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Agronomy 101: Soil & Plant Growth Backgrounder

KEY TAKEAWAY

Agronomy is the science, practice, and technology of soil management and crop production. For investors and other stakeholders involved in agroforestry development, a basic understanding of agronomy is key for success in the space. This report intends to act as a refresher on soil composition and plant growth, accordingly. Soils are created by geological and biological processes that can take thousands of years to materialize…outside of human life spans. They are largely made up of grains of weathered rock and the remains of dead, decayed plants alongside water and air. Although soil composition differs by location and region, an average soil is generally comprised of 45% mineral rock, 20%-30% water, 20%-30% air, and 5% organic matter. All plants need the same four things to grow: water, air, sunlight, and nutrients. There may perhaps be no more important area for plant growth than the rhizosphere, which is the place where the plant and its roots touch the soil and interact with a unique population of microorganisms critical for plant growth. Agroforestry – and regenerative agriculture more broadly – works to protect soil and enable healthy plant growth.

KEY POINTS

Agronomy 101. Agronomy is the science, practice, and technology of soil management and crop production. It sits at the center of the broader agricultural sciences, using parts of biology, chemistry, ecology (and more) to produce plants that are ultimately used for food, fuel, fiber, medicine, recreation, and conservation. For investors and other stakeholders involved in agroforestry development, a basic understanding of agronomy is key for success in the space. Don't remember everything from your Earth Science class in middle school? We've got you covered with a research update on soil and plant growth basics.

Soil Backgrounder. Soils are created by geological and biological processes that can take thousands of years to materialize…outside of human life spans. They are largely made up of grains of weathered rock and the remains of dead, decayed plants alongside water and air. Although soil composition differs by location and region, an average soil is generally comprised of 45% mineral rock, 20%-30% water, 20%-30% air, and 5% organic matter.

The biological health of soils is extremely important. Soil is a living organism bursting with microbes, fungi, insects, worms, and other invertebrates. All of these entities play important roles in breaking down material, delivering nutrients to plants and maintaining soil fertility (the ability of soil to sustain agricultural plant growth). More than one-quarter of all species on Earth lives in the soil.

There are a wide variety of soil classifications, or orders, around the world…each with a unique set of characteristics. However, all soils are increasingly under threat from microbiology and nutrient loss, lack of soil moisture, contamination, and erosion. Tilling (plowing) has become a big contributor to some of these challenges, and farmers are increasingly looking to reduce their effects by moving to more regenerative practices that foster better plant growth and health.

Plant Growth Backgrounder. All plants need the same four things to grow: water, air, sunlight, and nutrients. Plants take up water from the ground through their roots, as well as through their leaves. They also take in carbon dioxide (CO_2) from the air and release oxygen during the day. During photosynthesis, plants use water and CO_2 alongside energy from sunlight to create sugars that foster plant growth via cell growth and division. Nutrients from the soil (nitrogen, phosphorous, etc.) aid in this growth alongside sunlight.

There may perhaps be no more important area for plant growth than the rhizosphere. The rhizosphere is the place where the plant and its roots touch the soil, which is an area around the plant root that is inhabited by a unique population of microorganisms critical for plant growth. Plant roots can release anywhere from 10%-40% of their total photosynthetically fixed carbon into the soil, in exchange for nutrients from microorganisms in the ground. This symbiotic relationship is critical for plant health and, thus, food production.

However, soils are increasingly under pressure from conventional agriculture practices. This dynamics is believed to be affecting crop yields and nutrient levels in certain parts of the world. A commercial market is developing for biostimulants, defined as substances/ microorganisms that stimulate natural processes to benefit nutrient uptake and crop quality. Likewise, the 4R Nutrient Stewardship approach is practiced as a framework to achieve more efficient application of commercial fertilizers. While a holistic approach is needed, we believe that regenerative agriculture and agroforestry offer the best core solution set for healthy soils and plant growth.

SOIL BACKGROUNDER

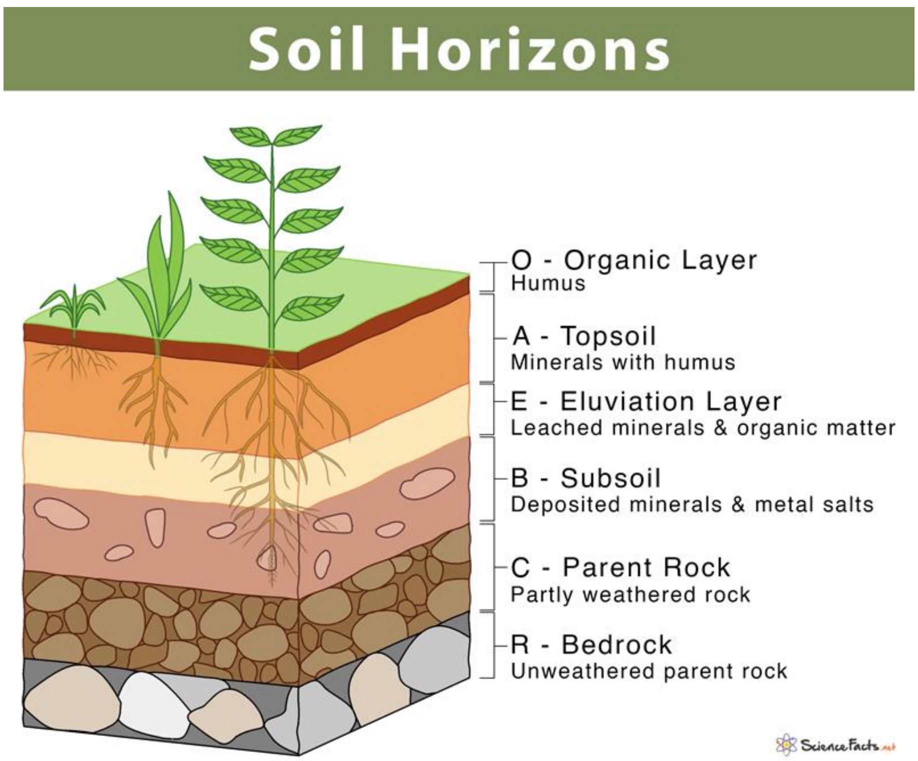
Basics

Soils are created by geological and biological processes that can take thousands of years to materialize…outside of human life spans. They are largely made up of grains of weathered rock and the remains of dead, decayed plants alongside water and air. Although soil composition differs by location and region, an average soil is generally comprised of 45% mineral rock, 20%-30% water, 20%-30% air, and 5% organic matter.

Soils have different layers, or *horizons*.

O: Organic/top layer; usually found in forested locations, including partially decomposed material such as leaves
A: Topsoil
E: Eluviated (concentrated sand and silt particles) soil
B: Subsoil
C: Parent material
R: Bedrock

Figure 1: Soil Horizon Visual



Source: Science Facts

When evaluating soil, stakeholders will many times talk in terms of the soil's *matrix*, which refers to the makeup of the soil profile (composition, particle size, temperature, texture, etc.). Parent material is the underlying geological material from which soil horizons form. The lower boundary of soil is arbitrarily set at 200 centimeters (cm), equivalent to 2,000 millimeters (mm) and roughly 78 inches. Today, average topsoil in the U.S. measures a depth of 6-8 inches, down from 14-18 inches about 100 years ago.

The biological health of soils is extremely important. Soil is a living organism bursting with microbes, fungi, insects, worms, and other invertebrates. All of these entities play important roles in breaking down material, delivering nutrients to plants and maintaining soil fertility (the ability of soil to sustain agricultural plant growth). More than one-quarter of all species on Earth lives in the soil.

In most situations, the following properties contribute to soil fertility:

- Sufficient soil depth for adequate root growth and water retention
- Good internal drainage…allowing sufficient aeration for optimal root growth
- Topsoil or horizon O with sufficient soil organic matter (SOM) for healthy soil structure and moisture retention
- Soil pH in the range of 5.5 to 7.0
- Adequate concentrations of essential plant nutrients in plant-available forms
- Presence of a range of microorganisms that support plant growth

SOM is characterized by plant and animal tissues in various stages of breakdown. Within SOM, *humus* is the portion of organic matter that is fully decomposed, represented by a solid, dark-colored component that plays a significant role in controlling soil acidity, nutrient cycling, and hazardous compound detoxification. When decomposers like microbes, fungi, and worms are lost or removed from soils (mycorrhizal fungi are very vulnerable to soil disturbance), rates of litter decomposition are slowed materially, leading to reduced carbon and nitrogen cycling and negatively impacted soil functionality. Plants aren't able to use nutrients as effectively, as a result.

The presence of microbes is key to healthy soils and thus optimal plant growth. Plants host bacteria in their roots that enable them to uptake atmospheric nitrogen in exchange for carbon, as discussed in the **PLANT GROWTH BACKGROUNDER** section of this report. Microbes fix nitrogen into the ground, making them a critical component of overall soil health. Microbes do not perform well in high heat (they perform best at or below 75°F). Diversity of microbes is also very important, typically as a result of plant diversity itself.

Healthy soil needs to hold various macronutrients and micronutrients. Examples of macronutrients include carbon, oxygen, nitrogen, hydrogen, potassium, and phosphorous. Examples of micronutrients include iron, zinc, manganese, and copper. Optimum availability of nutrients occurs around a pH of 6.5; pH stands for "potential of hydrogen" and refers to the acidity of a substance. A pH value of 7 is neutral, with lower values equating to increased acidity and higher values equating to increased alkalinity.

Soil's capacity to store water and moisture is determined by its texture, structure, organic carbon content, and depth (tilth). Soil erosion is the accelerated removal of topsoil from the land surface via water, wind, or tillage. Soil losses can happen gradually or quickly, however the generation of an inch or more of topsoil can take 1,000 years. Types of soil erosion include:

- Sheet – broad removal of the top thin layer of soil
- Rill – small downslope channels that form from water runoff
- Wind – gust-related removal of soil
- Gully – the washing away of soil through deep grooves or channels across unprotected land

Tilling/plowing has historically been an effective strategy for farmers as they prepare for planting crops, suppressing weeds and incorporating fertilizer deep into the soil where plant roots can access it. This has been a longstanding rational choice to maximize productivity and profitability. However, weather patterns today are changing so rapidly due to climate change that it is nearly impossible for farmers to adapt. Windstorms and rainfall severity/frequency are combining with extensive tilling to lead to steady soil losses and reduced productivity and profitability. Technology is enabling farmers to reduce or eliminate tilling thanks to seed drills that can penetrate through crop residues and plant seeds deep in the soil. The ability to plant cover crops and/or use agroforestry practices can keep roots in the ground year-round and help keep soil anchored down, as well. Where tilling is necessary, GPS-guided tractors can limit soil disruption to narrow strips, using precision planters to place seeds. Still, transition costs and uncertainty remain challenges and concerns for farmers alongside frustrations over increasingly abrupt soil erosion rates.

The Soil Tillage Intensity Rating (STIR) scale is a longstanding measure of overall disturbance to the soil layer, developed by the Natural Resources Conservation Service (NRCS) within the United States Department of Agriculture (USDA). The STIR is calculated for each individual field using the Revised Universal Soil Loss Equation Version 2 (RUSLE2) program, with lower numbers indicating less overall disturbance and higher numbers indicating more overall disturbance. Values range from zero to 200. The overall STIR value reflects the kind of soil disturbance as well as the severity of the disturbance caused by tillage operations. Conventional tillage results in a value greater than 80; no-till operations require a STIR value of 30 or less, while conservation tillage is generally below 80.

Aside from erosion challenges, soils are also becoming contaminated, acidified, and salinized, hurting crop production in the process. Soil becomes acidic, naturally, over long periods of time, however industrial effluents and nitrogenous fertilizers are increasingly powerful external inputs of acidity to soils today. Improper use of wastewater for irrigation – together with encroaching sea levels – can hurt soils, as well, leading to greater levels of trace elements and salinity in soils.

The USDA classifies soil according to regions, or orders. There are 12 soil orders, in addition to Rocky Land, Shifting Sand, and Ice/Glacier orders. The 12 main soil orders are:

1. Alfisols
2. Andisols
3. Aridisols
4. Entisols
5. Gelisols
6. Histosols
7. Inceptisols
8. Mollisols
9. Oxisols
10. Spodosols
11. Ultisols
12. Vertisols

Alfisols have a solid presence in the eastern Midwest United States. Mollisols are generally present in the western Midwest of the United States, as well as across the Plains. Inceptisols are generally present across the northeastern United States, while Spodosols are present in New England. Ultisols have a strong presence in the southeastern United States. Across the world, Inceptisols make up roughly 22% of Earth's land surface, followed by Aridisols (18.5%), Entisols (10.6%), Alfisols (9.8%), and Ultisols (8.1%) as the top five soil orders globally.

Many farmers refer to their soil type in terms of texture and thickness. These attributes are typically categorized into any of the following classifications:

- Sand – light, warm, dry, acidic, low in nutrients, quick water drainage
- Clay – heavy, high in nutrients, slow to drain (retains water/moisture)
- Silt – light, retains moisture, high fertility, risk of erosion
- Peat – high in organic matter, retains moisture
- Chalk – can be light or heavy, highly alkaline
- Loam – mixture of sand/silt/clay, good drainage, easy to work

PLANT GROWTH BACKGROUNDER

Basics

All plants need the same four things to grow: water, air, sunlight, and nutrients.

Plants take up water from the ground through their roots, as well as through their leaves. They also take in carbon dioxide (CO_2) from the air and release oxygen during the day. During photosynthesis, plants use water and CO_2 alongside energy from sunlight to create sugars that foster plant growth via cell growth and division. Nutrients from the soil (nitrogen, phosphorous, etc.) aid in this growth alongside sunlight.

The conversion of sunlight into energy takes place within a green pigment of the leaf, known as chlorophyll. The roots move water and nutrients to the leaves via xylem tissues. CO_2 is collected by specialized cells on the undersides of leaves called stomata. As a plant draws in carbon from the air through the stomata, it loses water to transpiration; thus, at certain temperatures water loss is so great that a plant will shut down photosynthesis in order to avoid water loss. The reaction of light energy and CO_2 within plant leaves creates simple sugars, or carbohydrates, for energy. This reaction involves 6 molecules of water and 6 molecules of carbon dioxide, which combine with solar energy to form a molecule of glucose and 6 molecules of oxygen. The oxygen is then released back into the air as a waste product. Plants use this glucose sugar energy to grow and break down carbohydrates in the presence of oxygen within cells. The buildup of carbon dioxide can be released into the environment at night, with the created energy being used to drive the production of starches, proteins, enzymes, growth regulators, and DNA/RNA structures.

There are 16 essential elements for plant growth, some of which can be taken from the air or water, such as carbon, oxygen, and hydrogen. Others can be taken from the soil, with plants requiring macronutrients like nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur. Micronutrients are also required, but at much lower levels: iron, copper, boron, zinc, manganese, molybdenum, chlorine. Assisting nutrients can also be helpful, such as silicon, cobalt, and nickel.

There may perhaps be no more important area for plant growth than the *rhizosphere*. The rhizosphere is the place where the plant and its roots touch the soil, which is an area around the plant root that is inhabited by a unique population of microorganisms critical for plant growth. The rhizosphere can be broken out into three distinct areas:

1. Endorhizosphere - inside the base of the plant where microbes and cations can occupy the "free space" between cells
2. Rhizoplane - medial zone directly adjacent to the root, including the root epidermis and mucilage
3. Ectorhizosphere - area that extends from the rhizoplane out into the bulk soil

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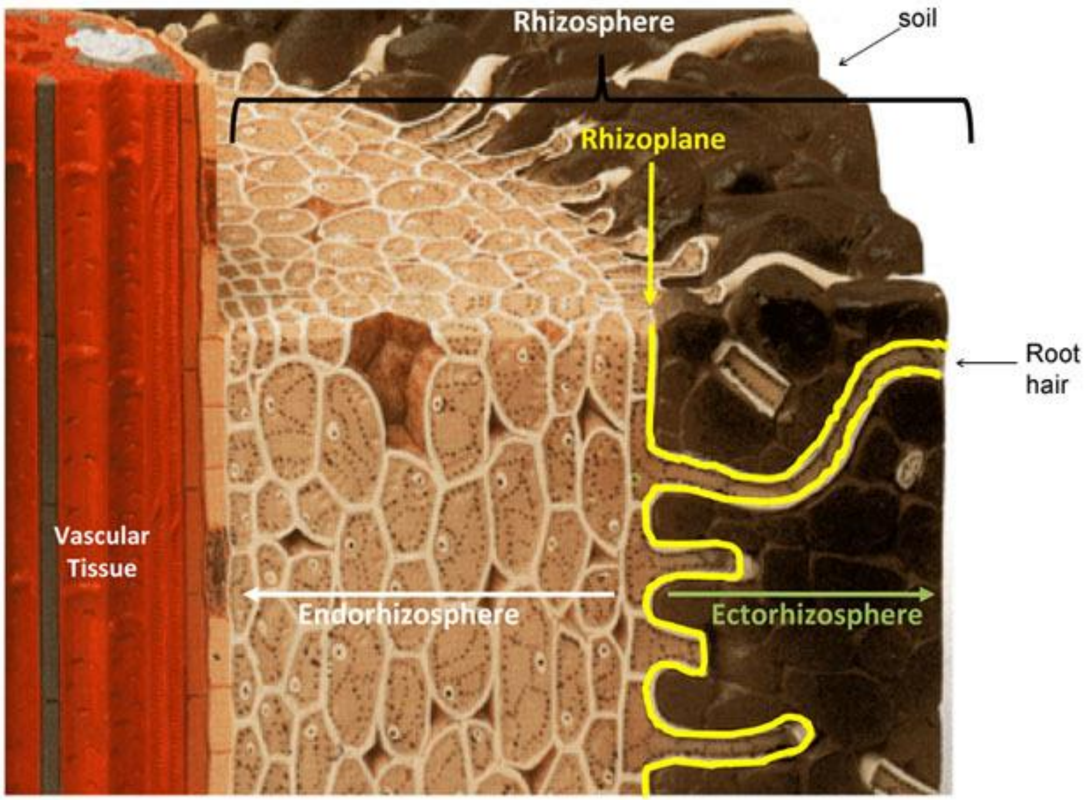
Figure 2: Rhizosphere Visual



Source: Nature

Plant roots can release anywhere from 10%-40% of their total photosynthetically fixed carbon into the soil. The composition and amount of the released compounds is influenced by many factors including plant type, climactic conditions, insect diets, nutrient deficiency or toxicity, and the chemical, physical, and biological properties of the surrounding soil (microorganism presence key among them). The nutrients most limiting to plant growth are nitrogen and phosphorous. Even though 78% of Earth's atmosphere is composed of nitrogen, it is in a form that is only accessible by nitrogen-fixing organisms. One teaspoon of bare soil contains more microorganisms than there are people on Earth…with the rhizosphere having 1,000 to 2,000 times that number.

The plant-microbe relationships in the rhizosphere that get the most attention include 1) Rhizobia bacteria and their symbiotic plant partners, 2) mycorrhizal fungi associations, and 3) beneficial plant growth promoting rhizobacteria (PGPR). First, rhizobium bacteria is able to easily gain entry into the roots of leguminous plants, allowing for the conversion of atmospheric nitrogen into ammonia, a form of nitrogen usable by plants; this helps to fix nitrogen in the soil as well. Secondly, mycorrhizae is a type of fungus that works symbiotically with many different plant types, assisting them in obtaining water, phosphorous and other micronutrients (e.g., zinc and copper) from the soil in return for carbon from the plant. These fungal spores remain in a resting state until they sense nearby roots; this is why perennial trees in place can be an ongoing positive for crop growth. Mycorrhizae can extend into the soil in order to capture nutrients for plants, leading to a tenfold increase in root surface area and a 2-3 fold increase in the uptake of phosphorous (and other nutrients) per unit root length. Thirdly, plant growth promoting rhizobacteria (PGPR) generally work to colonize 15%-40% of plant root surfaces, depending on nutrient availability and physicochemical variations throughout the root surface. Root exudates (secretions) like carbon serve as a food source for microbes which then attach to the root surface and form microcolonies…eventually growing into larger biofilms consisting of multiple layers, which ultimately release compounds that aid in plant growth. Again, perennial trees provide an ongoing positive. The goal is to keep the biology in soil as active as possible over as long a time period, as possible.

A commercial market is increasingly developing for biostimulants, defined as substances/microorganisms that stimulate natural processes to benefit nutrient uptake, crop quality, and protection against plant stress – independent of nutrient content. Likewise, the 4R Nutrient Stewardship approach is practiced as a framework to achieve cropping system goals, such as increased production, increased farmer profitability, enhanced environmental protection, and improved sustainability. The 4R concept advocates for the right fertilizer source…applied at the right rate…at the right time…in the right place.

Figure 3: 4R Nutrient Stewardship

Source: Yara International

While a holistic approach to conventional agriculture ailments is needed, we believe that regenerative agriculture and agroforestry offer the best core solution set for healthy soils and plant growth. Regenerative agriculture practices like agroforestry work proactively to displace harmful existing practices and naturally stimulate microorganism growth in the soil while contributing to more productive plant species.

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