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Forages

CONSERVATION OF SOIL RESOURCES ON LANDS USED FOR GRAZING

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Erosion is a process that involves detachment of soil particles and their removal from the site by either water or wind energy. This process is a function of several integrated factors (Fig. 1). Loss of soil due to erosion poses one of the greatest threats to the continued productivity of agricultural lands in the world today. This document discusses several factors that influence soil erosion with a special emphasis on the effects of grazing livestock. Techniques designed to reduce soil erosion are also considered.

The Hydrologic Cycle in Brief

The sun provides the energy necessary to evaporate water contained in both fresh- and salt-water reservoirs on the earth's surface. Solar energy is also responsible for moisture loss from plants through a process known as transpiration. As water vapor rises into the atmosphere, it is cooled, condenses, and is re-deposited to the earth as precipitation in a liquid phase (rain) or solid phase (snow, hail, or sleet). This closed system of recycling water is referred to as the

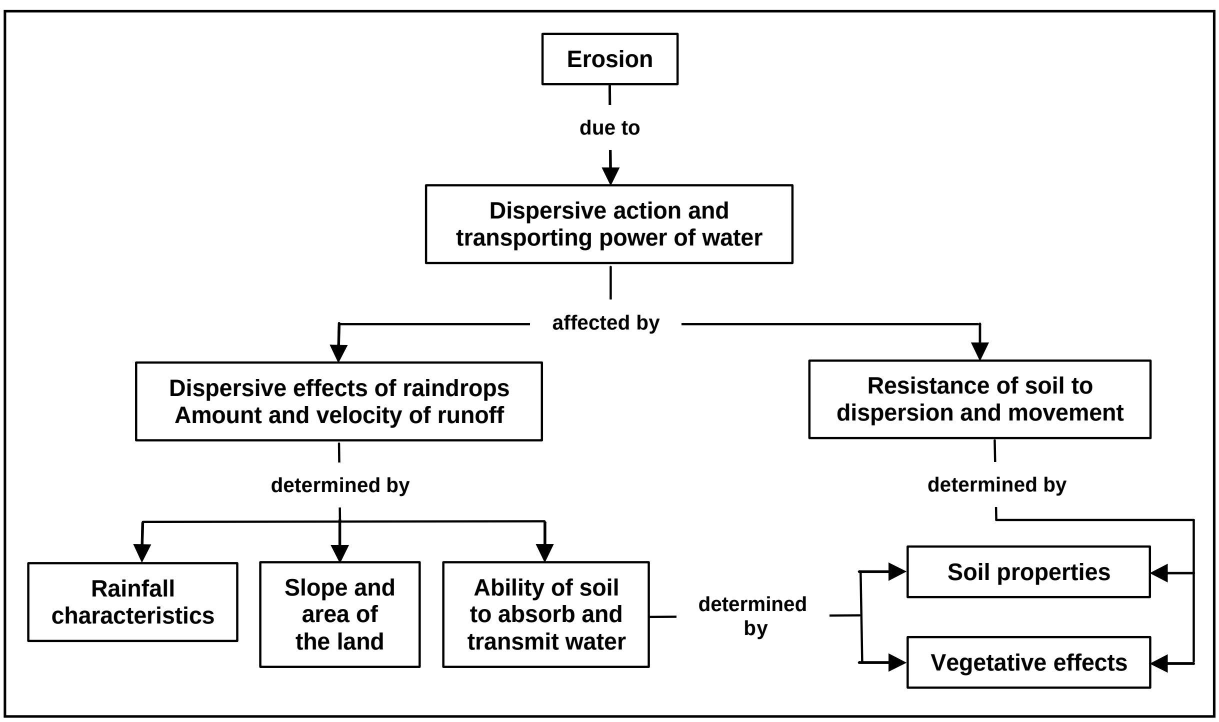

Figure 1. Factors affecting soil erosion by water (Baver 1965 as used by Branson et. al. 1981).

hydrologic cycle (Fig. 2). The hydrologic cycle plays a key role in soil loss due to water erosion.

Soil erosion by water is largely dictated by mean annual precipitation. Areas receiving <350mm annually are usually not subject to erosion by water, while areas receiving >1000mm have high levels of ground cover that significantly reduce soil erosion potential (Thurow, 1991). Regions receiving precipitation levels between these two extremes have the highest potential for soil erosion due to water. In the United States alone, 5 billion metric tons (Mg) of soil are lost to erosion annually, most of which (67%) is due to water erosion (Brady 1990). Precipitation plays an integral role in water erosion and is responsible for both detachment of soil particles due to raindrop impact and the transport of the particles from off the site. Erosion in excess of normal rates (0.2 - 0.5 Mg ha^{-1}) is referred to as accelerated erosion (Brady, 1990).

Erosion

Water Erosion

Accelerated erosion begins with raindrop impact (Fig. 3), and the effects are much ameliorated by ground cover. A raindrop impacting bare ground dislodges soil particles, destroys soil structure, and the splash can cause an appreciable transportation of the soil (Brady, 1990; Branson et al., 1981). Soil particles dislodged by raindrop impact can then be held in suspension and transported off site via overland flow (runoff). Dislodged particles also seal the soil surface by plugging micropores.

This sealing action reduces infiltration rates and increases runoff. Raindrops impacting ground cover, however, are intercepted by the plant canopy, which absorbs impact energy and protects the integrity of the soil surface. Energy of runoff is likewise diminished by ground cover, thus reducing erosion (Fig. 3). Precipitation intercepted by ground cover canopy is also subject to evaporation. This can be positive or negative depending on the moisture balance of the soil profile.

After a raindrop makes impact, it is subject to three fates: it can infiltrate the soil, evaporate, or become a part of runoff (Holechek et. al., 1998). Infiltration (movement into the soil) is primarily determined by soil texture. Fine-textured soils, such as clays generally have low infiltration rates, and slow percolation (movement through the soil) rates. Coarse-textured soils, such as sands, usually have high infiltration and percolation rates. Runoff occurs when precipitation rates exceed infiltration rates of the soil. Soil loss (erosion) then occurs due to detachment and transport of soil particles from the site. Loss of soil particles can be somewhat uniform in nature (*sheet* or *interrill* erosion).

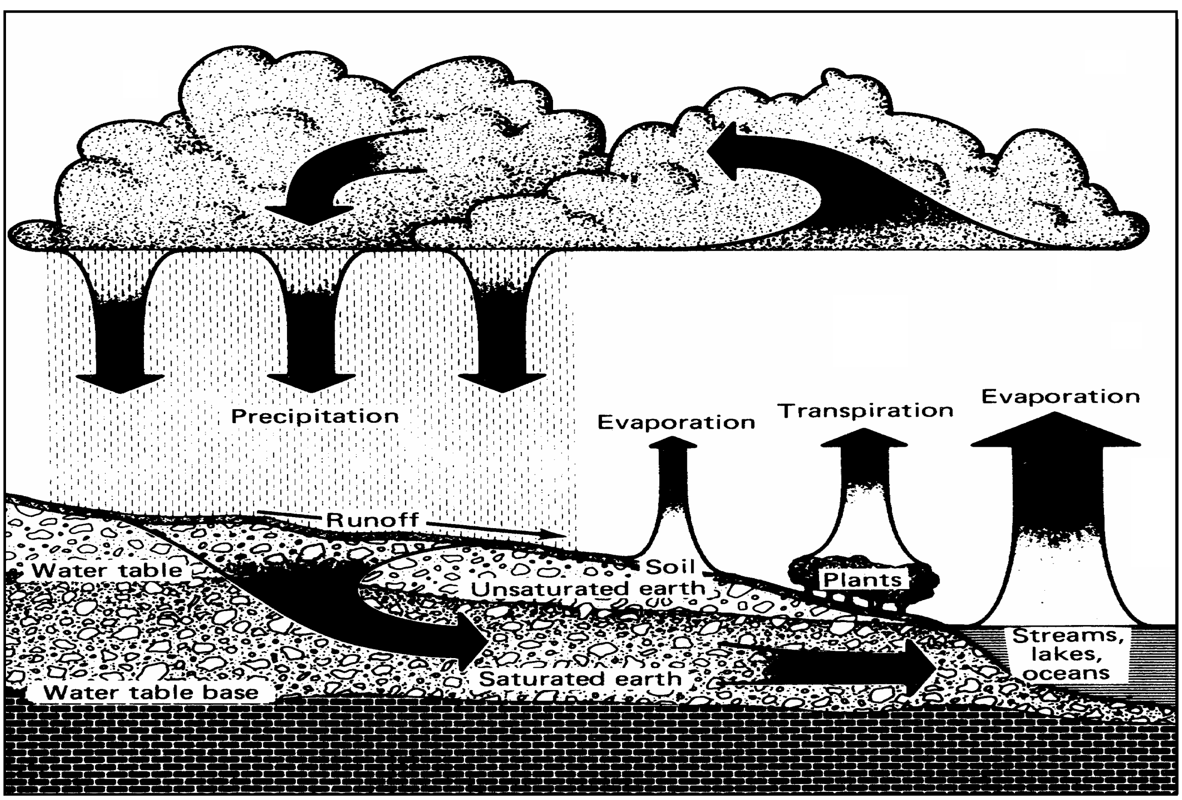

Figure 2. The hydrologic cycle. (From CAST 1982 as used by Holechek et. al., 1998).

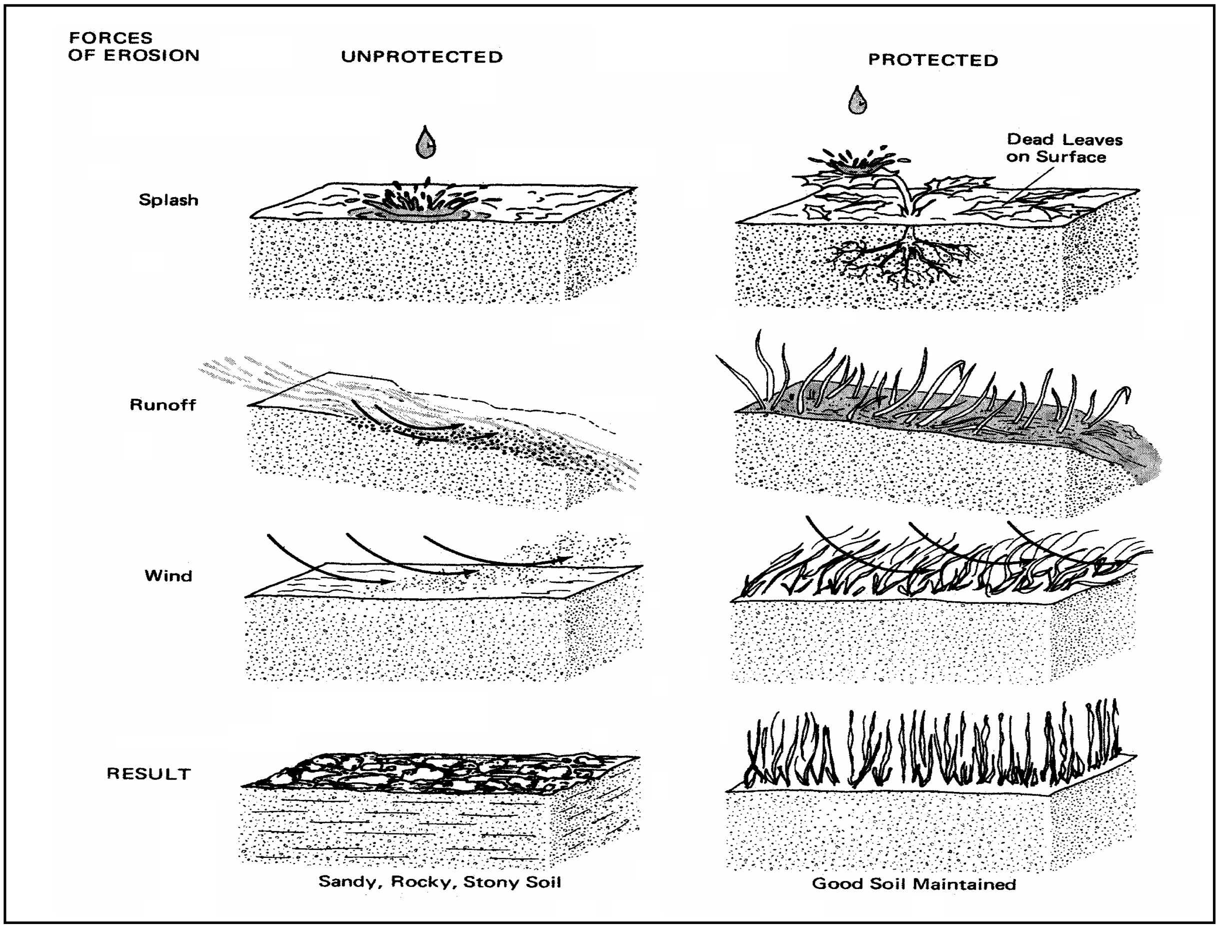

Figure 3. Vegetation effects on reducing soil erosion. (From Nebel 1981 as used by Holechek et. al., 1998).

Extreme interrill erosion is apparent when soil pedestals are created by erosion around an area covered by material resistant to raindrop impact, such as rock. The fact the surrounded soil is eroded without undercutting the soil under the resistant material illustrates the highly erosive nature of raindrop impact (Thurow, 1991). Further erosion results in creation of small, distinct flow paths that can be corrected with tillage (*rill* erosion). Erosion that continues unabated becomes severe enough tillage cannot repair damage to the site and vehicles cannot traverse the deepened channel (*gully* erosion). Streambank erosion is defined as soil displaced from banks of rivers or streams. Besides loss of essential topsoil, erosion also causes valuable soil nutrients such as N, P, and K to be lost from the site.

Universal Soil Loss Equation

Overland water flow energy, or the ability to detach and move soil particles, is a function of several integrated factors. These factors are included in what is referred to as the Universal Soil-Loss Equation (USLE), $A = RKLSCP$, where:

A = the predicted soil loss
R = climatic erosivity (rainfall amount and runoff)
K = soil erodibility
L = slope length
S = slope gradient
C = groundcover and management
P = erosion control practices

Although the USLE was not designed for rangelands, but for clean-tilled cropping systems, a brief discussion of the components of the equation illustrate the several factors, and their interaction, involved in accelerated soil erosion by water. For more detailed information, readers are encouraged to see Brady (1990), from which the following information regarding the USLE is adapted.

Rainfall and Runoff Factor

The rainfall and runoff factor, R, is a measure of the erosive force of rainfall and runoff. The kinetic energy of a storm is determined using the intensity and total amount of precipitation plus the average precipitation received during the 30-minute period of greatest intensity. A sum of all storms at a location for the year provides an annual index and an average of several years indices is used in the USLE. In the United States, values range from <20 in the intermountain west to >550 along the Gulf Coast.

Soil Erodibility Factor

The soil erodibility factor, *K*, is a measure of the inherent erodibility of soil and is based on soil loss from a 22m-long plot that is maintained in a continuous fallow state. Slope of the plot is 9% and infiltration rate and structural stability are the two most significant soil characteristics affecting erosion. Values range from near 0 for sandy soils to near 0.7 for tighter soils with lower infiltration rates.

Topographic Factor

The topographic factor, *LS*, demonstrates the effect of length of slope and the steepness of the slope and is a ratio of soil loss from an unknown field to that of the loss from the standard plot with a 9% slope and continuously fallowed. Values for *LS* range from 0.16 for a 2% slope only 15m long to 3.13 for 12% slopes 90m in length.

Cover and Management Factor

The cover and management factor, *C*, illustrate how the cropping practices and management variable can effect soil loss and is the factor over which the producer has the most control. Values for *C* range from <0.10 for fields that are in permanent grass or legume cover to approximately 1.0 for fields that have little or no cover.

Support Practice Factor

The support practice factor, *P*, indicates the benefits of farming on a contour, strip cropping, terraces, and other practices that help minimize soil loss. Values are a ratio of soil loss from a field with a given support practice versus a field that has been farmed up and down the slope of a field. Support practice factor values range from 1.0 for a field where no support practices are used to <0.30 where support practices have been implemented.

The benefits of management practices in conserving soil resources are evident when the factors included in the USLE are examined. Management decisions that include use of permanent ground cover or support practices in those instances where annual crops are part of the production system heavily effect the quantity of soil lost from a site. Likewise, if possible, fields with extreme slope should be avoided when using annual crops.

USDA-ARS scientists initiated a more recent development, the Water Erosion Prediction Project (WEPP), in 1984. WEPP is a system of computer programs designed to be employed by the same personnel currently using USLE. It will help users select the best erosion control practices, aid in choosing optimum locations for future project sites, and evaluate erosion and sedimentation over specified areas, including rangelands. For additional information on WEPP, including the tutorial describing the project and to obtain software necessary to use WEPP, readers are encouraged to visit the USDA-ARS website at http://soils.ecn.purdue.edu/~wepphtml/wepp/wepptut/jhtml/wepp.html.

Wind Erosion

Many areas of the world are affected by wind erosion; in fact, in many locales wind erosion is the predominant cause of soil loss. Most affected by wind erosion are areas that are characterized as arid or semi-arid; wet soils are not subject to wind erosion. As with water erosion, wind erosion involves detachment of soil particles and transport of the soil particles off site. The first and most important aspect of wind erosion is *saltation*. Saltation is the movement of soil particles with a diameter of 0.05mm to 0.5mm in a series of short bounces along the soil surface (Brady 1990) and may account for 50-70% of total soil movement. Saltation also leads to *soil creep* or *surface creep*, where smaller soil particles involved in saltation cause the rolling or sliding along the soil surface of larger soil particles. Soil particles are also subject to being transported off site by *suspension* in wind currents. If saltation is controlled, wind erosion is controlled because it is the saltating particle that caused surface creep and suspension. Most soil particles may only move a few meters via suspension. Under certain circumstances, however, particles can be moved many hundreds of kilometers. This was well documented in the southern Great Plains of the United States during the 1930s.

Factors affecting wind erosion are soil moisture, wind velocity and turbulence, soil surface conditions, soil characteristics, and the nature and orientation of vegetation (Brady, 1990). Soil moisture has already been alluded to in the preceding paragraph. Wind velocity can have a major impact on soil loss, and soil movement at wind speeds above 20 km/hr is proportional to the cube of the wind velocity (Brady, 1990). Irregular soil surfaces serve to reduce wind erosion. Cultural methods to obtain irregular surfaces include certain tillage practices that create rough surface textures or leaving stubble mulch from previous annual crops. Clay soils are less susceptible to wind erosion than sand soils due to the smaller soil particle size and better soil structure. Soils of higher organic matter concentrations are also less likely to experience wind erosion due to cementing agents associated with organic substances that bind soil particles. Finally, ground cover can play a major role in reducing wind erosion. Permanent ground cover leads to higher organic matter contents, better soil structure, and a barrier that prevents detachment of the soil. Roots also act as binding agents that reduce the potential for soil detachment. Besides perennial forage crops, permanent windbreaks comprised of woody vegetation or trees redirect surface winds and slow wind velocity to minimize wind erosion. Annual crops, if oriented in rows perpendicular to prevailing winds, can likewise reduce wind erosion potential.

In summary, landowner management strategies can have a significant effect on conserving soil resources. Most erosion occurs when landscapes are used for production systems they are not well suited for. Cultural practices that maintain permanent ground cover in a healthy state do much to ameliorate soil losses. Other cultural practices are available that can help reduce soil losses in systems utilizing annual crops. These practices will be discussed later in this document.

Effects of Grazing on Soil Erosion

Livestock affect soil erosion via two methods: (1) indirectly through consumption of plant parts, and (2) directly by hoof action. Both the quantity and type of vegetative cover are critical components in ameliorating the effects of raindrop impact and runoff. In areas subject to overstocking, the quantity of vegetative material is reduced, exposing soil to direct raindrop impact. At the same time, a reduction in vegetative material allows for increased runoff. As previously mentioned, decreased infiltration and increased runoff increase erosion. The relationship between heavy stocking rates and erosion are well documented (Dunford, 1949; Thurow et. al., 1986; Pluhar et. al., 1987). Likewise, studies indicate that erosion is increased under moderate stocking rates compared to ungrazed conditions (Wood and Blackburn, 1981; Thurow et. al., 1986). The differences, however, were generally not significant. Overstocking can also lead to an overgrazed condition resulting in a change in plant species composition that may not be as effective in intercepting raindrops and retarding runoff as the previous plant community. Thus, grazing management, and more importantly stocking rate, can have a direct impact on soil erosion, and *any* change in vegetative cover or species composition that reduces infiltration and increases runoff will increase erosion. Management strategies should maintain adequate vegetative cover that correspond with storm characteristics of the region (Thurow, 1991). Areas that are unlikely to experience runoff may allow more protective cover to be removed, while areas subject to increased runoff should be provided more cover. This strategy can be both spatially and temporally specific. It should be understood that a healthy vegetative cover provides multiple benefits that include reduced erosion potential and good animal performance; therefore, it is necessary to manage for good stands of herbaceous ground cover.

Livestock can also increase runoff by increasing soil compaction (Fig. 4). Although difficult to separate the

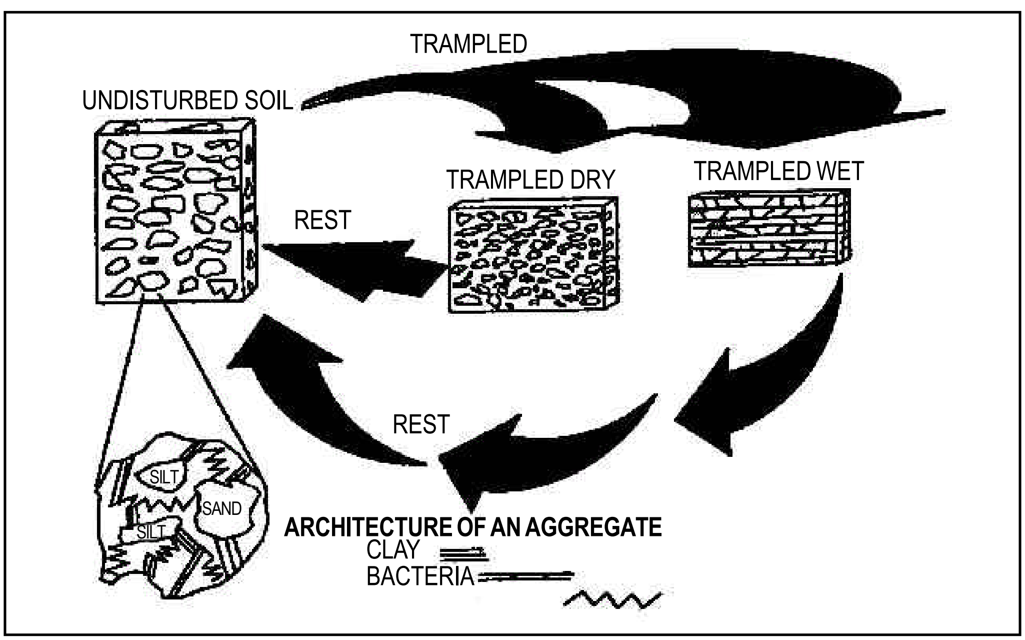

Figure 4. Conceptual architecture of a soil aggregate and the changes in soil aggregate structure caused by trampling under wet and dry conditions. (From Taylor et. al., 1993 as used by Holechek et. al., 1998).

effects of hoof impact and raindrop impact, most studies have indicated trampling increases soil compaction, destroys soil aggregate stability, reduces infiltration, and increases runoff. Early work in New Mexico by Flory (1936) indicated that lightly grazed, heavily grazed, and severely grazed ranges had soil pore spaces of 68%, 51%, and 46%, respectively. In areas where water, shade, salt, or mineral locations are inadequately distributed, compacted trails can provide initial channels for runoff and result in gully erosion if preventative measures are not taken (Thurow 1991).

Practices to Ameliorate Soil Erosion

As indicated previously, factors under direct control of the manager can have a major impact on the extent of soil erosion. Thus, the management plan for a production unit should contain erosion control practices that relate to stocking rate, grazing management, and vegetation.

Stocking Rate

Probably the most critical aspect of grazing management is using the appropriate stocking rate. Redmon and Bidwell (1997) have stated that no other single management practice has a greater effect on the profitability of a livestock production enterprise. A moderate stocking rate provides a good balance between plant and animal performance while maintaining adequate vegetative cover to protect soil resources. Although moderate stocking rate will be different depending on site and forage species, general guidelines can be obtained from County Soil Surveys produced by the Natural Resource Conservation Service (formerly Soil Conservation Service) in the United States. Other sources of information regarding appropriate stocking rates can be found in local Extension offices or by interviewing successful producers who have a long history of production in the area. Adequate vegetative cover must be provided to intercept raindrops and reduce runoff. Holechek et. al. (1998) cites numerous studies indicating a reduction in infiltration rates associated with heavy grazing. Holechek et. al. (1998) went on to summarize Gifford and Hawkins (1978) work with the following statements:

1. Ungrazed plots have higher infiltration rates than those of grazed plots.
2. Moderate and light grazing intensities have similar infiltration rates.
3. Heavy grazing causes definite reductions in infiltration rates over moderate and light grazing intensities.

Therefore, use of the appropriate stocking rate is paramount to the conservation of soil resources and the long-term viability of the livestock production system.

Grazing Management

Grazing systems can impact soil erosion. Moderate-stocked, continuous grazing, moderate-stocked three-herd, four-pasture, and high-intensity, low-frequency grazing systems appear to have the least effect on infiltration rate and sediment production (Table 1). Rest period appears

Table 1. Infiltration rates and sediment production for two types of plant communities and five grazing treatments[1]. (From Pluhar et. al., 1987 as used by Holechek et. al., 1988).

	Infiltration Rate (mm hr^{-1})		Sediment Production (kg ha^{-1})	
Treatment	**Midgrass**	**Shortgrass**	**Midgrass**	**Shortgrass**
Short-duration (14 pastures)				
Before grazing	95	75	37	63
After grazing	64	55	105	105
Short-duration (42 pastures)				
Before grazing	81	86	41	61
After grazing	85	79	75	53
Merrill 3-herd/4 pasture				
Before grazing	86	80	28	45
After grazing	81	68	71	54
Moderate continuous	89	85	35	30
Exclosure	88		23	

[1] Stocking rate was the same for all treatments.

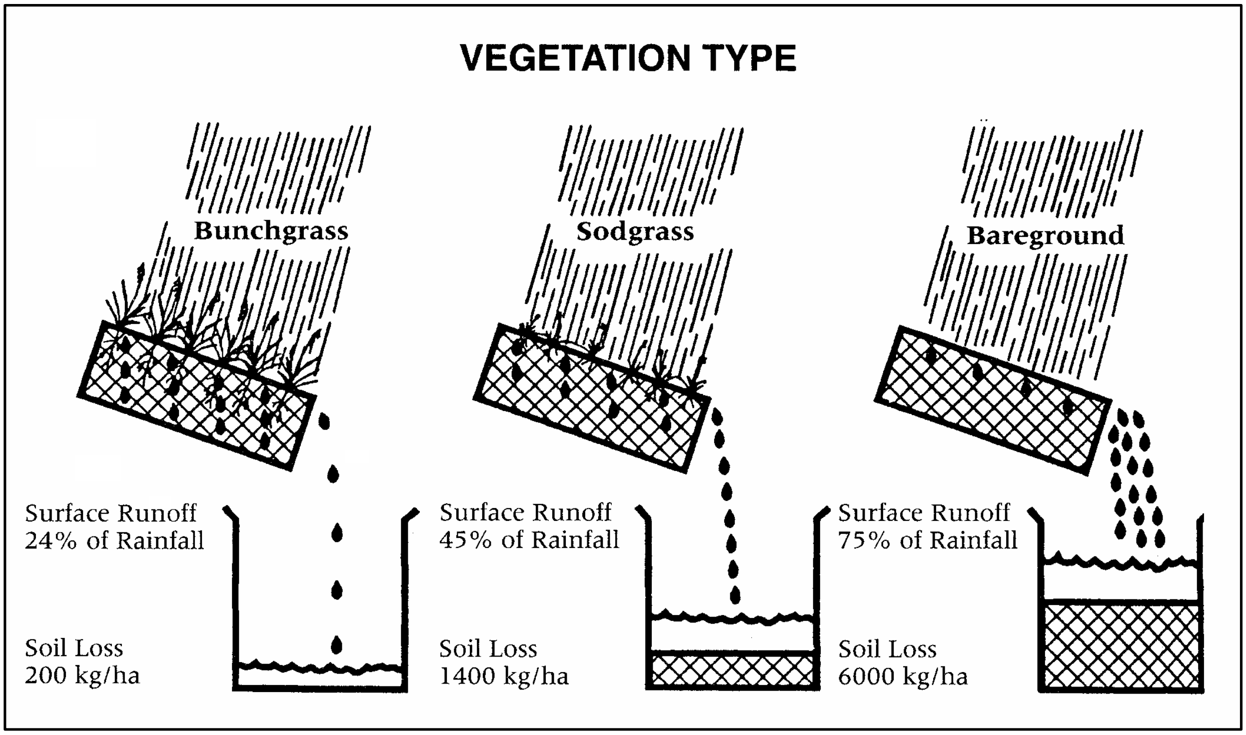

Figure 5. Influence of vegetation type on sediment loss, surface runoff, and rainfall infiltration from 10 cm of rain in 30 minutes. (Adapted from Blackburn et al., 1986, by Knight, 1993 as used by Holechek et al., 1998).

to be the critical factor regarding compaction, reduced infiltration, and increased runoff. Most research has been consistent in demonstrating that short-duration grazing increases sediment production compared to moderate-stocked continuous grazing (McCalla et. al., 1984; Thurow et. al., 1986; Weltz and Wood, 1986; Pluhar et. al., 1987; Warren et. al., 1986 a,b,c) also demonstrated reduced infiltration rates and increased sediment production compared to no grazing under moderate, double moderate, and triple moderate stocking rates. In this study, 30 days was insufficient to allow for hydrologic recovery. The severity of the effect was increased as stocking rate increased.

Special attention should be paid to riparian areas. Inappropriate use of riparian areas by livestock can result in deterioration of the streambank herbaceous community and increase the risk of streambank erosion. Riparian areas are also important as buffer strip filtering sediment from upland runoff. Once streambank plant communities are disturbed, they are difficult, if not impossible, to re-establish through natural processes. Riparian areas, as a rule should be (a) fenced to prevent entry by livestock, (b) fenced to allow limited access to riparian areas, or (c) used only during times when disruption to the riparian area is minimized. Concrete or gravel limited-access water points have become increasingly popular as a means to minimize damage to riparian areas. Due to surface water contamination from the animal feces and urine, these practices are no longer encouraged. However, freeze-proof tanks and stock ponds are alternative methods of providing water to livestock away from riparian areas.

Vegetation

Although native vegetation species composition is generally not subject to manipulation, the manager should be aware of the effect that vegetation type has on runoff and soil loss. Although it would generally be correct that sodgrasses provide more soil and water conservation than bunchgrasses, Texas researchers (Blackburn et, al., 1986) documented less runoff and sediment production for sites dominated by bunchgrasses compared with sodgrasses (Fig. 5). Either type of vegetation, however, reduces soil loss compared to bare ground. Certain areas that exhibit bare ground should be given special attention ranging from simple grazing deferment to allowing native vegetation to re-establish to complete renovation of the site.

In cases of extreme deterioration, pasture renovation may be necessary. Besides the type of vegetation (sodgrass vs. bunchgrass), it is important that producers use good establishment techniques that include the following:

1. Choose forage species that are well-adapted to the site. This includes adaptation to the soil type and to the prevailing environmental conditions. An

example would be the use of *Cenchrus ciliaris* (buffelgrass) in south Texas and northern Mexico.

2. Purchase good seed. Seed is a small part of the overall cost involved in establishment; therefore, purchase the best seed available.

3. Obtain a soil sample and apply fertilizer nutrients such as P, K, and/or lime ahead of planting and incorporate into the seedbed if possible if using introduced species.

4. Prepare a good seedbed. Most forage species will require firm, fine seedbeds.

5. Plant the seed at the appropriate rate. If the seedbed is less than desirable, increase seeding rate by 25%.

6. Plant the seed at the appropriate depth. Most forage species will be planted no deeper than 1cm.

7. Plant at the appropriate time. Realize that the window of opportunity for planting may be short. Producers should be prepared well in advance of the anticipated planting date.

8. Apply N after plant establishment, especially when using native species, to reduce the weed competition.

9. Apply P and K fertilizer annually based on soil test recommendations. Nitrogen should be applied based on yield goal.

10. Be aware of potential weed problems and be prepared to apply herbicide if necessary.

11. Use the appropriate stocking rate.

Always attempt to use perennial species if possible. Annual cropping of forages for livestock allow more opportunity for soil erosion due to both wind and water. Generally, the use of perennial forages will be less expensive. For example, the use of adapted cool-season perennial grass in Oklahoma can save producers approximately \$100 ha^{-1} compared tothe cost of grazeout wheat once establishment costs have been paid (Redmon 1998, unpublished data).

Vegetation, generally woody species, can also play an important role in reducing soil loss due to wind erosion. Windbreaks are quite effective in reducing topsoil loss and can significantly reduce wind velocity as far as 20 times the height of the windbreak (Brady, 1990).

Tillage Practices

Tillage practices can take the form of either support practices (*P* in USLE) such as contour plowing, strip cropping, and other practices that minimize soil loss. More recently, conservation tillage practices have provided additional alternatives that minimize soil loss when annual crops are used for pasture. Conservation tillage practices include the following (Brady, 1990):

No till

Soil is left undisturbed prior to planting and weed control is by herbicides.

Ridge till

Soil is undisturbed prior to planting, which is done on ridges incorporated on about one-third of the soil surface. Herbicides and cultivation control weeds.

Strip till

Soil is undisturbed prior to planting. Narrow, shallow tillage in row using rotary tiller, in-row chisel, etc. Up to one-third of soil surface is tilled at planting. Herbicides and cultivation for weed control.

Mulch till

Soil surface disturbed by tillage prior to planting, but at least 30% of residue remains on or near soil surface. Herbicides and cultivation for weed control.

Reduced till

Any other tillage/planting system that keeps at least 30% of residues on surface.

Summary

From this brief discussion regarding conservation of soil resources, it should be apparent that a vigorous stand of perennial herbaceous cover is requisite for providing adequate protection from the two main mechanisms of soil erosion, detachment due to raindrop impact (or wind) and transportation via runoff (or wind). Healthy stands of herbaceous material do not simply develop, nor are they maintained by accident. A well-devised plan emphasizing appropriate stocking rates is not only necessary, but also critical. The plan should carefully consider those grazing systems that do not concentrate animals in a management unit for too long a period without adequate time for soil and plant recovery. The plan should also examine whether the use of annual forage crops is in the best interest of the landscape for the long term. The use of annual crops is generally not as profitable as the use of perennials due to the annual cost of establishment and the equipment that must be owned and maintained. Usually there is a direct relationship between what is profitable for the manager and what is good for the land. There is much research evidence that lends support to the old rule of thumb for range management to "take half and leave half" regarding forage utilization. While we have always believed this rule to be important for balancing the requirements of both the forage system and the animal, we also realize that it is equally important in maintaining the long-term productivity of the site by reducing soil erosion to a minimum.

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