

The Soil Beneath Shrubs Before and After Wildfire: Implications for Revegetation

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Abstract—Physical and chemical attributes of the soil seedbed influence the success of seed germination and plant establishment. In big sagebrush (*Artemisia tridentata*)/bunchgrass plant communities, soil seedbed attributes are spatially and temporally heterogeneous. Wildfires can alter the seedbed beneath shrubs, thereby, affecting both natural and artificial post-wildfire revegetation. Soil physical and chemical attributes and the soil fabric were characterized in the seedbed beneath shrubs, pre- and post-wildfire. Compared with unburned controls, significant ($P \leq 0.05$) decreases in water-soluble nitrate and significant increases in water-soluble sulfate and several organic acids occurred immediately post-wildfire in the surface 5 cm of the soil. In addition, post-wildfire hydrophobicity reduced water infiltration into shrub subcanopy soil. Wildfires considerably altered the fabric of the soil seedbed. As compared to the pre-wildfire soil fabric, wildfires: (1) caused the compaction of mineral grains through loss of organic detritus, (2) carbonized plant litter to a depth of approximately 5 cm, (3) caused the loss of fluorescent compounds in sagebrush litter, (4) coated mineral particles with organic compounds, and (5) cleaved micaceous minerals. The synergism of fire effects undoubtedly influences post-wildfire revegetation. Field studies are underway to elucidate these effects.

The physical, chemical, and biological attributes of the soil seedbed influence seed germination and seedling establishment. Within the sagebrush-steppe of the intermountain west, the location of favorable sites for seedling emergence [safesites, Harper and others (1965)] are heterogeneously distributed. Eckert and others (1986) categorized the soil surface morphology in northern Nevada into: (1) coppice-eolian dust and litter accumulating beneath shrubs and bunchgrasses; (2) coppice bench-flat zone around coppice; (3) intercoppice micropain-gently sloping area from coppice bench to playette; and (4) playette-flat to slightly depressed areas among shrubs. These micropositions vary considerably in nutrient status, texture, moisture status, and the number of safesites. In general, the proportion of safesites increases as range condition increases and from playette to coppice positions.

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Wildfires occur at regular intervals in the sagebrush-steppe, becoming more frequent with the invasion of cheatgrass (*Bromus tectorum*). Wildfires represent a major ecological disturbance which considerably alters the soil seedbed via: (1) changing fertility (Raison 1979); (2) influencing seed viability and seed germination potential (Went and others 1951; Komarova 1985); (3) production of hydrophobic compounds (DeBano and others 1976); and (4) production of compounds stimulating germination of some seeds (Keeley and others 1985).

Few studies have examined fire-induced chemical changes, by microsite, in the heterogeneous sagebrush-steppe of North America. Moreover, we are unaware of research characterizing the fabric of the soil seedbed pre- and post-wildfire in the sagebrush-steppe. Our purpose, therefore, was: (a) quantify pre- and post-wildfire soil physical and chemical properties, by microsite, and; (b) characterize the soil fabric pre- and post-wildfire. In this paper, we will only report on fire-induced changes occurring in the soil beneath the shrubs big sagebrush (*Artemisia tridentata* ssp. *tridentata*) and antelope bitterbrush (*Purshia tridentata*). Due to high fuel amounts, shrub subcanopies attain higher temperatures than other positions and, as a consequence, are the focus of heat-induced changes in soil properties during and after wildfires (Blank and others 1994).

Materials and Methods

The Study Area

Research was conducted approximately 50 km north of Reno, NV, on coarse-textured granitic soils that occur on alluvial fans along the eastern Sierra Nevada front. Vegetation is dominated by sagebrush, bitterbrush, and cheatgrass. Other native species include desert peach (*Prunus andersonii*), needle-and-thread (*Stipa comata*), and Indian ricegrass (*Oryzopsis hymenoides*). The study area receives 250 mm of precipitation a year with considerable spatial and temporal variability.

In August of 1986, the Clark Incident fire burned over 16,000 hectares in the Plumas National Forest. We studied this wildfire at the Bird Flat ranch. The soils are sandy, mixed, mesic Torripsammentic Haploxerolls and loamy, mixed, mesic Xerollic Haplargids. In September 1987, the Hallelujah Junction fire burned about 300 hectares. The soils here are loamy-skeletal, mixed, frigid Lithic Haploxerolls. Field studies were initiated immediately post-fire, before any precipitation or soil-blowing events.

Laboratory

All field-collected soils were air dried, sieved through a 2-mm sieve, and stored before analysis. Samples were analyzed as soon as possible. Soluble anions in the soil were extracted with 0.15 percent KCl solution and quantified by ion chromatography (Blank and others 1994). Cation exchange capacity was determined by the neutral ammonium acetate procedure (Soil Survey Staff 1984). Soil pH was determined in CaCl₂ (McLean 1982). Hydrophobicity was quantified using the water drop penetration time (WDPT) method (DeBano 1981). Organic carbon determination used the Walkley-Black method (Nelson and Sommers 1982). Soil N was quantified by the Kjeldahl method (Bremner and Mulvaney 1982) with NH₄⁺ quantitation by membrane flow injection. Plant available Fe, Mn, Zn, and Cu was gauged by DTPA extraction (Lindsay and Norvell 1978). Phosphorus availability was determined by bicarbonate extraction (Olsen and Sommers 1982). Intake rate was measured with a single ring cylinder infiltrometer (Bouwer 1986).

To examine the soil fabric, replicate intact samples of burned and unburned sagebrush subcanopy soil were collected for manufacture into thin sections. Thin sections are made by grinding a block of material until it is thin enough to pass light—it can then be microscopically examined. Field samples were collected by carefully excavating material away to leave a mound the shape and size of a small paper cup. A paper cup was inserted over the mound until the soil surface contacted the bottom of the cup. The cup was carefully inverted so as to not disturb the soil, returned to the laboratory and impregnated with a commercial resin. The impregnated samples were sent to a commercial lab where they were cut into thin sections. Thin sections were examined with a polarizing microscope and by reflected light microscopy using blue-violet excitation and a barrier filter which attenuates wavelengths less than 500 nm.

Results and Discussion

Physical and Chemical Effects of Wildfire

Hydrophobic compounds, created by the wildfire, considerably reduce water intake rate of soil beneath sagebrush plants (fig. 1). Excavation of soil after the infiltration experiments showed preferential water flow paths through the upper 10 cm of the soil—much of the soil remained dry. Fire-induced hydrophobicity extends greater than 5 cm in the soil (table 1). A possible ramification of preferential water flow is that a portion of viable seeds remaining after the wildfire may not receive water for germination until the hydrophobic compounds are broken down. In the case of the Bird Flat wildfire, field measurements the following summer showed that elevated hydrophobicity had decreased to pre-wildfire levels.

A fire-induced chemical change that may impact seed germination and seedling establishment is the high levels of certain organic acids (table 1). We have measured

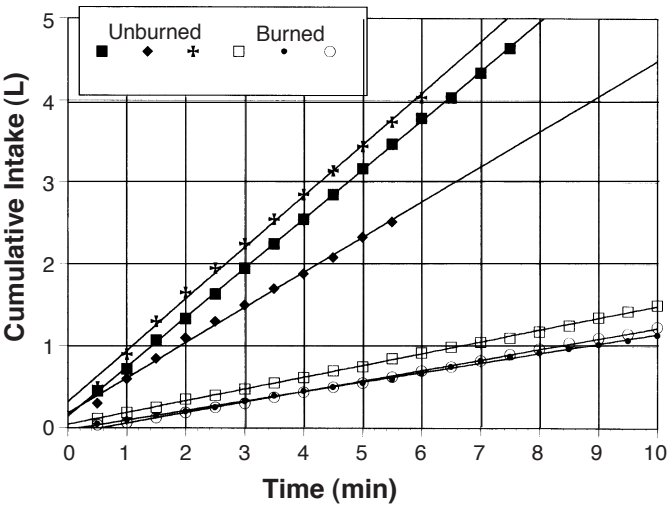


Figure 1—Cumulative constant head soil infiltration (three replicates) beneath burned and unburned sagebrush canopies. Basal area of infiltrometer 180 cm².

Table 1—Chemical attributes of soil collected beneath shrub subcanopies in post-wildfire and a similar unburned control at the Bird Flat study site

Attribute	Treatment	
	Unburned	Burned
CEC (cmol kg ⁻¹)	18.0a ³	8.0b
Bicarb-P (mg kg ⁻¹)	635a	462a
Khejdahl N (%)	0.32a	0.16b
pH	6.34a	6.41a
Organic C (%)	4.59a	2.02b
DTPA Fe (mg kg ⁻¹)	7.4a	16.9b
DTPA Mn (mg kg ⁻¹)	14.7a	18.4a
DTPA Cu (mg kg ⁻¹)	1.5a	0.8b
DTPA Zn (mg kg ⁻¹)	3.2a	1.1b
KCl-nitrate (mg kg ⁻¹)	43.5a	10.1b
KCl-ortho-P (mg kg ⁻¹)	25.4a	9.8b
KCl-sulfate (mg kg ⁻¹)	9.7a	38.8b
KCl-acetate (mg kg ⁻¹)	2.4a	139.4b
KCl-formate (mg kg ⁻¹)	0.5a	16.9b
WDPT ² (0-5 cm) (sec)	517a	1,224a
WDPT (5-10 cm) (sec)	1.3a	165b

¹Unless otherwise noted, data are for soil collected from 0-5 cm.
²WDPT is the water drop penetration time, the time it takes for one drop of water to penetrate the soil.
³Means followed by the same letter are not significantly different at the P ≤ 0.05 level.

elevated post-wildfire levels of acids such as acetic, glycolic, formic, oxalic, and succinic acid in shrub subcanopy soils which have been shown to retard or increase the germination of seeds (Mayer and Evenari 1953; Cohn and others 1987). Some of the organic acids are phytotoxic (Harper and Lynch 1982). Levels of organic acids in the seedbeds of shrub subcanopies can increase significantly in the months following the wildfires, but return to pre-fire levels by the following summer (Blank and others 1994). The compounds are leached downward by winter precipitation or lost via microbial utilization.

The heat from wildfires volatilize considerable nitrate in the soil (table 1; Raison 1979). Moreover, levels of ammonium increase following wildfires (Raison 1979). Such changes may impact seed germination and plant successional trajectories (Gigon and Rorison 1972; Hendricks and Taylorson 1974).

Other chemical changes, as a consequence of wildfire, may impact revegetation success and vigor of new plants (table 1). These changes include reduced cation exchange capacity, lower total soil N and C, and decreased levels of DTPA-extractable Cu and Zn.

Influence of Fire on the Soil Fabric

The surface fabric of sagebrush subcanopies consists of 0.5-2.0 cm of largely undecomposed litter which creates an open framework with high porosity (fig. 2A). The litter is mostly undecomposed and fluoresces strongly in greenish-yellow, under blue-violet excitation, around the margins of leaf material. The fluorescence appears to emanate from spheroidal oil-rich bodies in sagebrush leaves. Beneath this litter layer is a region 2 to 15 cm

thick consisting of a mixture of plant litter and eolian mineral particles (fig. 2B). The plant litter serves to form a more open structure than would occur if the eolian particles, themselves, packed together. Sagebrush litter is in various stages of decomposition, with increasing decomposition deeper in the soil; however, even in an advanced stage of decomposition, much of the leaf litter fluoresces strongly, suggesting the compounds are long-lived. Mineral grains in unburned soil are often coated with an alteration rim of clay minerals (figs. 2B, C). When decomposed, the spheroidal oil-rich bodies in sagebrush leaves are melanized (fig. 2C). Throughout sagebrush subcanopy soils, spheroidal to oblate fecal pellets are evident (fig. 2D). One pathway of sagebrush decomposition is via ingestion by soil invertebrates. Even though the litter has passed through the gut tract, the fluorescent compounds are still active.

The upper 3-5 cm of a burned sagebrush subcanopy soil is completely charred (fig. 2E). As compared to the surface of unburned sagebrush subcanopies, the formerly open fabric has collapsed due to destruction of plant litter. Moreover, in this charred region, no fluorescence of

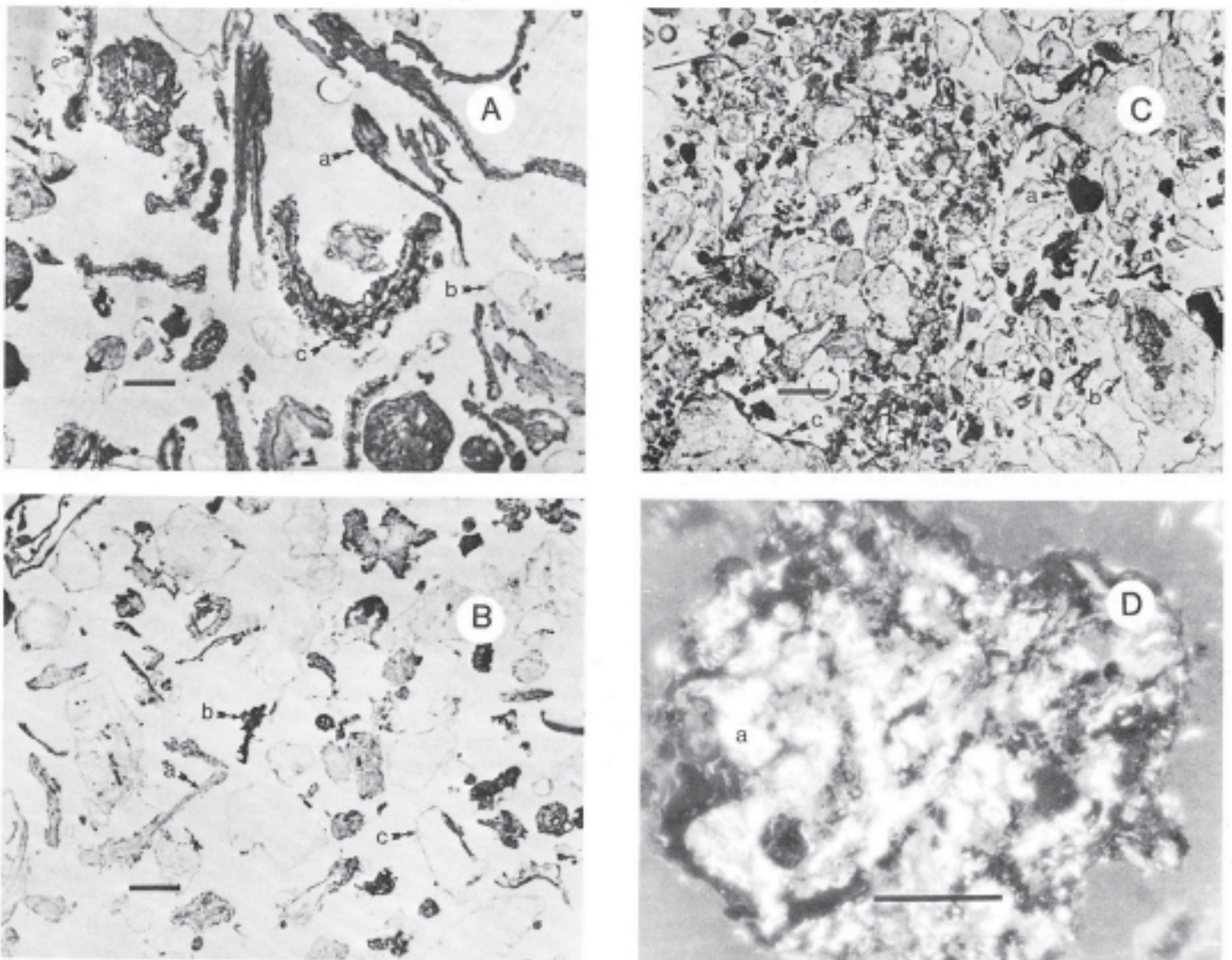


Figure 2 continued

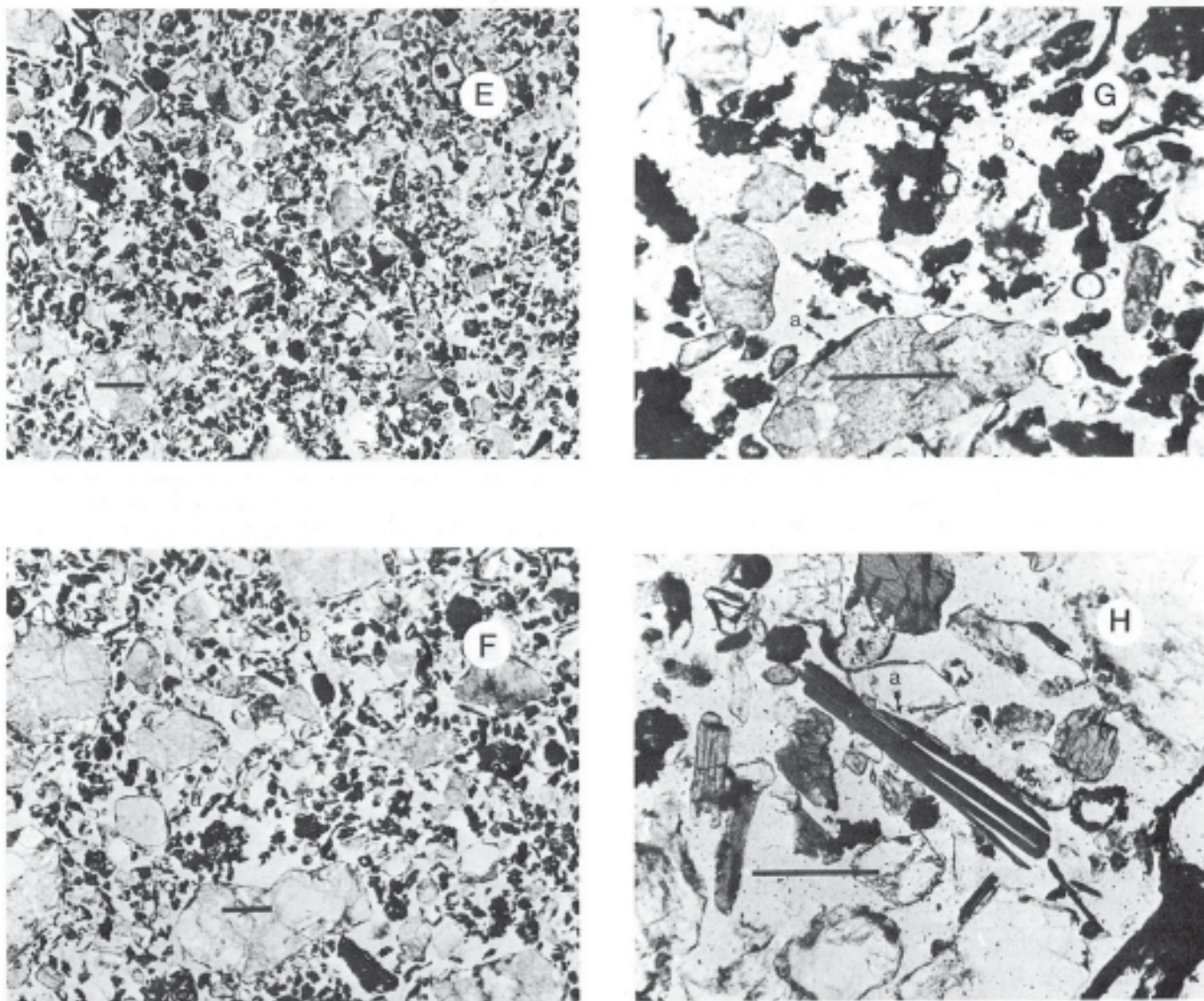


Figure 2—Thin section photomicrographs. (A) The fabric of the surface litter layer of an unburned sagebrush subcanopy soil consists of an open framework of slightly decomposed sagebrush leaves and stems (a) in which mineral grains (b) are rare. Unburned sagebrush leaves have numerous dark-colored oil-rich spheroidal bodies (c). Line scale = 1 mm. (B) Below the surface plant litter zone is a region 2 to 15 cm thick consisting of a mixture of plant litter in various stages of decomposition from slightly decomposed (a) to very melanized (b). Many mineral particles have thin alteration rims of clay (c). Line scale = 1 mm. (C) Deeper in the seedbed beneath unburned sagebrush, the fabric is more compact due to litter decomposition (a). Mineral particles have clay alteration rims (b) but also dark coatings (c) similar to those that occur in burned soil; are these a remnant of a previous wildfire? Line scale = 1 mm. (D) Numerous fecal pellets occur in unburned sagebrush subcanopy soils. Under blue-violet excitation, the fecal pellets strongly fluoresce, even after passing the gut tracts of an invertebrate (a). Line scale = 0.2 mm. (E) In burned sagebrush subcanopy soil, litter is charred (a) to a considerable depth. Line scale = 1 mm. (F) Magnified view of charred zone showing charred material (a) and organic coatings on mineral grains (b). Line scale = 1 mm. (G) Close-up view of mineral coatings that form after a wildfire (a). Line scale = 0.2 mm. (H) As a consequence of heat, biotite particles have been separated along cleavage faces (a). Line scale = 0.2 mm.

sagebrush leaves is left. Immediately below the charred zone, some mineral grains have become thickly coated by dark material and plant litter has become darkened (figs. 2F, G). We suspect that these coatings are formed by condensation of organic vapors on the cooler soil mineral particles at depth; these are the hydrophobic compounds so often found after wildfires (DeBano and others 1976). Another consequence of wildfires is the cleavage of biotite flakes (fig. 2H). Nearly all biotite in the surface 2 cm has been cleaved in this manner, which enhances post-wildfire potassium fertility.

Implications

Viable seeds attempting to germinate in the seedbed beneath unburned sagebrush are faced with several obstacles. Sagebrush litter may allelopathically reduce seed germination and plant growth (Groves and Anderson 1981). We suspect the fluorescence in sagebrush leaves is related to the compounds which are responsible for its allelopathy. If this is so, allelopathic compounds are long-lived in the soil. The open framework in unburned sagebrush subcanopies would also be an impediment for seed germination because the hydraulic gradient to the imbibing seed is reduced (Collis-George and Hector 1966). Seedbed conditions following wildfires would appear to mitigate these obstacles. Heat, generated from wildfires, destroys fluorescent compounds, which reduces allelopathic effects of litter. In addition, by compacting the soil seedbed, wildfires increase hydraulic conductivity to the seed. These positive influences of wildfires may be minimized by the negative effects of phytotoxic organic acid production, loss of nitrogen, and loss of carbon. It is exceedingly difficult to predict the synergism of these effects in real field situations. Moreover, these effects would undoubtedly differ depending on the degree of seedbed disturbance following artificial revegetation. We are presently undertaking field experiments to deduce how post-wildfire factors interact to influence natural and artificial revegetation.

References

- Blank, R.R.; Allen, F.; Young, J.A. 1994. Extractable anions in soils following wildfire in a sagebrush-grass community. *Soil Science Society of America Journal*. 58: 564-570.
- Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. In: Klute, A., ed. *Methods of soil analysis, Part 1, Physical and mineralogical methods*. Soil Science Society of America, Madison, WI: 825-844.
- Bremner, J.M.; Mulvaney, C.S. 1982. Nitrogen-Total. In: Page, A.L. and others, eds. *Methods of soil analysis, Part 2; Chemical and microbiological properties*. Soil Science Society of America, Madison, WI: 595-624.
- Cohn, M.A.; Chiles, L.A.; Hughes, J.A.; Boullion, K.J. 1987. Seed dormancy in red rice: II. Monocarboxylic acids, a new class of pH-dependent germination stimulants. *Plant Physiology*. 84: 716-718.
- Collis-George, N.; Hector, J.B. 1966. Germination of seeds as influenced by matric potential and by area of contact between seed and soil water. *Australian Journal of Soil Research*. 4: 145-164.
- DeBano, L.F.; Savage, S.M.; Hamilton, D.A. 1976. The transfer of heat and hydrophobic substances during burning. *Soil Science Society of America Journal*. 40: 779-782.
- DeBano, L.F. 1981. Water repellent soils: A state-of-the-art. Gen. Tech. Report PSW-46. USDA-Forest Service. GPO, Washington, DC. 21 p.
- Eckert, R.E., Jr.; Peterson, F.F.; Belton, J.T. 1986. Relation between ecological range condition and proportion of soil-surface types. *Journal of Range Management*. 39: 409-414.
- Gigon, A.; Rorison, I.H. 1972. The response of some ecologically distinct plant species to nitrate- and to ammonium-nitrogen. *Journal of Ecology*. 60: 93-102.
- Groves, C.R.; Anderson, J.E. 1981. Allelopathic effects of *Artemisia tridentata* leaves on germination and growth of two grass species. *American Midland Naturalist*. 106: 73-79.
- Harper, J.L.; Williams, J.T.; Sagar, G.R. 1965. The behavior of seeds in soil. Part I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. *Journal of Ecology*. 53: 273-286.
- Harper, S.H.T.; Lynch, J.M. 1982. The role of water-soluble components in phytotoxicity from decomposing straw. *Plant and Soil*. 65: 11-17.
- Hendricks, S.B.; Taylorson, R.B. 1974. Promotion of seed germination by nitrate, nitrite, hydroxylamine, and ammonium salts. *Plant Physiology*. 54: 304-309.
- Keeley, J.E.; Morton, B.A.; Pedrosa, A.; Trotter, P. 1985. Role of allelopathy, heat, and charred wood in the germination of chaparral herbs and suffrutescents. *Journal of Ecology*. 73: 445-458.
- Komarova, T.A. 1985. Role of forest fires in the germination of seeds dormant in the soil. *Ekologiya (translated)*. 6: 3-8.
- Lindsay, W.L.; Norvell, W.A. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal*. 42: 421-428.
- Mayer, A.M.; Evenari, M. 1953. The activity of organic acids as germination inhibitors and its relation to pH. *Journal of Experimental Botany*. 4: 257-263.
- McLean, E.O. 1982. Soil pH and lime requirement. In: Page, A.L. and others, eds. *Methods of soil analysis, Part 2; Chemical and microbiological properties*. Soil Science Society of America, Madison, WI: 199-224.
- Nelson, D.W.; Sommers, L.E. 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L. and others, eds. *Methods of soil analysis, Part 2; Chemical and microbiological properties*. Soil Science Society of America, Madison, WI: 539-579.
- Olson, S.R.; Sommers, L.E. 1982. Phosphorus. In: Page, A.L. and others, eds. *Methods of soil analysis, Part 2; Chemical and microbiological properties*. Soil Science Society of America, Madison, WI: 403-430.
- Raison, R.J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformation: A review. *Plant and Soil*. 51: 73-108.
- Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. USDA-SCS Soil Survey. Invest. Rep. 1. GPO, Washington, DC.
- Went, F.W.; Juhren, G.; Juhren, M.C. 1951. Fire and biotic factors affecting germination. *Ecology*. 33: 351-364.