soils and Sustainability: the Big Picture

Examining a handful of soil yields helpful information about the properties of that soil, enhancing the designer's understanding of the possibilities it offers and pointing the way towards effective management of the soil for the project at hand. Satisfying as that can be, there is more at stake than fulfillment of a pleasing landscape design: soil plays a critical role in environmental sustainability.

Soils are the foundation of the ecosystem.
The living systems occurring above and below ground are determined by the properties of the soil. Soils store and cycle nutrients needed by these living systems, supporting life all the way from microbes to humans. A healthy, diverse ecosystem is critical for life, and it begins with the health of the soil.

Soils store carbon.
Carbon dioxide, a greenhouse gas contributing to the warming of the atmosphere, is stored in the soil in both pore spaces within the soil structure and in the biomass, or living material, of plant roots underground. According to the U.S. Environmental Protection Agency, "the U.S. landscape acts as a net carbon sink—it sequesters more carbon than it emits. Two types of analyses confirm this: 1) atmospheric, or top-down, methods that look at changes in CO_2 concentrations; and 2) land-based, or bottom-up, methods that incorporate on-the-ground inventories or plot measurements."



The Carbon Cycle
United States Environmental Protection Agency

Soils manage water.
Water enters the soil through the channels created by vegetation and the activities of organisms such as earthworms. It fills the empty pore spaces and is taken up by plants. Healthy soils have sufficient open pore space to absorb the water and allow it to infiltrate the soil, recharging the groundwater. Wetlands, also known as hydric soils, manage large quantities of water and also serve as buffers and filters in addition to supporting a vast array of wildlife.

On the other hand, degraded soils exhibit erosion, which occurs when soils are not covered by vegetation, and rainfall both compacts the soils, forming a crust on the surface, and carries the top layer of sediment away. Compacted soil compresses the pore spaces so that air, water, and plant and animal life cannot penetrate.

Soils and Water

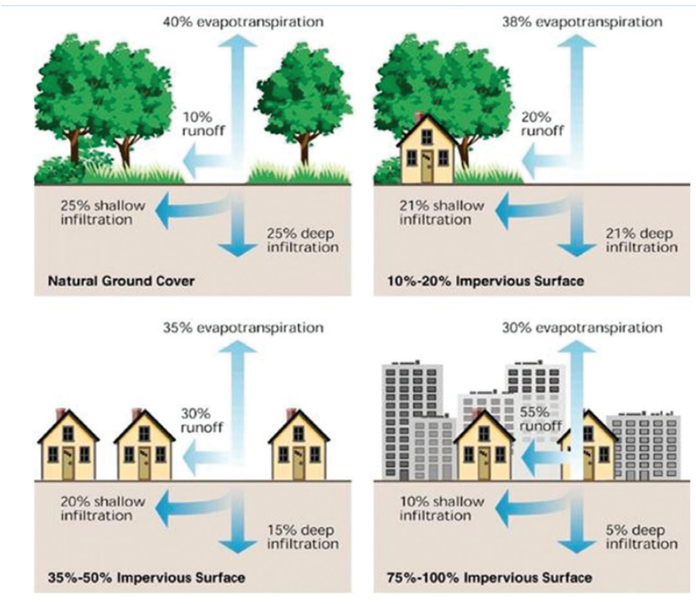
Our soils have changed.

When considering the loss of the eastern deciduous forest (75% gone) and the transition from native prairie / savanna plant systems to the mono-crops of industrial-agriculture, we are looking at an incredible change within our soils. The depth and bulk of our current root systems no longer exist as they did two hundred years ago. Trees have extensive root systems in the top 24" of soil, and can reach five to eight feet or more in depth. The prairie existed on a root system depth between two and three feet, with some plants reaching four to six feet deep. The extensive root systems of our original "ground cover" opened up the soil, allowing for a deep penetration of precipitation and the slow exhale of moisture back up into the atmosphere through plant transpiration.

Not any more: corn, soybeans, wheat and other annual crops have temporary root systems in the 12 to 18 inch range. Perennial turfgrass, our American lawn, covering an area about the size of Wisconsin, has a root system of around six to twelve inches in the best of conditions. Precipitation run-off is now something we have to plan for after almost every rain.

Garth Conrad, Professional Member
Garth Conrad Associates, LaPorte, IN

The diagram below illustrates the loss of water infiltration when natural ground cover (vegetation) is converted to impervious coverings such as roadways and buildings. The more impervious cover over the ground, the more rainfall passes over the surface rather than penetrating the surface. Pollutants are picked up and rushed into local waterways, adding too much contaminated water too quickly, and local vegetation is shortchanged in the water supply.



Environmental Impacts of Conventional Urban Development
U.S. Dept. of Agriculture, National Resources Conservation Service

Soils filter, buffer, degrade and detoxify potentially harmful chemicals.
Minerals and microbes in the soil filter organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits. The soil food web breaks down natural waste and cycles it back through the environment. Pollutants washed into the soil via rainwater, such as oil, pesticides, herbicides and heavy metals, are held in the soil and trapped from entering groundwater.

While microbes can beak down some of these materials, other pollutants can be held for long periods and are not broken down. Every effort should be made to limit the transmission of pollutants. Too heavy a concentration of synthetic waste can result in soil contamination, and water supplies can eventually be affected.

Soils influence climate.
Soils moderate temperature fluctuations, as soil heats more slowly than air and can absorb more heat on a hot day. Soils absorb heat during the day and radiate heat at night. Darker soils, which tend to have higher organic content, absorb the most heat. Soil temperature affects plant growth, which in turn affects climate.

In Conclusion

The bottom line is that soils should be valued and preserved, because, literally, life depends upon it. The mix of particles of clay, sand and silt that forms soils is a process occurring over thousands of years, influenced by organisms, topography and climate. Original soils developed as a result of several geological and long-term climate factors that determined native vegetation; the subsequent weathering of parent materials yielded native regional soils, thus building the ecosystems we know today.

Because of the vital function of our soils for supporting plant, animal and human life, soils should be preserved as close to their natural state as possible. Landscape designers are uniquely positioned to practice and promote stewardship of the soil, by protecting it and educating clients and colleagues about the critical importance of soil preservation.

Glossary and Additional Useful Terms

Adsorption - The attraction of dissolved substances onto a surface such as plant roots, soil particles and soil humus or organic matter.

Aggregate - Many soil particles held in a single mass or cluster, such as a clod, crumb or block.

Biomass - Total dry weight of all living organisms that can be supported at each tropic level in a food chain. Also, materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, crops, grasses, tree litter, roots, and animals and animal waste.

Bioremediation - Use of soil bacteria and microorganisms to cleanse pollution from soil or water.

Bioretention - A land-based practice that uses the chemical, biological and physical properties of plants, microbes and soils to control both the quality of water and the quantity of water within a landscape.

Brownfields - Polluted lands typically associated with postindustrial landscapes that usually suffer from polluted soil or groundwater or both.

Compost - Organic matter that has decomposed and is used as a soil amendment and includes carbon-rich (brown) materials such as dry leaves, vacuum lint, shredded newspaper, fruit waste and straw and nitrogen-rich (green materials) such as grass clippings, nut shells, coffee grounds and flowers.

Compost tea - A water extract of compost often made in a brewer or extractor under aerobic conditions. Additionally, specific secondary organic materials can be added to create compost teas for specific uses in the landscape.

Decomposition - The breakdown of chemicals and organic matter by soil microorganisms.

Erosion - The wearing away of the land surface by wind, water, gravity or a combination of these forces.

Greenfield - An area of land, or some other undeveloped site earmarked for development. Denotes pristine soil, undisturbed and clean.

Ground water - Subsurface water in the zone of saturation.

Infiltration - The movement of water into the soil through the soil surface.

Loam - A soil containing similar amounts of silt and sand and a smaller amount of clay.

Macronutrients - Essential elements needed by plants, in fairly high amounts, for optimal growth. The primary macronutrinets are nitrogen (N), phosphorous (P), and potassium (K). Calcium (Ca), magnesium (Mg) and Sulfur (S) are considered secondary macronutrients.

Micronutrients - Essential elements which are needed in very small quantities for optimal plant growth. The micronutrients are boron(B), copper (Cu), iron (Fe), chloride (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn).

Mycorrhizae - A fungus which forms a symbiotic relationship with the roots of a plant, and is primarily responsible for nutrient transfer. The benefits of mycorrhizae include increased drought and pathogen resistance and an increased ability of the plant to absorb water and nutrients from the soil.

Organic matter - Soil material derived from living material, composed of carbon-containing compounds.

pH Scale - A measure of how acidic or alkaline a soil is. The pH scale ranges from 0 to 14. A pH of 7 is neutral. A pH less than 7 is acidic. A pH greater than 7 is alkaline. Soil pH affects the availability of soil nutrients. Macronutrients tend to be less available in soils with low pH. Micronutrients tend to be less available in soils with high pH.

Pore space - That part of the total volume of the soil not occupied by solid particles.

Recruitment - Vegetation regrowth from relic seeds in existing soil or from adjacent sites.

Soil - Complex mixtures of minerals, water, air and organic matter (both dead and alive), forming at the surface of land.

Soil food web – The community of organisms living all or part of their lives in the soil.

Soil structure - The combination of primary particles into aggregates.

Sustainable ecosystems - The relationships between organisms and their environments without end and without destroying other environments.

Sustainable soils - A soils management system in which all plants grow in a healthy manner, producing adequate yields of flowers and fruit, maintaining appropriate structure and drainage, and minimizing any negative short-and long-term side effects on the environment and the well-being of the community, above and below ground.

Texture - The relative proportions of sand, silt and clay in a soil.

Tilth - The physical condition of a soil in relation to its plant growth.

References and Resources

Davis, J.G. and Wilson, C.R. (2005).
Choosing a soil amendment.
Colorado State University Extension.
http://www.ext.colostate.edu/pubs/garden/07235.html

Kohnke, H., and Franzmeier, D.P. (1995).
Soil science simplified (4th ed.).
Long Grove, IL: Waveland Press.

Lopez, J. (nd).
Home & garden mimeo # HG 11: Soil test basics.
Baltimore: Baltimore City/County,
Maryland Cooperative Extension.

Lowenfels, J., & Lewis, W. (2010).
Teaming with microbes: The organic gardener's guide to the soil food web (Rev. ed.).
Portland: Timber Press.

Scheyer, J. M., & Hipple, K. W. (2005).
Urban soil primer. Lincoln, NE: United States Department of Agriculture, National Resources Conservation Service, National Soil Survey Center.
http://soils.usda.gov/use

Soil Science Society of America.
https://www.soils.org/

Sustainable Sites Initiative. (2009).
The case for sustainable landscapes.
Available at http://www.sustainablesites.org/report.

Traunfeld, J., & Nibali, E. (2003).
Home & garden mimeo # 42: Soil amendments and fertilizers. Baltimore: Baltimore City/County, Maryland Cooperative Extension.

Tugel, A., Lewandowski, A., & Happe-vonArb, D. (Eds.). (2000). Soil biology primer. (Rev. ed).
Ankeny, IA: Soil and Water Conservation Society.

United States Department of Agriculture,
Natural Resource Conservation Service. (2011).
Soils. http://soils.usda.gov/

United States Environmental Protection Agency. (2011). Carbon sequestration in agriculture and forestry. http://www.epa.gov/sequestration/.

Labs for biological soil testing

Harrington's Organic Landcare:
http://www.harringtonsorganic.com/?page_id=343

Soil Food Web NY:
http://soilfoodwebnewyork.com/indexoriginal.html

Soil Food Web:
http://www.soilfoodweb.com/

For other soil testing labs, check with your local cooperative extension service.

Thank You

Thanks to all who provided writing, editing, ideas and support for the creation of this guidebook, including Jan-Marie Traynor of the County College of Morris in Randolph, NJ, and Jane Berger, APLD, communications chair of APLD and editor of *The Designer* Magazine. APLD's Sustainability Committee is especially grateful for the generosity and expertise of Christopher Smith of the United States Department of Agriculture National Resources Conservation Service, for his invaluable help in reviewing this document, and his associates Lenore Vasilas, Holli Kuykendall and Susan Andrews for expert assistance with information requests.

Writing:

Toni Bailey
Garth Conrad
Andrew B. Gagne
Denise Graybill-Donohoe
Greg Morris
Douglas Owens-Pike
Deborah Roberts
Sabrena Schweyer, APLD
Christopher Smith
Jan-Marie Traynor

Editing:

Jane Berger, APLD
Alison Evans
Lenore Vasilas

Committee:

Toni Bailey
Garth Conrad
Andrew B. Gagne
Denise Graybill-Donohoe
Greg Morris
Douglas Owens-Pike
Deborah Roberts
Sabrena Schweyer, APLD