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SOIL LOSS — KEY TO UNDERSTANDING SITE PRODUCTIVITY

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INTRODUCTION

The concept of site productivity has changed significantly over the past two decades. Foresters previously characterized site productivity in terms of "site index." Site index is based on height of dominant or dominant and codominant trees in even-aged stands at some index age, usually 25, 50, or 100 years (Wenger 1984). The recent emphasis on managing whole ecosystems has made it increasingly difficult to use a single index for describing the productivity of an ecosystem, however, because productivity should reflect a host of complex interacting functions and processes (Steele and Pfister 1991). Therefore, ecosystem productivity must be expressed as the integrated product of all the processes acting dynamically over time. Presently, our best concept of ecosystem productivity is based on the capacity of soil to support plant growth as reflected by some index of biomass production (Powers 1991).

Although ecosystems are made up of a wide range of component parts and interrelated processes, soil and vegetation are the fundamental building blocks of all terrestrial ecosystems and thereby can

serve as useful surrogates for studying and discussing ecosystem processes and their responses to perturbation. Soil is important because it not only provides a physical medium for plant growth, but also supplies most of the essential plant nutrients and, along with climate, relief, and biology, establishes the limits of biomass production. Vegetation is an important component of ecosystem productivity because it provides a mechanism for converting solar energy and carbon dioxide into biomass, and also provides a protective cover against surface erosion.

Ecosystem processes and subsequent productivity are affected by a wide range of natural and human perturbations (Powers 1991). Many of these human perturbations affect both vegetation and soils (the key surrogates for site productivity). For example, soil is disturbed during such management activities as grazing, prescribed fire, and timber harvesting. Therefore, there is an urgent need to better understand the influence of different management practices on soil disturbance. This knowledge will provide a better basis for developing guidelines for making future management decisions.

The objectives of this paper are to review the influences of management practices on site productivity, to discuss the importance and influence of soil erosion on productivity, and to describe some of the Forest Service research being used to address these issues in the Southwest.

MANAGEMENT INFLUENCE ON SITE PRODUCTIVITY

The three ecosystem properties most likely affected by human activities are losses of soil organic matter, porosity, and depth.

The soil normally contains 80% to 90% of the total ecosystem nitrogen and even more of the phosphorus (Powers 1991). The remaining nitrogen and phosphorus is in the aboveground biomass. Loss of organic matter from the vegetative and soil components of an ecosystem can produce nutrient and moisture stress and ultimately a reduction in site productivity (DeBano 1991), particularly on infertile and droughty sites (Powers 1991). Using information from Wells and Jorgensen (1979), Powers (1991) concludes that loss of organic matter and nutrients by conventional timber harvesting (leaving slash lobbed and scattered) is unlikely to have a major influence on productivity of most sites. However, shorter harvest rotations, whole-tree logging, and broadcast burning of slash and forest litter may detrimentally affect productivity over time. Management practices that expose the soil also increase the risk of erosional losses and could reduce site productivity.

Soil compaction and the associated increases in soil density by animals and machinery can limit plant growth (Powers 1991). Soils, according to Sands (1983), will also compact under their own weight if appreciable amounts of organic matter are lost (Powers 1991). Losses in productivity are generally proportional to increases in soil bulk density (Froehlich and McNabb 1984). Soil compaction reduces porosity and infiltration capacity of the soil, which leads to potential increases in surface runoff and erosion. Therefore, the type of equipment, animal use, distribution of animal and equipment traffic, and susceptibility of a given soil to compaction must be considered when making any management decisions.

Soil depth is important because organic matter (where many nutrients are concentrated) is not distributed evenly in the soil. Because organic matter generally is concentrated at the surface and

declines rapidly with depth (Powers 1989), small losses in surface soil can have a major effect on productivity. Displacing logging debris and layers of topsoil during site preparation (piling and windrowing slash) can produce nutrient deficiencies that result in loss of productivity (Powers 1991). These practices also expose the mineral soil, subjecting it to increased raindrop impact and surface sealing, which increases the potential erosion losses.

IMPORTANCE OF SOIL EROSION

Surface erosion rates are largely influenced by the amount of vegetative cover and surface litter available to protect the soil surface (Megahan 1991). Road construction and wildfire are often responsible for the greatest reduction in vegetation and, therefore, can result in the greatest increase in erosion (Megahan 1991).

The impact of erosion on site productivity depends on the depth of soil loss, the areal extent, the erosion rate, and the redistribution of eroded material (Megahan 1991). Surface erosion often has a relatively short-term effect (often a matter of a few years) on a site. It normally involves loss of a small depth of soil, but this loss can be widespread in a given area. In a few years, with reestablishment of vegetation, erosion rates are quickly reduced. In contrast, gully or rill erosion occurs on relatively small areas but involves greater loss in soil depths, and often occurs on highly productive sites such as swales or along channel bottoms. This concentrated gully erosion can have a long-term effect on site productivity. Although erosion generally reduces productivity from the area that is eroded, productivity of downslope areas of deposition floodplains can increase.

Management practices that accelerate soil erosion can have a major impact on site productivity by reducing nutrient supply and water-holding capacity of the soil, and damaging the vegetation (Megahan 1991). Examples of damage to vegetation include loss of mechanical support of the vegetation, removal of propagules (seeds, small plants, roots), and actual burial of the vegetation. However, even erosion rates under the most severe conditions can often be quickly mitigated with the rapid reestablishment of vegetation (Megahan 1991).

CURRENT RESEARCH

A wide variety of natural ecosystems in the southwestern United States are being subjected to increasing use by a rapidly expanding human population. To better understand these impacts, the U.S. Forest Service is conducting a series of basic and applied studies aimed at predicting the effect of different management activities on runoff, erosion, sediment movement, nutrient cycling, and soil productivity (DeBano 1989). These studies are formulated within the context of the cumulative effects of integrated land management activities on watershed condition and ecosystem productivity. Cumulative land-use effects are defined as changes to the environment caused by interactions of natural ecosystem processes with the effects of land-use activities distributed through time or space, or both (Sidle et al. 1988). The concept "cumulative effects" is the concern that, although each individual land-use activity can remain within the bounds of acceptable environmental damage, the cumulative effects can become unacceptable, particularly when several activities occur collectively. Although we are studying many facets of the overall cumulative effects, only two important areas of investigation dealing with water and wind erosion are reported below.

Water Erosion

When erosion studies were first initiated, water erosion was considered to be one of the most important processes affecting the productivity of southwestern ecosystems. To study water erosion, we used a rotating-boom rainfall simulator equipped with V-Jet nozzles (Swanson 1965). This simulator, which is capable of producing rainfall rates of 60 and 120 mm/hr, is situated between two, 3-m × 10-m plots (Simanton et al. 1989). Both naturally vegetated and mechanically bared plots are subjected to simulated rainfall (Baker et al. 1991). Runoff and sediment production from bared plots yield an estimate of soil erodibility which is independent of plant cover. Measurements from adjacent naturally vegetated plots indicate how different vegetative covers (e.g., pinyon-juniper woodlands, annual grasslands, forests) affect runoff and sediment production.

The initial results of rainfall simulator trials on several forest and range sites in California indicated that the soil loss from bare soils varied widely from 0 to over 14,000 kg/ha (Fig. 1). The inherent erod-

ibility of these soils was probably related to several soil chemical and physical properties. Soil physical properties such as aggregate stability are known to affect the susceptibility of soils to raindrop impact and detachability which affects infiltration and, finally, the rate and amount of runoff and erosion (Trott 1982).

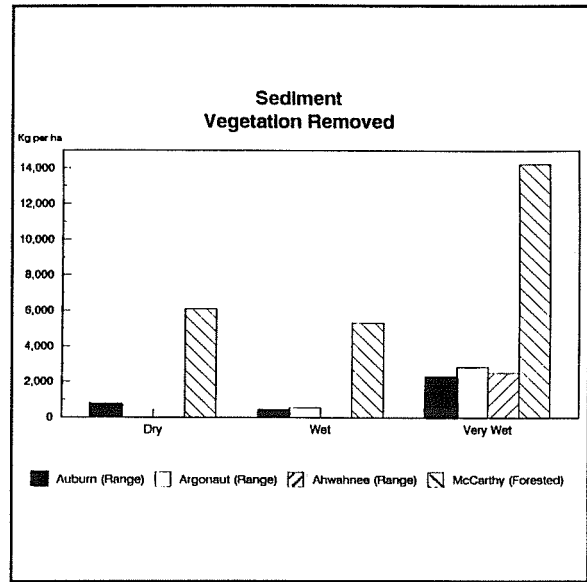


Figure 1. Sediment yields from four California soils in two vegetation types with cover removed. Simulations were made under three soil moisture conditions—dry, wet, and very wet.

Vegetative cover was also found to have a pronounced effect on runoff and sediment yields (Fig. 2). Sediment yields of the same range soils presented in Figure 1 were reduced to 150 kg/ha or less when vegetation was undisturbed. Vegetation is known to have several desirable effects including reduction of raindrop impact, thereby limiting soil detachment and splash (Trott 1982). Both vegetative cover and organic material improve the water storage capacity of the soil surface, thereby delaying and reducing runoff. Plant cover itself also obstructs overland flow, reducing flow velocity and sediment transport capacity. Soil crusting is also less likely to occur under vegetation.

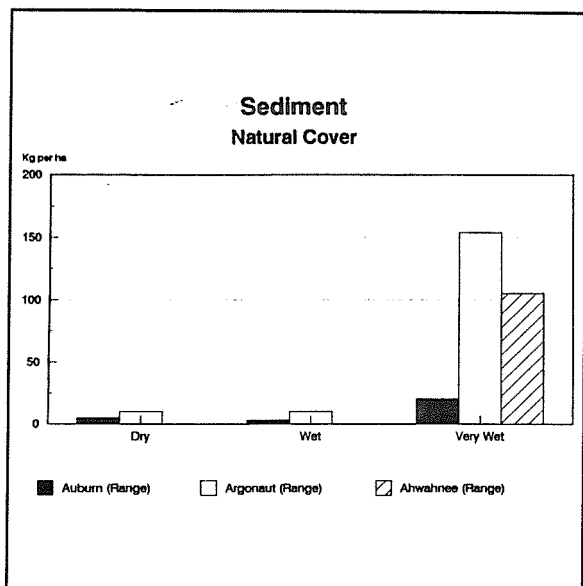


Figure 2. Sediment yields from three California range soils with vegetation undisturbed. Simulations were made under three soil moisture conditions—dry, wet, and very wet.

Wind Erosion

Studies using a rainfall simulator on pinyon-juniper woodlands revealed only small amounts of sediment movement. This finding, in conjunction with the observation of substantial soil deposition under and around the bases of trees and shrubs, suggested that wind erosion may be an important erosional process in pinyon-juniper woodlands. Ash and soil movement by wind were also observed, particularly following prescribed burning of fuelwood slash.

A study was initiated by the Forest Service to quantify the effects of slash and subsequent wind erosion on the transport of nutrients and sediment in pinyon-juniper woodlands (Baker 1991). A 10-ha opening was created in a pinyon-juniper stand during a firewood harvest (Fig. 3). The residual slash was lopped and scattered, and allowed to cure for two years. In the fall of 1990, the cured slash was mechanically crushed except for a 1-ha block, located near the center of this opening, that was burned in the spring of 1991.

Wind erosion samplers (Fryrear 1986), for sampling suspended particles in the air, were located along the windward edge of the opening (the prevailing wind is from the southwest), in the crushed slash area, and in the slash area that was burned (Fig. 3). These erosion samplers were located at heights of 1 m, 0.2 m, 0.1 m, and 0.05 m

above the soil surface. Mean sediment amounts (kg/m²) collected in the samplers during the summer season (May 15 through October) are given in Table 1. These measurements reflect the amount of windborne sediment caught in the vertical profile at each area sampled, not the total amounts that were removed from the site.

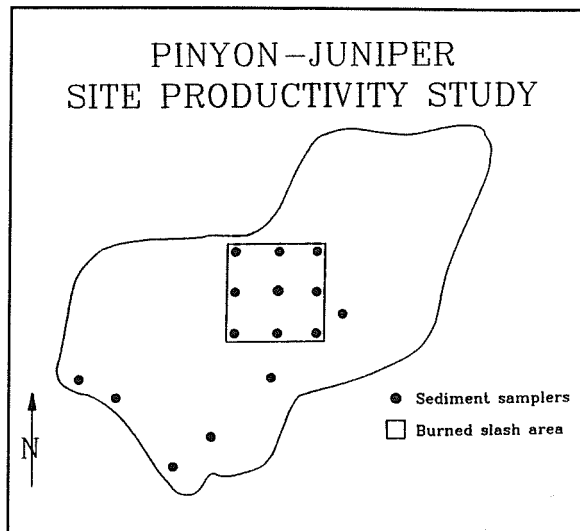


Figure 3. Layout of wind erosion study in a pinyon-juniper fuelwood harvest area.

Location	Height above the ground			
	1.0 m	0.2 m	0.1 m	0.05 m
	----- kg/m ² -----			
Windward	1.3	1.6	2.8	5.6
Crushed	0.3	2.8	8.7	11.5
Burned				
Windward	3.5	145.0	464.0	947.0
Middle	12.5	274.0	953.0	1154.0
Leeward	17.9	228.0	610.0	1164.0

The one-day catch immediately after slash burning was particularly high (Table 2). May is typically windy in the Southwest. On the day following the burn, winds gusted up to 95 km/hr. This one-day "sediment catch" represents 100% of the season catch at the 1-m height for the windward

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and crushed sampler locations. Catches in the lower samplers were 10% to 25% of the total seasonal catch. The one-day catch in the burned area was about 40% to 50% of the total catch.

Table 2. Mean sediment collected at four heights above the ground surface at Ancient Wind Study Site on 5/15/91, one day after slash was burned.

Location	Height above the ground			
	1.0 m	0.2 m	0.1 m	0.05 m
	----- kg/m ² -----			
Windward	1.3	1.0	0.7	1.1
Crushed	0.3	0.6	1.0	1.9
Burned				
Windward	1.5	69.0	242.0	549.0
Middle	5.5	115.0	470.0	492.0
Leeward	8.8	110.0	301.0	642.0

CONCLUSIONS

Management practices may affect site productivity by changing organic matter, soil porosity, and soil depth in a given ecosystem. Changes in these three factors influence the availability of nutrients, water, and gases to the vegetation.

Although erosion is a typically slow process in all ecosystems, natural disturbances (such as wild-fire, floods, and wind) and human disturbances often accelerate the erosion rates. Although humans generally have little control over natural disturbances, a better understanding of their influence on the productivity of southwestern ecosystems is needed to develop better management strategies, which can be used following such disasters. A better knowledge of the effects of natural disturbances also allows managers to isolate these effects from those caused by human activities.

Manipulations or uses of natural ecosystems can potentially increase the risk of erosion. The impact of erosion on site productivity depends mainly on the depth, areal extent, and rate of soil loss along with redistribution of eroded material. Better knowledge of these factors is needed to reduce their impacts on productivity.

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