Fire Effects on Rangeland
FACTSHEET

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Fire Effects on Soil

This factsheet will focus on how fire affects soils. All fires, regardless of whether they are natural or human-caused, alter the cycling of nutrients and the biotic, physical, moisture, and temperature characteristics of soil. In many cases however, these impacts are either negligible or short-lived and thus have little, if any, impact on the overall ecosystem. In some cases however, the impact of fire on soil conditions can be moderate to severe. The overall degree and longevity of this impact is determined by numerous factors including fire severity, temperature, fire frequency, soil type and moisture, vegetation type and amount, topography, season of burning, and pre- and post-fire weather conditions.

Past research has identified many fire-related impacts on soil conditions. They have divided them into the following categories: Physical and Chemical Properties, Nutrient Properties, Soil Temperature, Soil Moisture, and Soil Biota. In general, when compared to the impacts felt by other ecosystem components, fire effects on soil are typically minor, are often short-lived and can be either positive or negative, with degree of impact increasing with increased fire severity.

PHYSICAL AND CHEMICAL PROPERTIES

Fire can impact a variety of soil physical and chemical properties including the loss or reduction of structure and soil organic matter, reduced porosity, and increased pH. These changes can also result in various indirect impacts including increased hydrophobicity (water repellency) which results in decreased infiltration and increased runoff which often results in increased erosion. Most of these changes to the soil, including a loss or reduction of structure and reduced porosity, are caused by an alteration in soil chemistry resulting from complex interactions among geomorphic processes, climate, vegetation, and landforms. Organic matter is also consumed or lost during a fire. This is dependant on the soil moisture content of the organic layer of the soil profile, fire severity and the subsequent precipitation. Any alteration in soil organic matter is significant, since it not only acts as a reservoir for site nutrients (particularly nitrogen), it also helps regulate the hydrologic cycle, and carbon/nitrogen ratio, provides a site for nitrogen fixation, and maintains soil structure porosity and cation exchange capacity. The degree of impact that reduced organic matter has on a site is primarily dependant on the ecological makeup of the site. For example, reduced organic matter is especially critical on nutrient deficient sites including arid and semi-arid rangelands.

pH

During the combustion process, several previously bound nutrients are released in their elemental or radical form. This process is described by the National Wildfire Coordinating Group (2001), “Certain positive ions, collectively called cations, are stable at typical combustion temperatures, and remain onsite after burning in the form of ash or uncombusted hydrocarbons. If in the ash form they are subsequently leached into the soil where they exchange with H+ ions; the resulting increase in H+ ions in solution increases the pH.” These changes are significant on low pH sites (e.g.,,, cold, wet, acidic sites) since a higher pH typically increases the nutrient cycling of various elements critical for plant growth, including nitrogen and phosphorus. In addition to the pre-fire pH of a site, the degree of impact this process has on a site is dependant on fuel loading, with the degree of impact typically increasing with increased fuel loading. Ash deposited after a fire is composed mostly of salts. If exchange sites are available, these salts can effectively increase soil pH by capturing the salt cations as they leach through the soil profile.

Hydrophobicity

Changes in soil organic matter may also cause hydrophobicity. This phenomenon occurs during the combustion process when distilled aliphatic hydrocarbons migrate into the soil profile and condense on soil particles to form a water repellent layer. Hydrophobicity, which typically results in reduced infiltration rates, appears to be most common in dry, coarse textured soils that are heated to 349 to 399 ^{O}F (176 to 204 ^{O}C). These effects however, are usually short-lived, generally disappearing after the first year.

Erosion

Vegetation removal, combined with the above changes in soil physical properties, will typically result in erosion following a fire. Whether or not erosion occurs, is not only dependant on fire-influenced changes (bare soil, soil structural changes, altered hydrology etc.), but also on a variety of topographical factors, including slope and aspect, and climatic factors, such as rate and amount of precipitation. Since root systems of top-killed shrubs and trees assist in maintaining soil stability, erosion may not occur immediately; instead, it may be delayed several years following a fire. Other factors such as soil texture also influence the erosion potential of a site. For example, in general, coarse-textured soils are considered more erodible than fine textured soils. Overall, a variety of factors including slope steepness, aspect, soil texture, vegetation recovery time, the amount of residual litter and duff and climatic factors such as the timing, intensity, and amount of precipitation, all interact with one another to determine a sites susceptibility to erosion. When compared to unburned sites, the overall extent of erosion will vary considerably from excessive, to little, if any change. The agent responsible for erosion is also dependant on local climatic and topographic parameters. Past studies have found post-fire erosion to be facilitated by wind, water, and/or gravity. This includes all of the following types of erosion: raindrop splash, sheet and rill erosion, soil creep, and mass wasting.

NUTRIENT PROPERTIES

Numerous exchangeable cations including P, Mg, K, Ca, and Mg typically increase following a fire. This results in an abrupt release of elements, which in the absence of fire, would only have become gradually available through the slow decay of plant litter. These cations are generally released during various combustion stages with the total amount released being dependant on fire severity, intensity and fuel type. Overall, in most cases, a fire increases the amount of nutrients available, and as a result nutrient cycling is increased.

Nitrogen may be reintroduced back into an ecosystem via symbiotic and non-symbiotic fixation. Fixation, which is commonly more active following fires, can in some ecosystems actually restore lost nitrogen. This process is generally facilitated by both heterotrophic (can not survive on its own) bacteria as well as symbiotic fixation taking place within nodulated plant roots. Nodulated plant roots occur in numerous plants species including alder, ceanothus and various legumes. Depending on the site, bacterial fixation in decomposing wood may also provide an important post-fire nitrogen source. The process is enhanced by the ash and the blackened soil surface which acts as a black body (absorbs energy and warms quickly).

While various nutrients can become more available during and after a fire, others may be volatilized and thus lost during a fire. Volatilization, which is temperature dependant, most commonly affects nitrogen and to a lesser extent, sulphur, phosphorus and carbon. Even though volatilization removes nutrients from a system, it can also convert them to a more available form. For example, nitrogen is often converted to the more available form ammonium, during the volatilization process. Thus, even though the total amount of nitrogen on a site decreases, the amount of available nitrogen to plants may actually increase or decrease, depending on the site.

Some nutrients may also be lost by other means including convection, runoff, or leaching. This loss while generally insignificant for prescribed burns, may, depending on fire severity, be significant during or after intense wildfires. When compared to fire severity, fire frequency appears to play a minor role in nutrient loss. For example, several light to moderately severe controlled burns may have less impact on the soil than a single severe wildfire resulting from large fuel accumulation. This is not always the case however. For example, on some nitrogen deficient sites, such as semi-arid rangelands, nitrogen may actually be lost by frequent fires.

SOIL TEMPERATURE

Following vegetation removal, an increase in soil temperature is often experienced. Numerous factors contribute to this increase including, the removal of vegetative cover, consumption of fuels, thinning or removal of the litter and/or duff layer, the enhanced "black body" thermal characteristics of the charred material on the soil surface (National Wildfire Coordinating Group 2001). The removal of vegetation is significant since plant residue (stubble), litter and duff cover, all moderate soil temperatures by intercepting direct sunlight and moderating the loss of soil heat by radiation.

Higher surface temperatures often enhance seed germination and plant growth as well as cause deeper annual soil thawing (in northern areas). This latter effect is significant, as it can increase both the depth and the temperature of the rooting zone. All of these effects, combined with increased nutrient availability, are hypothesized as being the reason why plant growth is often stimulated following a fire. In fact, increased soil temperatures may actually be more important than increased nutrient availability. Reduced shade combined with increased soil temperatures, may however, impact nutrient cycling by allowing the soil surface to dry, thus decreasing soil microbial activity.

SOIL MOISTURE

Fires can either reduce or increase soil moisture. Reductions in soil moisture occur when increased soil temperatures decrease water viscosity, thus allowing more water to percolate through the soil profile. In addition, reduced shade, combined with increased soil temperatures, also results in higher evaporation rates, which in turn, restricts the movement of water into the soil profile. Late season fire-induced effects may also reduce soil moisture. For example, if increased plant productivity occurs (due to increased soil temperatures and nutrient availability) higher transpiration rates will result, further lowering soil moisture levels. Other factors, such as decreased infiltration rates, resulting from hydrophobicity (discussed above) can also further reduce soil moisture levels.

While the above factors may reduce soil moisture, other fire effects can actually increase soil moisture levels. For example, early in the year, before vegetation gets firmly established, a site will be subjected to decreased plant interception and transpiration. This allows a greater amount of water to enter the soil profile than what would have occurred during pre-burn conditions. Overall, the impact of fire on soil moisture is important, since it facilitates both seed germination and plant development. For example, most bunchgrasses require sufficient soil moisture to enable a seedling to reach the three-leaf or greater stage of growth and thus allow it to survive an extended dormant period.

SOIL BIOTA

Following fire, soil biota (living soil organisms) is commonly affected to varying degrees. In general, it appears that soil will often protect subsurface soil biota (including insect pupae) from fire. This level of protection is dependant upon the depth of the organism in relation to the depth of heat penetration. In general, hot fires typically have a more significant and longer-lasting impact on soil biota than low intensity fires which tend to have little or no effect on soil biota. Overall, it appears that changes in soil biota are typically minor, and thus have little impact on the ecosystem as a whole. The exact impact of fire on soil biota however, is complex, and for the most part still poorly understood.

REFERENCES

National Wildfire Coordinating Group. 2001. Fire Effects Guide. Available online: http://www.nwcg.gov/pms/RxFire/FEG.pdf. 313 p.

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