



## Soils of the Arid and Semi-Arid Western United States

By Howard Wilshire and Jane Nielson

Soil is a lightly-regarded and widely abused substance. A complexly modified mix of mineral and organic rubble, soil is the foundation of life and no less critical to our well-being than clean air and water. As we explain below, soil is not a renewable resource in terms of human life expectancy, but humans are using it up or wearing it down at rates far exceeding its rate of formation. We need to better understand its makeup, origins, and resilience in the face of such widespread mistreatment.

### **Building Soils**

An intricate series of natural geological and biological processes build natural soils in a series of discontinuous steps, which scientists still cannot define with any confidence. In general, rainwater interacts with carbon dioxide (CO<sub>2</sub>) to release minerals from rock debris. Chemical weathering releases inorganic nutrients from the minerals that composed the rocks and converts what remains into clay minerals, plus residual, chemically resistant materials. Dead and decomposing plant and animal remains add critical organic carbon, and abundant bacteria, fungi, algae, and other microscopic organisms from decaying living things process the minerals into the nutrients that plants need to grow and thrive.

The mixture is continuously modified by air, rainwater, and chemical and biological processes that form new minerals, dissolve and redeposit chemicals, move small clay mineral grains to deeper levels, and eventually create a layered soil structure (profile).<sup>1</sup>

### **Soil and Ecosystems**

All living things must absorb nutrients to grow and thrive, and soils are nature's pre-eminent organ for conveying natural nutrients—nature's plant food—to the plants that higher animals eat. Healthy soils are the most vital long-term life support for ecosystems, natural communities of interdependent plants and animals. A natural soil's layered structure is capped with protective and stabilizing biotic and inorganic surface crusts. Upper soil layers develop openings that hold water and air, absorb raindrops, retard

erosion-causing runoff, and enhance water seepage to natural groundwater-storage aquifers. Soil organisms, including plant and tree roots, remove natural waste substances, purifying the seeping water.

Fertile, healthy soil is itself an ecosystem, with a rich and changing cast of living things (biota), including microscopic bacteria, insects, earthworms and nematodes, fungi – and microscopic plants such as algae in its upper layer.<sup>2</sup> The biota decompose plant litter and maintain soil moisture, release soil-enriching or poisonous wastes, maintain open soil textures that roots can penetrate, and much more. In undisturbed soils, the actions of earthworms, insects, bacteria, and fungi constantly process and exchange nutrients.

Particularly important to a soil ecosystem are the bacteria, protozoans, microfungi, and algae, which variously fix mineral nutrients in their cells or release them. Some bacteria add oxygen to relatively insoluble natural chemicals, creating soluble forms – such as nitrates – that plants can absorb easily. Other bacteria variously release: hormones that enhance root growth; vitamins, proteins, and sugars that feed plants; and antibiotics that protect them. The soil biota prey upon each other, balancing beneficial and harmful types. This balance preserves the fertility of undisturbed natural soils and the health of the plants growing in them.

Climatic conditions, the type of parent material, and the shape of the land (topography) determine a soil's characteristics.<sup>3</sup> Compared to temperate climate soils (developed between the tropics and the Arctic or Antarctic circles), tropical soils are generally nutrient poor because rainwater constantly flushes through them, dissolving nutrients and carrying them away. Temperate soils are exposed to less rain, so are more nutrient rich and more resistant to degradation and erosion. But most soils probably formed and became modified under varying climatic conditions, over long periods of time.

### **Rates of Soil Creation**

America's rich agricultural soils probably developed over many hundreds to thousands of years. Many western U.S. desert soils probably are relics because they developed under past climate regimes.<sup>4</sup> Some widespread southwestern soils formed tens of thousands of years ago when the climate was wetter than today, for example. Where soil is completely stripped to expose hard bedrock, a series of processes must break up enough rock and weather it deeply before biological processes can convert the debris into soil, especially on slopes. These processes probably require many millennia.

Over the last few thousand years, soils formed more slowly as climates became dryer. The dryer soils have lower moisture contents and so support less plant growth, which in turn reduces the soil's content of organic material. Lower moisture and organic contents also reduce the biological activity within a soil.

Measuring the rates of soil formation is both difficult and complex. Before many studies could be completed, the U.S. Department of Agriculture's Soil Conservation Service (now named the Natural Resources Conservation Service) attempted to specify Soil

Loss Tolerances – values specifying the rate of farmland soil losses that would not harm long-term soil productivity. After many years of study, researchers have found out that these “T values” allow soil to be lost at a much faster rate than it is likely to be renewed.

Broadly, the climate, topography, and nature of the starting rock material govern soil formation rates, but all these factors can vary enormously on relatively small scales. For example, north- and south-facing hillsides can have significantly different microclimates. Measured formation rates generally are applied to large areas, and so represent averages. Such broad estimates for the world’s agricultural soils range from roughly 2 to 3 inches of new soil per 1000 years.<sup>5</sup>

### **Rates of Soil Loss**

We know more about rates of agricultural soil formation than we do about non-agricultural arid lands soils. Estimates of agricultural land soil loss under modern farming methods average 24 inches per 1000 years, which exceed long-term geologic rates of erosion by 10 to 100 times and long-term agricultural soil formation rates by 6 to 8 times.<sup>5</sup> If we wish to preserve existing soils, there should be zero tolerance for practices that contribute to losing soils that formed under previous climates.

Erosion rates commonly are measured by establishing traps that collect a volume of soil derived from a small area of contained erosion. The volume of sediment trapped in a specific time period is then converted to a figure expressed as loss per unit area based on the trap size. The measurements are then extrapolated over larger areas. This approach is problematic because actual rates of erosion are likely to vary widely across the extrapolation area. The measured rates also ignore the potential for infrequent severe storms that suddenly increase erosion rates – an example is the 1977 San Joaquin Valley, California, windstorm that eroded as much as one inch per hour over a period of 24 hours. Equally severe soil losses occurred in another 1977 windstorm in New Mexico.<sup>6</sup>

Most human activities in western U.S. deserts, including road-building, agriculture, grazing, forest conversion, mining, military training, weapons testing, urbanization, and recreation, particularly motorized recreation, accelerate erosion rates. All these activities, render impossible even rough estimates of the annual soil losses from our arid lands. But the rate must be astronomical. Local erosion measurements of sensitive soils in off-road vehicle areas indicate losses 10 to 20 times the rate on undisturbed lands nearby.

### **Restoration vs Recovery**

From the disparity between soil formation and loss rates, it is evident that restoring damaged soils will require leaving them undisturbed for very long periods of time. Recovery in the sense of ameliorating soil compaction, and of restoring enough plant cover to slow erosion while developing soil biota and nutrient exchanges, can occur in about a century by natural processes. But the recovery of native plant diversity and abundance, developing soil layering and stabilizing soil crusts, if even possible, would require millenia.<sup>7</sup>

The continuing and accelerating losses of fertile soils and clean water are the greatest long-term threats to our life support. Human activities that destroy more and more soils will only add to the depletion of other resources to make us more and more vulnerable to future climatic variations and societal upheavals. The words of soil scientists Jacks and Whyte are worth bearing in mind: "Below that thin layer comprising the delicate organism known as soil is a planet as lifeless as the moon."<sup>8</sup>

### Notes and References

<sup>1</sup>Mature soils in western arid lands commonly have profiles consisting of a thin surficial layer (A horizon) of windblown silt, overlying a red oxidized layer (B horizon) of clayey sand and gravel, and a basal layer (C horizon) rich in calcium carbonate.

<sup>2</sup>High-quality temperate zone soil contains an average of more than a ton each of earthworms and arthropods, more than 300 pounds each of protozoa and algae, nearly two tons of bacteria, and three tons of fungi in each 2.5 acres.

<sup>3</sup>Daniel Hillel. *Out of the Earth, Civilization and the Life of the Soil* (Berkeley: University of California Press, 1991).

<sup>4</sup>Howard Wilshire et al. *Geologic Processes at the Land Surface*. U.S. Geological Survey Bulletin 2149, 1996.

<sup>5</sup>D. R. Montgomery, *Dirt: The Erosion of Civilization* (Berkeley, California: University of California Press, 2007).

<sup>6</sup>T. L. Péwé, ed. 1981. *Desert Dust: Origin, Characteristics, and Effect on Man*. *Geological Society of America Special Paper* 186.

<sup>7</sup>R. H. Webb, et al. 2003. *Perennial Vegetation Data From Permanent Plots on the Nevada Test Site, Nye County, Nevada*. U.S. Geological Survey Open-File Report 03-336.

<sup>8</sup>G. V. Jacks and R. O. Whyte. *Vanishing Lands, a World Survey of Soil Erosion* (New York: Arno Press, 1939).

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