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Effects of Fire on Forest Soil and Nutrient Cycling: An Annotated Bibliography

by

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ABSTRACT

Literature published since 1952 pertaining to prescribed burning and subsequent effects on forest soils is described. The 76 main entries are indexed by subject. Additional undescribed references are also listed. Most researchers have found that effects of fire on soil and related properties varied considerably, depending on fire intensity, geographic region, soil conditions, forest cover, and numerous other factors. Published and ongoing research at the University of New Hampshire is described.

KEY WORDS: Prescribed burning, Wildfire, Forest floor, Litter, Organic matter, Slash

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EFFECTS OF FIRE ON FOREST SOIL AND NUTRIENT CYCLING:

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P.S. Downer and R.D. Harter*

INTRODUCTION

The forest floor and underlying mineral soil contain most of a forest's nutrient reserve. Intensive and long term production on forested land requires that forestry practices be carefully evaluated in light of their potential to modify the cycling of nutrients. Among questioned practices, prescribed burning has received considerable attention because fire is highly visible, and uncontrolled fire is potentially disastrous. However, naturally occurring fire has repeatedly influenced forest development in many geographic regions. Research to determine how important forest nutrients are affected by fire has had conflicting results. Both site improvement and detriment following fire have been documented, and the problem remains largely unresolved.

In theory, certain elements, notably carbon (C) and nitrogen (N), are volatilized when organic material is burned. Among other nutrients, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) remain on the surface in ash. Subsequent movement of the ash material into mineral soil would increase base saturation and pH. Research results have not led to clear conclusions because fire intensity, amount and kind of fuel consumed, soil properties, range of site variability, time since burn, vegetation and climatic conditions differ for each study site.

While the abundance and availability of Ca, Mg, and K are largely related to mineralogical properties, N supply is dependent on microbiological processes. Fire directly effects soil properties which influence microbial activity. Indirectly, then, effects on microorganisms will also be extremely important to the' supply of plant-available nutrients.

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In addition to chemical and physical properties of the soil, suggested mechanisms for the retention of nutrients after fire are: 1) recovery of herbaceous and woody plants, 2) increased microbial assimilation, perhaps involving altered species composition, 3) increased growth of fungal rhizomorphs and fruiting bodies, and 4) lichen and algal growth. Many factors, notably fire intensity, affect post-fire nutrient redistribution, causing individual sites to respond quite differently after burning.

Ecologists have noted that certain plant communities have evolved with frequent fires, and such disturbances perpetuate early successional stages. Prescribed fire, then might be used to maintain subclimax forests such as pine or oak. In dry climates of the western U.S. where fire has been excluded, forest debris can accumulate to hazardous levels, ultimately resulting in severe wildfire. Periodic light fires reduce fuel and prevent such disasters. Prescribed burning at short intervals has been used in forestry practice for site preparation and stand improvement in the southern U.S. The term "prescribed burn" can be defined as fire set for the purpose of burning fuels that naturally occur on the forest floor, while "slash burning" following timber harvest involves a much heavier concentration of fuel and hotter fires. Both burning practices have been found to be less expensive and may have less impact on forest soils than compaction from heavy machinery, or wildfire resulting from fuel accumulation.

The utility of prescribed burning and its potential effects in northern forests have not been established. Several uses in southern New Hampshire are currently under investigation. Prescribed fire has potential in suppressing understory hardwood regeneration that competes with larger, fire-resistant trees like white pine, or impedes establishment of desired regeneration. Improvement of wildlife habitat may result when trees and shrubs respond to fire by sprouting at the ground level, increasing availability and, perhaps, nutrient content of succulent browse. If fires mobilize elements without causing detrimental loss, increased levels of plant nutrients might be channeled into tree growth as well.

In New Hampshire forests, accumulated, slowly decomposing surface organic material is an important reservoir of potentially available plant nutrients and contains a high concentration of plant roots. The organic forest floor is often subdivided into 3 horizons: 1) L (litter) 2) F (fermentation), 3) H (humification). Alternatively the organic horizons are designated as O1 (litter) and O2 (F + H). Of the 3 horizons, the F is the site of most active biological decomposition. Fires which destroy this layer may begin to deplete the site's nutrient pool, or diminish the ability to retain nutrients left in ash after burning. In addition, the removal of vegetation by severe fire results in proportional lack of plant roots to utilize fire-released nutrients as well as the normal load of available nutrients. Even so, severe fires may not deplete forest nutrients as much as was once thought. Earlier literature (prior to 1952) was generally unfavorable toward the use of fire, while research since 1970 has indicated that most fires have relatively little effect on forest soil properties. Some research has indicated possible beneficial effects such as increased soil nutrients.

This annotated bibliography was designed to include references to published literature relating to prescribed burning and subsequent effects on forest soils. Because of the large quantity of literature now available on the subject, a review format could not clearly convey individual research results. Major journals in forestry, soils, and ecology written in the English language were covered in the search, as well as USDA Experiment Station publications. Abstracts in _Soils and Fertilizers_ were also covered. A subject index to entry number is included for specific topic reference. Entries include related materials since 1951, subsequent to a bibliography compiled by Metz (1952).

1. Ahlgren, C.E. 1963. Some basic ecological factors in prescribed burning in northern Minnesota. p. 143-161 in Proceedings 2nd Annual Tall Timbers Fire Ecology Conference, Tall Timbers Research Sta., Tallahassee, Florida.

   Burning reduced the litter layer from 3" to 1", caused greater average temperature fluctuation for one year, and increase in pH, total soil N, phosphates, Mg, K, Ca. Soil P increase and moisture decrease continued through the 2nd season. Soil o.m. was not significantly affected. Plant growth in soil from burned plots was better than in unburned after the first rain.

2. Ahlgren, I.F. 1974. Effects of fire on organisms. p. 47-72 in T.T. Kozlowski and C.E. Ahlgren (eds.) Fire and Ecosystems. Academic Press, N.Y.

   Based on a review of literature, the author suggested that effects on soil organisms are greater in forests than grassland. Populations may be immediately reduced, but some subsequently increase to greater than preburn levels. Many population reductions do not seem to be directly caused by heat of fire. However, postfire changes vary greatly.

3. Ahlgren, I.F. and C.E. Ahlgren. 1960. Ecological effects of forest fires. Bot. Rev. 26:483-533.

   This paper summarizes literature to date on the effects of fire on soil, soil organisms, and plant succession. Generally, increases in soil temperature extremes, Ca, P, and K were shown; N reports were contradictory.

4. Ahlgren, I.F. and C.E. Ahlgren. 1965 Effects of prescribed burning on soil microorganisms in a Minnesota jack pine forest. Ecol. 46:304-310.

   Plate counts and carbon dioxide evolution showed that numbers and activity of microorganisms decreased immediately after fire but increased greatly following the first rainfall, attributed to leaching down of ash materials. Streptomycete populations increased in the 3rd season. Species composition changes were not studied.

5. Alban, D.H. 1977. Influence on soil properties of prescribed burning under mature red pine. USDA For. Serv. Res. Pap., NC-139. North Cent. For. Exp. Sta., St. Paul, Minn.

   In Minnesota, burning at various intervals to control understory shrubs resulted in decreased quantities of organic matter (o.m.) and certain nutrients in forest floor horizons (L,F,H). In mineral soil, however, pH, cation exchange capacity (CEC), P, Ca, Mg, and K increased, indicating transfer of nutrients from organic to mineral horizons.

6. Allen, S.E. 1964. Chemical aspects of heather burning. J. Appl. Ecol. 1:347-368.

   In Great Britain, soil monoliths 14-30 cm deep and 20-30 cm wide were removed from the field and treated under laboratory conditions with ash, simulated rain, and direct burning of surface litter. Soil and leachates were analyzed. Peat soils retained most of the ash nutrient additions in the top 2 cm and showed soil nutrient gains. Sandstone soils showed net loss of K and no change in Ca, Mg, and P.

7. Austin, R.C. and D.H. Baisinger. 1955. Some effects of burning on forest soils of western Oregon and Washington. J. Forestry. 53:275-280.

   After severe to moderate slash burning and cleanup, soil water holding capacity was reduced 33.7%, o.m. decreased by 75.5%, total N decreased 67% while P, K, Ca and Mg increased. The pH increased from 4.5 to 7.6. Effects were confined to the top 5 cm of soil. Two years later, little or no recovery had occured; P, K, and Mg had returned to non-burn levels, but Ca was still 3 times that in unburned soil.

8. Baker, J. 1968. Effects of prescribed burning on nutrient status of forest soils and seedling growth. Forestry Chron. 44:40.

   Immediate effects of fire were increased pH, extractable cations, and in some cases CEC; % carbon and C/N ratio decreased. Field moisture fluctuated more rapidly, but no physical properties were significantly changed. Conifer seedling growth was better on unburned soil, but scarification improved the burned soil.

9. Beaton, J.D. 1959. The influence of burning on the soil in the timber range area of Lac le Jeune, British Columbia. I. Physical properties. II. Chemical properties. Can. J. Soil. Sci. 39:1-11.

Total porosity decreased with burning on most sites, especially on twice-burned areas; some areas showed increased total porosity due to increased grass vegetation. Bulk density increased and infiltration rate decreased. Average soil temperature increased by 8 C on burned sites and by 16 C on twice-burned sites. Organic matter and total N decreased in the O horizon, no trend was seen in the A2. Total P varied, but acid-soluble P decreased in the O, no change in the A2.

10. Biswell, H.H. and A.M. Schultz. 1957. Surface runoff and erosion related to prescribed burning. J. Forestry 55:372-374.

In Ponderosa pine forests, prescribed burning reduced the litter and duff by about 50%. No accelerated erosion and runoff was determined to be due to burning on slopes of 20-43%, since mineral soil was not exposed; nearby logging and skid roads did show pronounced erosion. Prescribed burning could be done every 4 or 5 years, maintaining sufficient duff to prevent erosion.

11. Bollen, W.B. 1974. Soil microbes. p. B1-B41. <u>in</u> O.P. Cramer (ed.) Environmental effects of forest residues management in the Pacific northwest: a state-of-knowledge compendium. USDA For. Serv. General Technical Report PNW-24. Portland, Oregon.

Detailed description of nutrient cycling and microorganisms in Douglas-fir forests and reference to other research is given. Effects from burning were too variable to allow generalization about short-term or long-term effects on soil microorganisms. Nitrogen loss and soil physical property effects from burning may be very unfavorable for microorganisms; stimulation of microorganisms to increase the rate of o.m. turnover may be preferable to burning forest residues.

12. Boyle, J.R. 1973. Forest soil chemical changes following fire. Communications in Soil Sci. and Plant Anal. 4:369-374.

    Slash burning on coarse sandy soil resulted in increased pH, P, K, and Ca in the top 20 cm of soil during the first 15 months after fire, and increased soil organic matter, but no change in total N.

13. Brown, G.W., A.R. Gahler, and R.B. Marston. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon Coast range. Water Resources Research 9:1450-1453.

    Nitrate-N dissolved in stream water increased from 4 to 15 kg/ha after logging and burning, compared to check that was logged but not burned, and returned to normal after 3 years. K increased about 3 times over the unburned check but the increase lasted only 1 month. Total P was unchanged.

14. Burns, P.Y. 1952. Effect of fire on forest soils in the pine barren region of N.J. Yale Univ. School of Forestry Bull. 57.

    This paper reviews older literature on effects of fire. Generally, conflicting results were common, especially concerning nitrogen. Differing results were partly due to differences in measurement techniques and interpretation, as well as different soils and locations.

15. Chertov, O.G. 1973. The humus of weakly developed forest podzols of the Karelian Isthmus. Pochnovedenie (1973) No. 1. 35-42. (c.f. Soils Fert. 36:326.)

    Forest fires in pine and spruce-fir vegetation decreased acidity and N of A and B horizons. Humic acid content and P increased. Increased rate of litter decomposition was observed after fires.

16. Christensen, N.L. 1973. Fire and the nitrogen cycle in California Chaparral. Science 181:66-68.

    Seasonal changes in ammonium and nitrate concentrations as well as total N were analyzed in burned and unburned soils. Total N and o.m. decreased after burning, but both ammonium and nitrate-N were significantly higher in burned soils than unburned. Continued increase in nitrate-N occurred throughout the growing season on burned areas. Nitrate was also leached from shrubs on unburned soils.

17. Clayton, J.L. 1976. Nutrient gains to adjacent ecosystems during a forest fire: an evaluation. Forest Sci. 22:162-166.

Precipitation falling through smoke was collected at sites adjacent to a forest fire in central Idaho. Concentrations of Na, K, Ca, Mg, and total N were 20 to 70 times greater than that in normal precipitation. Annual gains to the adjacent ecosystem by this means would be 1-4% of the total annual gain, and probably does not represent an important input.

18. Czapowskyj, M.M., R.V. Rourke, and R.M. Frank. 1977. Strip clearcutting did not degrade the site in a spruce-fir forest in central Maine. USDA For. Serv. Res. Pap. NE-367. Northeast For. Exp. Sta., Upper Darby, Pa.

Nutrient concentrations were determined in forest floor and mineral soil 8 years after clearcutting and slash disposal treatments. Effects from burning slash were compared to leaving slash or removal by skidding, as well as to an undisturbed control. Variability due to differences in site soil and drainage characteristics was usually greater than differences due to treatments. Most of the data pertained to poorly drained sites. There were no significant differences among treatments by multivariate analysis, but burning tended to have less effect than slash removal by skidding.

19. DeBano, L.F. and C.E. Conrad. 1978. The effect of fire on nutrients in a chaparral ecosystem. Ecol. 59:489-497.

Effects of fire on nutrient distribution among plants, litter, and soil in California were studied before and after burning using paired plots. About 66% of plant material was consumed by burning where flame temperatures were greater than 1000 C in the canopy. While o.m. was reduced an average of 46%, reduction ranged from 0 to 76%. Losses of N and K were detected, but no significant changes in P, Ca, Na, or pH occurred.

Some additional K, Ca, Mg, and Na were lost through runoff and erosion after fire.

20. DeBano, L.F., L.D. Mann, and D.A. Hamilton. 1970. Translocation of hydrophobic substances into soil by burning organic litter. Soil Sci. Soc. Am. Proc. 34:130-133.

Substances distilled downward from a burned litter layer in California chaparral and induced greater water-repellency in sandy soils than in fine-textured soils. Laboratory apparatus was used to heat soils to prescribed temperatures and water-repellency was assessed by contact angles.

21. DeBano, L.F. and R.M. Rice. 1973. Water repellent soils: their implication in forestry. J. Forestry 71: 220-223.

Water repellent soils are likely to be present in most vegetation types, and to be increased by burning. Hotter fires induce repellency in subsurface areas, resulting in all subsequent water retention concentrated in the top soil layer. Excess erosion and runoff could occur. Mechanical and chemical treatment to diminish repellency had only minor success.

22. DeBell, D.S. and C.W. Ralston. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc. 34:936-938.

Smoke from burning loblolly pine litter was analyzed for ammonium and nitrates; no ammonium was detected. Most of the 62% of the total N that was released was thought to have been volatilized as nitrogen gas. Only a small amount of the N could be returned to soil through precipitation and made available for tree growth.

23. DeByle, N.V. 1976. Soil fertility as affected by broadcast burning following clearcutting in Northern Rocky Mountain larch/fir forests. p. 447-464 in Proceedings, 14th Annual Tall Timbers Fire Ecology Conference. Tall Timbers Research Sta., Tallahassee, Florida.

Comparison was made between wildfire conditions and logging and slash burning conditions. After wildfire, pH increased initially, then decreased slightly after 2 years; pH increased gradually over 2 years on the logged and burned site. No change was found in total N or CEC of the mineral soil but o.m. in the surface 10 cm decreased. Total P, K, and Na increased slightly the first year, but decreased to below preburn levels the second year; soluble Ca and Mg decreased in all soil samples. The data were grouped by aspect.

24. DeByle, N.V. and P.E. Packer, 1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. p. 296-307 in Watersheds in Transition. American Water Resources Association.

Total nutrient losses due to overland flow after burning in Montana on slopes ranging from 9-35% were twice that of unlogged and unburned controls. Dissolved K and Na losses were especially great; Ca and Mg were lost in both dissolved and in sediment form. Losses of P were negligible.

25. Dunford, E.G. 1958. Forest soils: enigma of northwest watersheds. p. 22-23 in 1st North American Forest Soils Conference. Mich. State Univ.

In reviewing forest burning effects, contradictory reports indicate that fire as a silvicultural tool should not receive blanket approval. The reported temporary effects of increased soil nutrients could result in net losses due to leaching.

26. Dyrness, C.T. and C.T. Youngberg. 1957. Effect of logging and slash burning on soil structure. Soil Sci. Soc. Am. Proc. 21:444-447.

Slash burning had no appreciable effect on percentage of water-stable aggregates except in severly burned spots where aggregates decreased. Severely burned spots occurred on 8% of plot area in western Oregon Douglas-fir.

27. Dyrness. C.T. 1976. Effect of wildfire on soil wettability in the high Cascades of Oregon. USDA For. Serv. Res. Pap. PNW-202. 18 p.

Considerable runoff and erosion was observed due to decreased infiltration rate after severe wildfire. Subsurface (2-9") sandy loam soils became highly non-wettable for 5 years after burning, abrubtly decreasing in the 6th year. Substances causing repellency appeared to be large amounts of burned pine litter (products of decomposition and possibly fungal mycelia). Use of wetting agents did not improve soil wettability.

28. Fuller, W.H., S. Shannon, and P.S. Burgess. 1955. Effects of burning on certain forest soils of northern Arizona. Forest Sci. 1:44-50.

Effects of light controlled burning, uncontrolled (severe) burning and slash burning were compared. Severe burning resulted in weaker soil structure, and compaction of surface soil by raindrop action. Soil pH, concentrations of available P, exchangeable Na, K, Ca, and soluble salts increased. Organic carbon and C/N ratio decreased. The ratio of bacteria to fungi increased.

29. Gagnon, J.D. 1965. Nitrogen deficiency in the York River burn, Gaspe, Quebec. Plant and Soil 23:49-59.

Twenty years after a severe spruce forest fire, soil pH was .6 to .8 unit lower than the pH of 4.6-4.8 in a non-burned control area. Total N was 80% lower, and P was 70-90% lower than in the non-burned area. K was lower in the A2, but twice as high in the B2; Ca and Mg were greater in the burned soil. Vegetation on the burned site was confined to lichens which contained relatively high concentrations of N, K, Ca, and Mg.

30. Grier, C. C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Can J. For. Res. 5:599-607.

In central Washington, intense fire burned nearly all surface organic material, leaving a surface ash layer. Losses of Ca and Mg were small relative to N and K. Nitrogen decreased in surface soil but increased in subsoil. Total N lost from the site was proportional to the loss of fuel dry weight. Little change was found in nutrient status of mineral soil.

31. Grigal, D.F. and J.G. McColl. 1975. Litter fall after wildfire in virgin forests of northeastern Minnesota. Can. J. For. Res. 5:655-661.

After a spring wildfire, more litter fell in burned areas than in unburned due to conifer needle drop and woody material from dead trees. Less litter fell on burns in the third year after fire.

32. Grigal, D.F., and J.G. McColl. 1977. Litter decomposition following forest fire in northeastern Minnesota. J. Appl. Ecol. 14:531-538.

Decomposition of aspen and aster leaf litter placed in litter bags was the same in burned or unburned areas.

33. Gupta, P.L. and I.H. Rorison. 1975. Seasonal differences in the availability of nutrients down a podzolic profile. J. Ecol. 63:521-533.

Seasonal flushes in available P and N occurred in May-June and Jan.-Feb. in Great Britain, but times of peak availability may vary from year to year and site to site. Seasonal depression in available P and N was thought due to plant uptake during summer months. Depression of pH occurred in June-July. Normal seasonal variation needs to be considered in fire effects on soil when measuring available plant nutrients.

34. Harvey, A.E., M.F. Jurgensen, and M.F. Larsen. 1976. Intensive fiber utilization and prescribed fire: effects on the microbial ecology of forests. USDA For. Serv. General Technical Report INT-28. Intermountain For. and Range Exp. Sta., Ogden, Utah. 46 p.

Literature on the effects of prescribed fire on soil properties which affect microorganisms is summarized. In addition to direct effects, saprophytic and pathogenic activities are affected by humidity, aeration, temperature, moisture, pH, C/N ratio, and soil nutrient changes caused by fire. Extensive bibliographies and suggestions of areas where research is needed are included.

35. Humphreys, F.R. and M.J. Lambert. 1965. An examination of a forest site which has exhibited the ash-bed effect. Aust. J. Soil Res. 3:81-94.

Nine years after planting radiata pine in Australia on sites where Eucalyptus slash had been burned, trees were higher and had twice the volume of those planted on unburned sites. Foliage analysis indicated higher P content than trees from unburned sites. Burned soils had higher pH and exchangeable Ca. Loss on ignition, total N, ammonium, total P, exchangeable K, Mg, and Na were the same for burned and unburned sites. Authors felt that increased P availability resulted from soil changes which altered the composition of soil P, including pH and aluminum effects. Additionally, higher soil Ca may have stimulated root and mycorrhizal development.

36. Jalaluddin, M. 1968. Micro-organic colonization of forest soil after burning. Pak. J. Sci. 21:42-44.

Burning of 1.5-2 m plots increased pH 3 units initially, but pH returned to preburn level after 6 months. Soil was reinvaded rapidly from margin areas and by air-borne spores. Species included a number of pyrophilous fungi not found in adjacent unburned areas.

37. Jorgensen, J.R. and C.S. Hodges. 1970. Microbial characteristics of a forest soil after 20 years of prescribed burning. Mycologia 62:721-726.

Sampling of the sites studied by Metz (1961) and Wells (1971) in South Carolina showed no significant effects on numbers of fungi, bacteria, or actinomycetes in mineral soil. Organic layer numbers were reduced considerably in proportion to decreased depth of O1 and O2 horizons. Certain species of fungi increased in annually burned plots.

38. Jorgensen, J.R. and C.G. Wells. 1971. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil Sci. Soc. Am. Proc. 35:806-810.

Acetylene-ethylene assay for N-fixation proved to be more sensitive than carbon dioxide evolution or Kjeldahl analysis. Samples from burned plots in South Carolina showed an average of 10 times greater N-fixing ability than those from unburned plots in 0-1 cm soil. N-fixation was localized since 2/3 of the samples showed little or no N-fixation, and some fixed 50 times the amount in unburned samples. Greater soil moisture apparently favored such high rates of N-fixation. Soil characteristics for this study area were reported by Wells (1971).

39. Klemmedson, J.O. 1976. Effect of thinning and slash burning on nitrogen and carbon in ecosystems of young dense pondersoa pine. Forest Sci. 22:45-53.

The authors suggested that one result of burning forest litter may be a shift to organic matter that is more resistant to decay. Therefore, less N would be available in the short and long run. Larger and fewer slash piles might reduce N loss.

40. Klemmedson, J.O., A.M. Schultz, H. Jenny, and H.H. Biswell. 1962. Effect of prescribed burning of forest litter on total soil nitrogen. Soil Sci. Soc. Am. Proc. 26:200-202.

Soil samples were removed from a ponderosa pine stand dried and sieved, and laboratory-analyzed. Contained samples were replaced and rewetted before burning. Organic layers were reduced by 1/4 after light burning, 1/2 after severe burning. Light burning and no burning resulted in a slight net gain of nutrients in mineral soil over 18 months; intense burning showed a slight decrease. Authors felt increases were due to leaching of nitrogenous compounds from decomposing organic material. Possible effects from drying and sieving, eliminating plant roots and other organisms, were not considered.

41. Knight, H. 1966. Loss of nitrogen from the forest floor by burning. Forestry Chron. 42:149-152.

Forest litter from Western hemlock and Douglas-fir stands was burned in a muffle furnace at various temperatures. Little N volatilized from litter burned at temperatures up to 200 C, but loss increased with temperature.

42. Knighton, M.D. 1977. Hydrologic response and nutrient concentrations following spring burns in an oak-hickory forest. Soil Sci. Soc. Am. J. 41:627-631.

In an area with fine silty soils, burning reduced L and F by as much as 30%. There was no change in soil o.m., but there were slight increases in phosphate, nitrate, Ca, Mg, and K in soil leachate collected at 15 cm depth.

43. Lewis, W. M. 1974. Effects of fire on nutrient movement in a South Carolina pine forest. Ecol. 55:1120-1127.

Rainwater, runoff, groundwater and leachate derived from litter had greater quantities of nutrients after burning. Nitrate and phosphate did not increase in leachate until some time later, suggesting biological release processes. Cations, however, were highly susceptible to various means of translocation.

44. Lloyd P.S. 1971. Effects of fire on the chemical status of herbacious communities of the Derbyshire Dales. J. Ecol. 59:261-273.

Retention of soluble nutrients in soil at intervals after fire was studied in blocks of soil in the laboratory. Potassium leached from soil after plant ash addition, but P and Ca did not. A short-term increase in P and in one case, N, in plant tissues occurred during the first season after fire. Effects from fire on the soils studied were not great.

45. Lunt, H.A. 1951. Liming and 20 years of litter raking and burning under red and white pine. Soil Sci. Soc. Am. Proc. 15:381-390.

Comparison of mechanical litter removal and removal by burning showed that pH increase from liming was similar to pH increase by burning. Total N and organic C increased in mineral soil over check in all treatments, but was highest on the burned treatment. Available P in the All horizon of burned plots increased markedly over other treatments. Liming of burned areas increased the effect even more. Effects on volume of wood and height growth were shown.

46. McColl, J.G. and D.F. Grigal. 1977. Nutrient changes following a forest wildfire in northern Minnesota: effects in watersheds with differing soils. Oikos 28:105-112.

Nutrient input to nearby lakes was monitored for 3 years following a spring wildfire. Input differed due to soil type but was unaffected by the fire. Authors felt that revegetation retained fire-released nutrients in the forest.

47. Mayland, H.F. 1967. Nitrogen availability on fall-burned oak-mountainmahogany chaparral. J. Range Manage. 20:33-35.

One year after burning vegetation in winter, total N increased in ash and mineral soil by 20%; available N also increased in burned plots. Average soil pH increased from 6.5 to 7.0 after burning. Increased uptake of N by barley plants indicated increased available N.

48. Metz, L.J. 1952. Annotated bibliography on effect of fire on soil. Southeast. For. Exp. Sta., Asheville, N.C. 7p.

The 32 entries cover research from 1928-1952.

49. Metz, L.J., T. Lotti, and R.A. Klawitter. 1961. Some effects of prescribed burning on coastal plain forest soil. USDA For. Serv. Sta. Paper 133, Southeast. For. Exp. Sta.,Asheville, N.C. 10 p.

No significant differences were found in soil physical properties. Organic matter increased in mineral soil. Slight increases in N, available P, Ca, K, and Mg in soil resulted from annual burning.

50. Moore, D.G. and L.A. Norris. 1974. Soil processes and introduced chemicals. p. C1-C33. in O.P. Cramer (ed.) Environmental effects of forest residues management in the Pacific northwest: a state-of-knowledge compendium. USDA For. Serv. General Technical Report PNW-24. Portland , Oregon.

Use of fire for disposal of logging residues is still the most controversial method. The nutrient capital in organic surface layers, although it represents only a small % of the total, is the site where nutrients are being most actively recycled; destruction of surface o.m. and its organisms therefore must have substantial impact. Pit burning with very intense fires results in loss of sulfur and boron as well as nearly all N. Concentration of nutrients that results from burning in one spot exceeds the capability of underlying soil to absorb the nutrients. Exclusion of fire where rate of litter accumulation exceeds decomposition would be a greater hazard than periodic light burns if intense wildfire results.

51. Packer, P.E. and B.D. Williams. 1974. Logging and prescribed burning effects on the hydrologic and soil stability behavior of larch/Douglas-fir forests in the northern Rocky Mountains. p. 465-479 in Proceedings 14th Annual Tall Timbers Fire Ecology Conference, Tall Timbers Research Sta., Tallahassee, Florida.

Logging exerted a beneficial effect on infiltration and stability of soil as organic debris was incorporated into mineral soil by the action of heavy machinery. Burning was detrimental, however, with effects lasting longer on south slopes, recovering sooner on north slopes. South slopes were driest and showed the most intensive burn effects. Runoff and erosion increased after burning, but recovery was apparent after 3 years except on south slopes.

52. Ralston, G.W. and G.E. Hatchell. 1971. Effects of prescribed burning on physical properties of soil. p. 68-84. in Proc. Prescribed Burning Symp. USDA For. Serv., Southeast. For. Exp. Sta., Asheville, N.C.

Prescribed burning in the Southeast caused no detectable change in the total amount of o.m. in surface soils. Severe fires can cause irreversible changes in clay structure; temperature of 100-200 C drives off structural water, producing properties in montmorillinite similar to sand or gravel. Removal of the litter layer exposes mineral soil to raindrop action, increases erosion, and results in higher average soil temperatures, which may favor subclimax species.

53. Rothacher, J. and W. Lopushinsky. 1974. Soil stability and water yield quality. p. D1-D23 in O.P. Cramer (ed.) Environmental effects of forest residues management in the Pacific Northwest: a state-of-knowledge compendium. USDA For. Serv. General Technical Report PNW-24. Portland, Oregon.

Prescribed light burns which leave o.m. on the soil surface have only minimal influence on watersheds. Piling and burning and pit burning leave areas of soil uncovered and lead to greater surface runoff. Controlled burns are less damaging to soil surface than wildfires but may release as much chemical to stream water as wildfires.

54. Rowe, J.S. and G.W. Scotter. 1973. Fire in the boreal forest. Quaternary Res. 3:444-464.

In boreal forests, fire provides a means of rapid organic matter turnover where annual average temperatures are too low to accomplish rapid decomposition. Sphagnum bogs can develop in areas of rising water tables following removal of trees by fire. Where soils are shallow, they may be destroyed by fires. Burning of surface humus raises soil temperature in summer; many other side-effects can occur in permafrost areas.

55. Russell, J.D., A.R. Fraser, J.R. Watson, and J.W. Parsons. 1974. Thermal decomposition of protein in soil organic matter. Geoderma 11:63-66.

Ammonia was evolved from protein structures in soil clay-organic complexes heated in the lab to 100 C; 66% of the N in samples was released after heating to 400 C. Most of the ammonia release occurred from 300-400 C; higher than 400 C, half the N was released as other volatile products. The formation of ammonia at lower temperatures may contribute to increased available N after burning organic material.

56. St. John, T.V. and P.W. Rundel. 1976. The role of fire as a mineralizing agent in a Sierran coniferous forest. Oecologia 25:35-45.

Soil C, total N, and C/N ratio were significantly lower after burning while ammonium, nitrate, water-soluble P, Ca, Mg, K, and pH were significantly higher.

57. Savage, S.M. 1974. Mechanism of fire-induced water repellency in soil. Soil Sci. Soc. Am. Proc. 38:652-657.

Organic substances volatilized and moved into underlying sand during burning of litter in the laboratory, and condensed on cooler soil below. The resulting area of water-repellency then increased and was "fixed" with additional transfer of heat into soil.

58. Savage, S.M., J.P. Martin, and J. Letey. 1969. Contribution of some soil fungi to natural and heat-induced water repellency in sand. Soil Sci. Soc. Am. Proc. 33:405-409.

Laboratory cultures of the common fungi Penicillium nigricans and Aspergillus sydowi in sand caused water repellency in the absence of plant material. Subsequent heat treatment at 200-400 C increased the effect. The water repellent substances were extractable by water and methanol but not ether and acetone; they were not extractable at all after heating. Numerous organic compounds tested were capable of causing water repellency in sand. The extent of water repellency in soil could depend on soil factors affecting fungal growth as well as litter decomposition.

59. Savage, S.M., J. Osborn, J. Letey, and C. Heaton. 1972. Substances contributing to fire-induced water repellency in soils. Soil Sci. Soc. Am. Proc. 36:674-678.

At 300-400 C, aliphatic hydrocarbons coming from undecomposed and partially decomposed plant materials heated in the lab induced water-repellency in sand. The water-repellent substances were not extractable with solvents and were thought to be polar molecules.

60. Scott, V.H. and R.H. Burgy. 1956. Effects of heat and brush burning on the physical properties of certain upland soils that influence infiltration. Soil Sci. 82:63-70.

Soil columns heated in a laboratory oven at various tempertatures showed increased infiltration rate, attributed to increased water-stable aggregates.

61. Scotter, G.W. 1963. Effects of forest fires on soil properties in northern Saskatchewan. Forestry Chron. 39:412-421.

After forest fire, soil temperatures were 10.5 F higher than in unburned soil at 2.5 cm, and 9.7 F higher at 6.5 cm. Infiltration rates were unchanged for sandy loams. CEC decreased on 3 of 4 sites, increased on 1; pH increased on all burned sites. Exchangeable Ca increased on 3 sites, was unchanged on 1. No change was found in K, Mg, or Na. Total N was inconsistent, but available P was greater on burned sites.

62. Sharrow, S.H. and H.A. Wright. 1977. Effects of fire, ash, and litter on soil nitrate, temperature, and moisture, and tobosa grass production in the Rolling Plains. J. Range Manage. 30:266-270.

Although burning induced higher grass yields and higher soil temperature and nitrate than that on unburned areas, moisture was usually the more limiting factor. Therefore, in dry years, burning may be a disadvantage.

63. Sims, H.P. 1976. The effect of prescribed burning on some physical soil properties of jack pine sites in southeastern Manitoba. Can. J. For. Res. 6:58-68.

Prescribed burning was done for mineral seedbed preparation after clearcutting. Temperatures recorded during burns were 52 C at 5 cm depth and 300 C at the organic/mineral soil interface. Over 1/3 of the organic forest floor was burned, but there was much variation. Organic matter decreased in the Bt horizon, gradually increasing during the following year. Soil moisture was greatly reduced compared to a scarified mineral seedbed. Temperature and moisture extremes resulting from burns severe enough to create a mineral seedbed, were too detrimental to jack pine seedlings to be worth cost. Scarification still must be done after light burns.

64. Smith, D.W. 1970. Concentrations of soil nutrients before and after fire. Can. J. Soil Sci. 50:17-29.

Severe fire in northern Ontario with temperatures exceeding 1000 C, burned most of the organic forest floor in a jack pine community. Cations released on burning were mainly water-soluble; CEC increased for 3 months after the burn, then decreased to preburn levels or lower. Organic matter decreased in the upper few cm, but increased in lower horizons. Water soluble K, Na and Ca increased at first, then decreased to below preburn levels. Acid-soluble K increased at first, Na did not change; then both decreased to below preburn level after 13 months. Fe and Al increased in the O1+O2, then Fe decreased to below preburn. Extractable P initially increased, then decreased in upper horizons and increased in lower.

65. Stark, N.M. 1977. Fire and nutrient cycling in a Douglas-fir/larch forest. Ecol. 58: 16-30.

Prescribed burning for fuel load reduction in Montana produced temperatures reaching 300 C and higher at the soil surface. Concentrations of Ca, Mg, and nitrate were significantly higher in soil water sampled with lysimeters after these burns. Ca input by precipitation was enough to offset the loss. Magnesium, however, was not replenished by rainfall. In general, anions moved into soil more slowly than cations. Fall burns were hotter than spring, and effects were generally proportional to burn intensity. Litter decomposition rate increased slightly on severely burned sites. Fe, Al, and Mn increased in soil water.

66. Sweeney, J.R. and H.H. Biswell. 1961. Quantitative studies of the removal of litter and duff by fire under controlled conditions. Ecol. 42:572-575.

Litter was removed and measured, then replaced before broadcast burning in a ponderosa pine forest type in California. Average loss was 75% of the O1 and 23% of the O2; remaining litter was enough to cover the soil. Percentage loss increased with the amount available; other factors were temperature, humidity, wind, and slope.

67. Tarrant, R.F. 1956. Effects of slash burning on some soils of the Douglas-fir region. Soil Sci. Soc. Am. Proc. 20:408-411.

Severe burning amounted to 2.8% of total area, light burn, 46.95%, and unburned, 47.15%. Soil responses to burning depended on these varying burn intensity areas and soil texture. Change in pH after burning was typically from pH 4.4 to 7.2 and was still higher than unburned 4 years later. Light burning stimulated nitrification and increased acid-soluble P and exchangeable K. Severe burning strongly reduced N content, but increased P and K more than light burning. CEC was not effected by light burning but was strongly reduced by severe burning. No differences were found in seedling growth on burned and unburned soils. One and 2 year-old seedlings grown on burned soil had 20% less ectomycorrhizae.

68. Tarrant, R.F. 1956. Effects of slash burning on some physical soil properties. For. Sci. 2:18-22.

Severe burning (complete removal of litter) lowered the percolation rate to 30% and macro-pore space to 25% of unburned in 2 soils, sandy loam and sandy clay loam. Light burning did not impede percolation (increased in the sandy loam); bulk density decreased, macro-pore space was reduced. Severely burned areas were small, discontinuous patches amounting to only a small portion of plots in Douglas-fir forests.

69. Tarrant, R.F. 1956. Changes in some physical soil properties after a prescribed burn in young pondersosa pine. J. Forestry. 54:439-441.

(Same material, with additional illustrations)

70. Viro, P.J. 1974. Effects of forest fire on soils. p. 7-45 *in* T.T. Kozlowski and C.E. Ahlgren (eds.) Fire and Ecosystems. Academic Press, N.Y.

Burning in Scandinavia to reduce depth of the humus layer in spruce forests resulted in less water retention and increased soil temperature, both desired results. An increase in nitrification was attributed to higher pH. Changes in the C/N ratio affected microbial activity. While K and Mg tended to be leached into mineral soil, Ca was better adsorbed in humus. Phosphorus did not change appreciably. Organic matter in mineral soil was 10% less than in unburned areas, attributed to increased decomposition. Weight of the humus layer diminished from 33 to 25 T/ha. The author suggested that burning may eliminate rapidly decomposable surfaces, leaving lignins which are more slowly decomposed.

71. Vlamis, J., H.H. Biswell, and A.M. Schultz. 1955. Effects of prescribed burning on soil fertility in second growth pondersosa pine. J. Forestry 53:905-909.

Greenhouse tests were done to determine the ability of soils after prescribed burning to supply plant nutrients. Severely burned soil showed an increase in N supply over lightly burned and unburned soil. The effect was greatest in surface soil, and in the first year after burning. Plants growing on one burned soil showed an increase in P as a result of burning; the possibility that P-fixation precluded the effect in the other soil was suggested.

72. Wagle, R.F. and J.H. Kitchen. 1972. Influence of fire on soil nutrients in a ponderosa pine type. Ecol. 53:118-125.

Lettuce and ponderosa pine seedlings were used as indicator plants and grown in soil from wildfire and unburned areas to test the nutrient supplying ability of sites with different fire histories. Dry weight yields of ponderosa pine seedings (among unamended soils only) were highest on soil from a recently burned area.

73. Wells, C.G. 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. p. 86-97. in Proc. Prescribed Burning Symp. USDA For. Serv., Southeast. For. Exp. Sta., Asheville, North Carolina.

Effects were studied for 20 years after annual burning in winter and summer, and after periodic winter and summer burns. After annual burning, effects were greatest in the first 10 years. Summer burning was more severe than winter in annual as well as periodic burns. Organic matter and N increased by 30% in 0-2" of mineral soil, while the O1+O2 was diminshed by 65% in annual burn plots. Periodic burns showed no significant difference in total N; some annually burned areas showed increases in N, attributed to microbial N fixation in wet spots. P increased in the 0-4" depth of soil in annual winter burns; K was unchanged; Ca and Mg increased in 0-2". Average pH increased from pH 3.5 to 4.0. Seedlings showed greater uptake of P on burned plot soil, but less N.

74. Wells, C.G., R.E. Campbell, L.F. DeBano, C.E. Lewis, R.L. Fredriksen, E.C. Franklin, R.C. Froelich, and P.H. Dunn. 1978. Effects of fire on soil: a state-of-knowledge review. USDA For. Serv. General Technical Report WO-7. 34 p.

The authors of this current review have been directly involved in research regarding fire effects on soil. The report encompasses chemical, physical, and microbiological aspects of burning, and addresses management and nutrient cycling in forest and rangeland. An extensive list of references is included.

75. White, E.M., W.W. Thompson, and F.R. Gartner. 1973. Heat effects on nutrient release from soils under ponderosa pine. J. Range Manage. 26:22-24.

Samples of litter, mor humus, and upper Al horizons were heated in laboratory ovens to temperatures ranging from 25-500 C. Water-soluble P and K concentrations increased up to 200 C. At higher temperature, water- soluble P and total N decreased in all samples, but water-soluble K increased in the Al material.

76. Youngberg, C.T. 1953. Slash burning and soil organic matter maintenance. J. Forestry 51:202-203.

Slash burning in Douglas-fir forests contributed to erosion during the winter rain season, and substantial organic matter depletion. Slash burning following 4-5" of rainfall resulted in no o.m. loss and no soil damage.

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FIRE RESEARCH AT THE UNIVERSITY OF NEW HAMPSHIRE

PUBLISHED

Downer, P.S. 1979. Influence of burning on distribution and cycling of elements in New Hampshire forest soil profiles. Master's Thesis, Institute of Natural and Environmental Resources, Univ. of New Hampshire, Durham, N.H.

Evaluates light burning and severe burning using a torch as well as actual prescribed burning. Effects on soil and surface organic matter after light burning were very small. While severe burning resulted in some net losses of nutrients, light burning redistributed small quantities of C, N, and K from surface into underlying material. Severe burning resulted in increased susceptibilty to runoff or leaching during rain and little movement of nutrients into mineral soil.

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Philleo, B., J.B. Cavanagh, and D.P. Olson. 1978. Browse utilization by deer in relation to cutting and prescribed burning in southeastern N.H. p.16-26 in Transactions of the Northeastern Section, The Wildlife Society. 35th Northeastern Fish and Wildlife Conference, White Sulphur Springs, W. Va.

Deer utilized sprouts more heavily on burned areas than nonburned.

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Herbaceous plants showed only minor changes after light burning, with some species decreasing in number while others tended to increase.

IN PROGRESS, 1979

Bauer, K. Effects of fire on soil microorganisms. Master's Research, Dept. of Microbiology

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Trotta, G.A. Effects of prescribed burning on woody plants. I.N.E.R.

Weyrick, R. Use of prescribed burning in management of young white pine stands. I.N.E.R.

SUBJECT INDEX