Development of Nutrient Status in Forest Soils[•]

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Abstract --Most of the elements which are considered essential for plant growth come from the soil. The inland northwest region is very young geologically, and therefore rock type strongly influences soil characteristics and forest nutrient status. A number of significant geologic events in the history of the inland northwest result in the predominance of a few common rock types in the area, including basalts, granites, metasedimentary rocks and glacial deposits. Average geochemistry of rocks collected from Intermountain Forest Tree Nutrition Cooperative (IFTNC) research sites show that basalts contain the greatest percent by weight of elements which are considered mineral nutrients, followed by granites and then metasedimentary rocks. Mineralogical analyses of the same rocks show that basalts contain the most weatherable minerals, followed by granites and then metasedimentary rocks. These findings are supported by a geochemical-based weathering potential index calculated for each rock type. Glacial deposits typically reflect a wide variety of characteristics due to the variety of rock types comprising such deposits. Climate, biota, time and topography also interact with geology to influence soil formation in the inland northwest.

Plant Nutrients

Nutrients are those elements which are considered essential for plant growth{Salisbury & Ross 1985 #910}. Three of these elements, carbon (C), hydrogen (H), and oxygen (O), are provided by the air, earth and water, and are not considered limiting factors to plant growth. Six elements, nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), sulfur (S), and magnesium (Mg), are considered macronutrients, which means that plants require these in relatively large quantities (500-14000 ppm) in order to grow and function adequately (Foth and Ellis, 1997). Eight elements are required in trace quantities (usually <100 ppm) for plant growth, and these are known as micronutrients. Table 1 lists the macro and micronutrients, their principal functions in higher plants, and their sources (Marschner, 1995; Foth and Ellis, 1997).

Table 1-- The macronutrients and micronutrients: their function and source All information on nutrient function is from Marschner (1995) and Foth and Ellis (1997) except for that indicated by (1) which is based on IFTNC research. An asterisk indicates that this nutrient is available in fertilizer form.

Symbol	Element	Function	Source
The Macronutrients			
N*	Nitrogen	Biomass production[1] Photosynthesis (proteins)[1]	Organic matter N-cycle
K*	Potassium	Disease resistance[1] Osmotic potential, turgor Enzymatic transfer of glucose to starch Nitrate synthesis Photosynthesis and CO_2 fixation	Soil
P*	Phosphorus	Structural constituent of DNA and RNA Basal metabolism (ATP and energy transfer) Photosynthesis (carbon partitioning)	Soil
S*	Sulfur	Photosynthesis (proteins) Membrane structure	Atmosphere Soil

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		Some defense substances	
Ca*	Calcium	Structural component (cell walls, membranes)	Soil
Mg*	Magnesium	Chlorophyll Protein synthesis Enzymes and enzymatic reactions Carbohydrate partitioning	Soil
The Micronutrients			
Fe*	Iron	Chloroplast development, photorespiration Enzymatic reactions	Soil
Mn*	Manganese	Enzymatic reactions Photosynthetic O_2 evolution	Soil
Cu*	Copper	Nitrogen metabolism (NOTE: High N rates can induce Cu deficiency!) Cell wall lignification Pollen formation and fertilization Carbohydrate and lipid content Enzymatic reactions	Soil
Zn*	Zinc	Metabolic functions Complexes with N, O and S DNA replication Regulation of gene expression (NOTE: High P rates can induce Zn deficiency!)	Soil
Ni	Nickel	N metabolism	Soil
Mo*	Molybdenum	N metabolism N_2-fixation May affect pollen formation/fruit formation Critical level increases with increasing N supply	Soil
B*	Boron	Cell wall biosynthesis and structure Plasma membrane integrity Root elongation, apical dominance Deficient B associated with Eucosma sp. borer[1]	Soil
Cl*	Chlorine	Photosynthetic O_2 evolution Stomatal regulation	Soil Atmosphere

Soil Formation

The nutrient sources listed in Tables 1a and 1b indicate that most elements are supplied by soils. Modern day soils are considered to be the result of five soil-forming factors (Brady and Weil, 1999). These include:

1. Parent material
2. Climate
3. Biota
4. Topography
5. Time

Parent materials are the geologic or organic precursors to soil. Climate affects soil formation in that warmth and moisture are the primary drivers of chemical weathering. Biota refers to microorganisms that decompose organic materials, plants and trees whose root action and exudates affect soil characteristics, and humans and animals who plow, burrow or otherwise contribute to soil mixing. Topography affects soil formation in that slope, elevation and aspect influence moisture infiltration, insolation, erosion, accumulation and other processes which contribute to soil weathering and material transport. Time interacts with the other factors to determine the rate of soil formation. In the intermountain northwest, our soils are very young in a geologic sense, and therefore the parent rock characteristics strongly influence current soil properties.

Geology

Rocks are broadly classified as igneous, sedimentary or metamorphic. Igneous rocks are those which solidified from cooling magma, and are further categorized as 'plutonic' or 'volcanic.' Plutonic rocks form from magma within the earth's crust, where the slow rate of cooling results in the development of large crystals, such as those in granitic rocks. Volcanic rocks form after magma is extruded to the earth's surface, where it cools very rapidly, resulting in fine grain sizes such as those in basaltic rocks. Sedimentary rocks are the result of physical and/or chemical weathering and subsequent transport and accumulation of the weathered materials. Sometimes these sediments are cemented together (lithified) such as in sandstones or claystones, where in other cases the sediments are unconsolidated, such as in glacial and alluvial deposits. Metamorphic rocks are igneous, sedimentary or previously metamorphosed rocks which have been subjected to additional pressure and/or temperature, which causes recrystallization of the rock. Most of the time the original rock (protolith) is not identifiable, however if only slightly metamorphosed the protolith may still be evident. For example, quartzite is a slightly metamorphosed sandstone, while schist is a highly metamorphosed rock which may have started out as either sedimentary or plutonic.

Several events in the geologic history of the northwest resulted in the modern-day assortment of rocks which comprise the intermountain region. The Belt Sedimentary Basin existed between 1500 and 800 million years ago (Alt and Hyndmann, 1995). This sedimentary basin was a large, roughly circular basin which encompassed much of current-day north Idaho, northeastern Washington, and northwestern Montana in the U.S., and portions of southeastern British Columbia and southern Alberta in Canada. The basin was probably a shallow lake environment, and over millennia materials accumulated in layers of sand, silt and clay. Over time the weight of these materials caused the basin to subside into the earth's crust, causing some metamorphosis of the underlying layers of sediment. Sometime between 800 and 90 million years ago, the western portion of the continent sheared off, including part of the western edge of the Belt basin. While no one knows for certain where this piece of continent landed, some speculate that it forms part of modern-day northeastern Russia and eastern Asia. Between 100 and 65 million years ago, large granitic masses lifted the earth's crust along the Idaho-Montana border, resulting in the shearing of large portions of the crust eastward into modern-day Montana, forming the northern Rocky Mountains. One such granitic mass was the Idaho batholith which currently comprises much of central Idaho. The uplifting of earth's crust in the north Idaho region also resulted in the uplift and exposure of the Belt sedimentary rocks at the earth's surface, one of the few places in the world where rocks this ancient are visible today. Between 55 and 17 million years ago, various continental 'islands' known as terranes attached themselves to the west edge of our continent, eventually forming much of our modern-day west coast. Between 17 and 15 million years ago, a serious of immense basalt flows spouted from fissures in northeastern Oregon and southeastern Washington. These Columbia River basalt flows covered much of eastern Washington, northeastern Oregon and central and northern Idaho. Estimates indicate that the basaltic magma would have been moving as fast as 40 miles per hour, filling up valleys and drainages like a bathtub. Hundreds of flows erupted during these two million years, and between flows some accumulation of sedimentary materials probably occurred from surrounding high points on to the flat basaltic surfaces. Between 15 and 2 million years ago, a long dry spell occurred during which stream channels were not able form due to lack of sufficient moisture. The primary form of rock weathering during this time would have been physical weathering, and material transport would have been colluvial (gravity deposit) or eolian (wind deposit) in nature. About 12 million years ago the modern-day Cascade range formed, including many of the modern-day volcanic peaks. Beginning about 2 million years ago, moisture returned and glaciation began. Modern-day stream channels began to form, and continental glaciers periodically advanced and retreated across the northern portions of Washington, Idaho and Montana, leaving many of the mixed glacial deposits we see today. The glaciation era lasted until about 10 thousand years ago. The last major event to shape the geologic character of the modern intermountain region was the eruption of Mt. Mazama about 7 thousand years ago, which resulted in the deposit of vast quantities of volcanic ash across the northwest and also formed Crater Lake.

As a result of these various events, today we see primarily basalt, granite, metasedimentary rocks, and glacial deposits in the intermountain region. A layer of volcanic ash resulting from the Mt. Mazama eruption also covers much of the area. The primary function of volcanic ash is its moisture-holding capacity, which can often results in a vegetation series shift to the next moister series. Most of the cedar and hemlock types in the inland northwest are accompanied by an ash layer.

Geologic analyses

Geologists commonly identify and classify rocks based on their chemical composition and their mineral composition. Whole-rock geochemical analyses provide the percent by weight of major elements including O, silicon (Si), aluminum (Al), titanium (Ti), Fe, Mn, Ca, Mg, K, Na, and P, as well as trace elements including Ni, Cu and Zn. Most rocks are about half O by weight, followed by Si and then other elements. The average geochemistry for a number of rocks sampled from IFTNC research sites across the inland northwest indicates that basalts show the lowest quantity of silicon and the highest quantity of cations, followed by granites, followed by metasedimentary rocks which show the greatest silicon and lowest cation percentages (Figure 1). Within rock types, basalts and granites show low variability in geochemistry, while metasedimentary rocks are highly variable.

Mineralogic analyses are performed by cutting a thin section of rock and mounting it on a microscope slide, and then viewing the slide through a polarizing light microscope. The minerals may be identified by the colors and patterns which result as polarized light passes through the sample. The most common minerals are silicate minerals, which are classified according to the physical arrangement of Si and O within the mineral. A few of the more common minerals and their most common constituents are listed in Table 2, in order of decreasing stability.

Table 2–Common rock-forming minerals and their constituents, listed in order of decreasing stability (Buol, Hole, and McCracken, 1980; Klein and Hurlbut, 1993).

Mineral Name	Common Chemical Constituents
Quartz	Si, O
Potassium feldspar	K, Al, Si, O
Muscovite mica	K, Al, Si, O
Plagioclase feldspar	Na, Ca, Al, Si, O
Biotite mica	K, Mg, Fe, Al, Si, O
Hornblende	Ca, K, Na, Mg, Fe, Al, Si, O
Pyroxene	Ca, Mg, Fe, Al, Si, O
Olivine	Mg, Fe, Si, O
Carbonate	Ca, Mg, Mn, Fe, O

Rock Weathering Rates

In addition to chemical content, rock weatherability is important in determining soil texture and nutrient availability. Rock weatherability is directly tied to the stability and size of the component minerals. Granites are typically composed of large crystals of quartz, potassium feldspar, plagioclase feldspar and muscovite mica, and occasionally biotite or hornblende. These minerals are all high on the stability list, and granites typically weather to a coarse-grained, gravelly soil with low nutrient-holding and moisture-holding capabilities. Metasedimentary rocks typically contain medium to small grains of quartz, feldspars and muscovite. Since the mineral grains comprising metasedimentary rocks have already gone through at least one sedimentary weathering and transport episode, they are particularly stable residual minerals. Metasedimentary rocks can form anything from a thin clayey to a deep sandy soil, and typically show poor nutrient status because of the residual, stable nature of the component minerals. Basalts typically contains very fine grains of plagioclase feldspar, pyroxene, and occasionally olivine. These tend to be less stable minerals and since they are small in size, their greater surface area allows for more rapid mineral decomposition. Basaltic soils are often loamy with good nutrient status and high moisture-holding capacity.

Rock weatherability can be quantified based on chemistry by using a 'weathering potential index,' which is the ratio of Si, O, Al and cations to Si, O and Al measured during geochemical analyses. The same data set which was used to produce the geochemical averages shown in Figure 1 was also used to produce weathering potential indices for the same groups of rocks, and the results are shown in Figure 2. Basalts clearly show the greatest weathering potential in our region, followed by granites and then by metasedimentary rocks, as expected based on their component mineralogy.

Summary

The source for most plant macro- and micro- nutrients is the soil. Since the inland northwest is so young geologically, rock type strongly influences soil characteristics including texture, nutrient status and moisture-holding capacity. The most common rock types in this region are granites, basalts, metasedimentary rocks and glacial deposits. A layer of volcanic ash is present on many forested sites in the region, and primarily functions to improve moisture-holding capacity, but not fertility. Rocks may be analyzed for both chemical content and mineral composition. Basalts are typically lower in Si and higher in mineral nutrients than other rock types, and also comprised of small-sized, easily weatherable minerals. Granites show higher Si and lower mineral nutrient content, and are comprised of large crystals of stable minerals. Metasedimentary rocks typically show the highest Si and lowest mineral nutrient contents, and are comprised of stable, residual minerals. Average weathering potential indices of these rock types shows that basalts are the most weatherable, followed by granites and then metasedimentary rocks. Glacial deposits have not been included in the geochemical and mineralogical analyses because they are composed of a mix of rocks from many different sources. Glacial soils show a wide variety of characteristics due to the eclectic nature of the parent material. While not discussed in depth, climate, biota and topography also interact with geology and time to affect soil formation in the inland northwest.

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