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Soil Surface Management of Annual Rangelands

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Introduction

Soil surface conditions influence the water cycle, energy flow, nutrient cycling, and succession. Soil surface conditions have direct and indirect effects on water infiltration, soil organic matter, soil aeration, soil compaction, runoff, and evaporation. The microenvironment at the soil surface influences seed germination and seedling establishment, thus influencing plant species composition and plant succession. Residual dry matter (RDM) standards to improve soil surface management have been recommended (Clawson et al., 1982).

Mineral cycling is greatly influenced by the water cycle. In an effective water cycle plants make maximum use of rainfall. Little evaporates directly off of the soil. Any runoff causes no erosion and remains clear. A good air to water balance exists in the soil allowing plant roots to absorb water readily. In a noneffective water cycle plants get minimal opportunity to use the full amount of precipitation received. Much is lost to surface evaporation or runoff and what soaks in is often not readily available to plants because the pore space has been compacted.

A good mineral cycle implies a biologically active “living” soil with good aeration and energy to sustain an abundance of organisms which are in continuous contact with nitrogen, oxygen, and carbon from the atmosphere. Because the organisms require energy derived from sunlight but do not come to the surface to obtain it first hand, they will rely on a continuous supply of decomposing plant and animal residues. A good mineral cycle cannot function in a dead soil.

Plant roots are the main agents for lifting mineral nutrients to the surface layers of soil or taking them aboveground. For a good mineral cycle we need deep healthy root systems. We need a diversity of plants with different rooting habits, some with roots concentrated near the surface and others with deep root systems that seek water and nutrients from below the soil in rock crevices.

Small animals play a role in mineral uplift also. Earthworms, termites, dung beetles, ground squirrels, and gophers all contribute to the cycling of deep nutrients to the surface.

Plant material containing nutrients must be returned to the soil, thus the importance of adequate litter or residue. Animal impact (trampling and manure), fire, and physical weathering by rain and wind are the main modes of returning plant bound minerals to the soil. Inadequate plant residue on the soil surface reduces the flow of minerals back to the surface layers of the soil.

Soil Compaction

Researchers and managers have observed that livestock-free areas at Sierra Foothill Research and Extension Center, Hopland Research and Extension Center, San Joaquin Experimental Range, and Hastings Natural History

Reservation have surface soils that are more friable and more resilient underfoot. Several studies have compared bulk density of rangeland soils that are grazed with those that have been protected from grazing. Bulk density is the weight of a volume of soil usually reported in metric units of grams per cubic centimeter of soil. If the pore (air) space decreases then bulk density increases.

Liacos (1962*a* and 1962*b*) found that the bulk density of the surface horizon on ungrazed Los Osos clay loam soils in the hills east of Berkeley averaged 1.4 mg/cc, while soils grazed heavily for 35 years were more dense with an average bulk density of 1.6 g/cc. Sites that were lightly or moderately grazed were intermediate. The heavily grazed, lightly grazed, and ungrazed sites had September RDM levels of 600, 1250, and 3400 lb/a, respectively. Root penetration on the protected sites exceeded 0.9 m, and root development was extensive. Earthworm activity was markedly lower on heavily grazed sites.

Liacos (1962*a*) found low soil moisture storage with heavy cattle grazing due to low rates of infiltration and percolation. Soil moisture in the lower half of the profile only increased by about 3 percent during the rainy season, and roots were so sparse that only 6 percent depletion occurred during the growing season. Deep cracks in the surface soil allowed the 24-40 cm layer to be wetted during the first big autumn storm, but sealing the cracks after that event retarded further infiltration. Both the low infiltration and percolation rates and the almost insignificant withdrawal of soil moisture from the lower layer by shallow-rooted plants reduce water storage in compacted soils on heavily grazed sites, and therefore runoff is enhanced. Ungrazed plots had high infiltration and percolation rates and heavy use of stored moisture from throughout the profile by deeply rooted annual and perennial grasses, so little runoff occurred.

Assaeed (1982) observed higher bulk densities due to grazing only on swale sites (Visalia sandy loams) in the surface 0-5 cm layer at the San Joaquin Experimental Range (SJER). Swales ungrazed by cattle for 10 years had densities of 1.22 mg/cc, while those continuously grazed had densities of 1.38 g/cc. There was no difference in bulk density on grazed and ungrazed slopes (Ahwahnee sandy loam). No grazing effect was found for the 5-10 cm layer on either site, but bulk density was higher at this depth.

Ratliff and Westfall (1971) found that bulk density was 24 percent lower on an ungrazed Ahwahnee soil series than on a grazed site at SJER. They noted that gophers were also most active near the surface when the soil was most compacted in late winter and spring, and that cattle trampling recompacted gopher mounds, and cattle hooves broke into surface burrows, reversing the loosening effect of gophers.

Heady (1966) found that late summer removal of dry plant residue reduced herbage production as well as increased bulk density of fine sand loam soil with clayey subsoils (Sutherlin series) on ungrazed sites at Hopland Research and Extension Center. Bulk density following eight years of treatment ranged from 1.14 g/cc on untreated plots to 1.36 g/cc where residue was removed each year; corresponding average (1954-1960) peak herbage biomass standing crop was 116 and 256 g/m^2. Lower organic matter and lower pH in the surface horizon correlated with higher bulk densities. Heady also observed a decline in the loose, crumb structure and aeration. Greater exposure of bare soil to raindrop impact in autumn and early winter prior to full herbage canopy coverage and reduced root growth due to drier soil conditions caused by higher runoff and lower infiltration were probably the primary causes of soil compaction.

Bulk density is lower under blue oak canopies (1.07 g/cc) than in natural openings (Kay and Leonard, 1979) on well drained, reddish brown, loam surface soils with varying degrees and depths to a clayey subsoil (Auburn, Las Posas, and Sobrante series complex) following 14 years of protection from cattle and deer grazing at the Sierra Foothill Research and Extension Center. Soil bulk densities on adjacent sites where oaks were removed 14 years previously became as compacted as those in natural openings. These results indicate that the oak canopy and oak litter may provide protection from raindrop impact

and provide for increased soil organic matter and more porous soil structure.
Compacted soils reduce the effective depth of water storage and concentrate roots near the surface. Heavy grazing reduces shoot biomass and therefore root biomass and rooting depth. The result is a smaller effective pool of water and nutrient use efficiency and depressed grassland productivity (Liacos, 1962*a*).

Soil Organic Matter

It is well known that the periodic addition of organic matter is advantageous, if not absolutely necessary, in order to keep soil in the highest state of productivity. The soil organic matter consists largely of plant roots and other residues in various stages of decomposition. When a plant dies or when plant material is mixed with the soil, decomposition sets in rapidly if moisture and temperature conditions are favorable. The material soon loses its original identity and structure, leaving a dark-colored, structureless residue called humus. High moisture and high temperature are particularly favorable for the activity of microorganisms of the soil and hence favor a rapid rate of decay (Miller et al., 1989). On annual range these conditions normally occur in the spring prior to depletion of soil moisture, but early autumn rainfall can also speed up decomposition. During winter decomposition is slowed by cold temperatures. During the summer high soil surface temperatures and dry soils preclude most biological activity, thus decomposition is probably nil.

Organic matter benefits soil physical condition by making it more friable, improving its tilth and structure, and facilitating water infiltration. As the organic matter decreases, the soil becomes less friable and more inclined to puddle and form surface sealing crusts, reducing the rate of water infiltration. Low nitrogen, high fiber plant residues, such as dry forage residue, are more resistant to microbial decay and persist longer in the soil than more succulent material. It seems likely that such residual materials provide physical channels that improve the movement of air and water into the soil. High nitrogen containing material, such as clover and vetch roots, are less resistant to decay and decompose more rapidly.

Plant Succession

On annual rangelands plant species composition is heavily influenced by soil surface conditions. Most seeds germinate on the soil surface or at depths to 1 cm (0.4 in.) below it. Dormant filaree seeds (Rice 1985) and small seeded legumes (Williams and Elliott, 1960) require heat treatment to break dormancy. Moderation of summertime diurnal temperature variation and reduction of maximum temperature at the soil surface by litter cover significantly reduces the softening rate of filaree seed in the soil, and thus reduces germination (Rice, 1985).

There is a tendency for dominance by forbs, including many range weeds and wildflowers, when little or no residue is present on the soil surface in the form of standing and surface litter. When mulch is allowed to accumulate species composition tends toward the taller annual grasses, such as soft chess brome and wild oats. Apparently, mulch alters botanical composition through influence on physical conditions at the soil surface and on the bulk density of the surface soil horizon. Mulch has little influence on pH and phosphorus and nitrogen content in the grassland system (Heady, 1966).

Managing the Soil Surface

Soil porosity influences soil aeration and water holding capacity. Under heavy grazing conditions bulk density decreases because of trampling, reduced residue leading to lower soil organic matter, reduced root and shoot production leading to lower organic matter, and shallower rooting depths. Raindrops on bare soil tend to seal the soil surface and reduce water infiltration and increase runoff. Cracked soil surfaces tend to seal over following the first big autumn storm.

Managing residual dry matter is the rancher’s main means of influencing soil surface conditions and ultimately soil permeability, water holding capacity, and plant productivity.

However, this approach to range improvement can only be a long-term process with little apparent change from year to year.

If pasture plants are vigorous above and below ground, productivity will increase, thus providing more forage for animal production. More surface residue and increased root productivity and rooting depth will result. Gradually deepening rooting systems should increase soil organic matter and porosity at greater depths. Over time the volume of soil contributing nutrients to forage will increase.

Increasing the vigor of grazed range plants can be accomplished by maintaining light to moderate grazing. At heavy grazing intensities intensive grazing management systems that use pasture subdivision and rotation to provide periods of rest between grazing may be appropriate.

Pasture rotation allows grazed plants a period of rest following grazing. The length of this rest period depends on the intensity of grazing. Heavily grazed plants will regrow slowly, requiring longer rests than lightly grazed plants.

Monitoring Soil Surface Conditions

Savory (1988) has listed several indicators of poor and good water cycles (Tables 1 and 2) and mineral cycles (Tables 3 and 4) that can be assessed and monitored. Residual dry matter can be monitored following the guidelines of Clawson et al. (1982). Soil surface conditions can be assessed at points along a transect as can cover and species composition (Love and Evans, 1957). Photo points can be used to monitor vegetation on a large scale and portray this information to audiences of different backgrounds.

Table 1. Indicators of a Poor Water Cycle

1. Soil surface exposed, sealed, or capped.
2. Soil below surface compacted and aeration poor.
3. Water runoff high.
4. Excessive evaporation from exposed soil surface.
5. Vegetative productivity low and declining.
6. Low soil organic matter content.
7. Declining underground water supplies.
8. Droughts and floods tend to be more severe.

Table 2. Indicators of a Good Water Cycle

1. Soil surface permeable.
2. Soil under surface permeable and not compacted.
3. Soil well aerated.
4. High soil organic matter content.
5. Low water runoff.
6. Underground water supplies replenished.
7. Vegetative production high with potential for increase.
8. Soil surface is covered.
9. Droughts and floods less severe.

Table 3. Indicators of a Poor Mineral Cycle.

1. Low residue volume and slow decomposition rates.
2. High soil losses to erosion
3. Shallow root systems.
4. Manure lying on surface, slow decomposition.
5. Low soil organism populations and activity.
6. Soil compacted excessively.
7. Low soil organic matter.

Table 4. Indicators of a Good Mineral Cycle

1. High soil residue volume and rapid decomposition.
2. Minimal soil erosion.
3. Deep root systems tapping deep minerals.
4. Rapid decomposition of manure.
5. Healthy root systems on grazed plants.
6. Porous soil, rich in organic matter.
7. Good soil organism activity

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