Soil Properties Associated with Aspen to Conifer Succession

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In a companion paper Bartos and Campbell (p. 17–24) discuss reasons for the decline of aspen (*Populus tremuloides* Michx.) in the western U.S. using the Burnt Flat Analysis Area, Fishlake National Forest, Utah as an example. Many resource managers have expressed concern over the suitability of late successional soils on sites currently dominated by conifer or sagebrush to once again support aspen. Cryer and Murray (1992) warned that aspen may have difficulty occupying late successional sites where clearcutting is used as a restoration tool. They attribute the observed mortality of aspen suckers on such sites to low soil pH and nutrient levels.

Declining aspen stands in the Burnt Flat Analysis Area and elsewhere are prime candidates for restoration treatments. However, it is not known if late successional soils in the Burnt Flat Analysis Area have lower nutrient levels than soils under stable (regenerating) aspen stands. If significant loss of nutrients has occurred, then burning may be needed to help restore soil nutrients prior to aspen regeneration. Burning late successional aspen may increase soil pH and add organic carbon and available nutrients to the soil (Martin and Dell 1978). If nutrient loss has not occurred, then cutting alone may be sufficient to promote aspen regeneration. Several properties of the surface horizon of soils under stable and declining aspen stands in the Burnt Flat Analysis Area were measured. This paper will present some of these results.

Study Area

The study area is in south-central Utah on the Burnt Flat Analysis Area of the Monroe Mountain Demonstration Area, Fishlake National Forest. The Burnt Flat Analysis Area consists of about 14,000 acres between 8,000 and 10,000 feet in elevation and is dominated by three general cover types: sagebrush/grass/forb communities (42%), aspen (20%), and mixed conifer/aspen (34%) (Mrowka and Campbell 1997). There is some grass/forb under-story in aspen and almost none in mixed conifer/aspen stands. Initial fire history data from this area show that a 20 to 60 year fire-free interval occurred prior to 1850 (Unpublished data on file with Linda Chappell. A fire history study conducted on the Monroe Mountain Demonstration Area. USDA Forest Service, Fishlake National Forest. Feb., 1997. 25 p.). Subsequently, management practices were implemented that removed fine fuels via grazing by domestic livestock and most fires were contained.

Methods

Soil samples were collected in pure aspen and mixed conifer/aspen stands used for an aspen root study (Data on file with Wayne Shepperd, USDA Forest Service, Rocky Mountain Research Station, Ft. Collins, Colo.). The surface 6-in of soil was sampled in tree interspaces where aspen suckering is most likely to originate using a 1-in. diameter stainless steel soil sampling probe. Thirteen sample locations are shown in Figure 1 and stand and soil types for the various sample locations are detailed in Table 1. The samples were air-dried at room temperature and sieved through a 2-mm stainless steel sieve. Soil properties measured and methods used are summarized in Table 2.

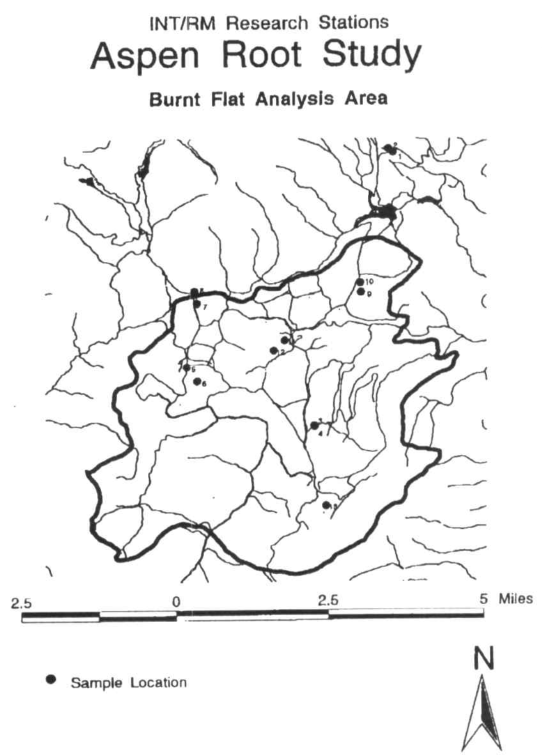

Fig. 1. *Map of Burnt Flat Analysis Area, Monroe Mountain, Fishlake National Forest, Utah showing thirteen sample locations.*

Table 1. Soil types associated with aspen and mixed conifer/aspen stands on the Burnt Flat Analysis Area, Monroe Mountain, Fishlake NF, Ut. (Data provided by Mike Smith, Fishlake NF, Richfield, Ut.).

Location	Stand type	Map Unit	Soil series	Slope %	Taxonomic classification
1	Aspen (r[1])	137	Tellura	3 to 25	Argic cryoboroll, clayey-skeletal, montmorillonitic
2	Aspen (d)	137	Tellura	3 to 25	Argic cryoboroll, clayey-skeletal, montmorillonitic
3	Aspen (d)	159	Buckskin	3 to 15	Argic cryoboroll, fine, montmorillonitic
			Devoy		Argic cryoborroll, clayey-skeletal, montmorillonitic
			Mult		Argic cryoboroll, fine-loamy, mixed
4	Aspen (r)	159	Buckskin	3 to 15	Argic cryoboroll, fine, montmorillonitic
			Devoy		Argic cryoboroll, clayey-skeletal, montmorillonitic
			Mult		Argic cryoboroll, fine-loamy, mixed
5	Mixed (46% aspen)	148	Cluff	3 to 25	Mollic cryoboralf, clayey-skeletal, montmorillonitic
			Powderhorn		Boralfic cryoboroll, fine, montmorillonitic
			Deefore		Lithic mollic cryoboralf, loamy, mixed
6	Aspen	155	Friedman	3 to 25	Argic pachic cryoboroll, clayey-skeletal, montmorillontic
7	Mixed	153	Condie	8 to 25	Mollic cryoboralf, loamy-skeletal, mixed
	(29% aspen)		Pando		Boralfic cryoboroll, loamy-skeletal, mixed
8	Aspen	175	Packer	25 to 60	Argic cryoboroll, loamy-skeletal, mixed
			Rogert		Lithic cryoboroll, loamy-skeletal, mixed
9	Aspen (nr)	150	Skutum	3 to 25	Argic pachic cryoboroll, fine, montmorillontic
10	Aspen (r)	150	Skutum	3 to 25	Argic pachic cryoboroll, fine, montmorillonitic
11	Mixed (42% aspen)	155	Friedman	3 to 25	Argic pachic cryoboroll, clayey-skeletal, montmorillonitic
12	Aspen (nr)	155	Friedman	3 to 25	Argic pachic cryoboroll, clayey-skeletal, montmorillonitic
13	Mixed (< 5% aspen)	151	Vulcan	8 to 25	Tylic cryoboralf, clayey-skeletal, montmorillonitic
			Herd		Mollic cryoboralf, fine montmorillonitic

[1] r = regenerating, nr = not regenerating, d = declining

An unpaired t-test was used to determine if the measured soil properties under aspen were significantly different from measured soil properties under mixed conifer/aspen stands for normally distributed data. When the data were non-normally distributed, a Mann-Whitney rank sum test was used instead.

Table 2. Methods used to determine properties of soils developed under aspen and mixed conifer/aspen stands.

Soil Property	Method	Reference
pH	1:1 soil/water paste	Thomas (1996)
Exchangeable Na, K, Mg, and Ca	1 M NH_4Cl	Sumner and Miller (1996)
Cation exchange capacity (CEC)	Sum of exchangeable cations	Sumner and Miller (1996)
Organic matter (OM)	LOI (loss on ignition), 16 h @ 450° C	Lowther et al. (1990)
Total organic carbon (TOC)	LECO CHN analyzer	Nelson and Sommers (1996)
Total N	LECO CHN analyzer	Bremner (1996)
Fe-strip extractable P	Fe oxide filter paper strips	Buselli (1994)
Bicarbonate extractable P	0.5 M $NaHCO_3$	Kuo (1996)
Organic P	Ignition-extraction	Kuo (1996)
Noncrystaline Fe oxide P	0.2 M NH_4 oxalate + 0.2 M oxalic acid in dark	Chao and Zhou (1983)
Crystalline Fe oxide P	02. M NH_4 oxalate + 0.2 M oxalic acid + 0.1 M ascorbic acid	Shuman (1982)
Calcium P	1 M HCl	Kuo (1996)

Results and Discussion

None of the surface soil properties under aspen except pH and exchangeable potassium (K) were significantly different from those under mixed conifer/aspen stands (Table 3). The pH and exchangeable K of mixed conifer/aspen soils were slightly lower than their corresponding values for soils under pure aspen stands.

None of the forms of phosphorus (P) for aspen soils were different from those for mixed conifer/aspen soils (Table 4). The iron (Fe)-strip and bicarbonate methods extracted similar amounts of available P from the soils. Most of the P in these soils is organic in origin or associated with noncrystalline Fe oxides. Of the P associated with specific soil components, P associated with calcium (Ca) (either sorbed to carbonate surfaces or as Ca phosphate minerals) comprised the smallest fraction.

Western U.S. soils developed under stable aspen are Mollisols. The O (organic) horizon is absent or very thin

Table 3. Comparison of properties of soils developed under aspen and mixed conifer/aspen stands. Samples from the Burnt Flat Analysis Area, Fishlake NF, Ut. (n = 19).

Soil Property	Aspen	Mixed
pH	6.50 ± 0.03[1] a[2]	6.33 ± 0.06 b
Na, $cmol_c$/kg	0.27 ± 0.00 a	0.28 ± 0.01 a
K, $cmol_c$/kg	2.07 ± 0.24 a	1.39 ± 0.13 a
	1.79[3] a	1.33 b
Mg, $cmol_c$/kg	4.26 ± 0.26 a	4.21 ± 0.41 a
Ca, $cmol_c$/kg	25.5 ± 1.5 a	31.0 ± 2.1 a
CEC, $cmol_c$/kg	32.1 ± 1.8 a	36.9 ± 2.4 a
LOI (OM), %	22.9 ± 2.2 a	29.2 ± 4.1 a
TOC, %	11.8 ± 1.2 a	14.2 ± 1.9 a
OM/TOC	1.94 ± 0.04 a	2.08 ± 0.09 a
Total N, %	0.85 ± 0.07 a	0.88 ± 0.10 a
C/N	14.0 ± 0.7 a	15.8 ± 0.8 a

[1] Mean ± SE.
[2] Means not followed by the same letter are significantly different ($p < 0.05$).
[3] Median.

and the A (surface mineral) horizon is thick and mollic (dark and enriched in organic matter). The addition and rapid turnover of aspen leaves to the soil each year (Bartos and DeByle 1981) contribute to formation of the mollic horizon (Jones and DeByle 1985a, Cryer and Murray 1992).

In contrast, soils developed under conifers in the climatic conditions of the Intermountain western U.S. are primarily Alfisols. These soils may have significant O horizons of conifer needles in various stages of decomposition, have a relatively thin A horizon, may have an albic (leached) E horizon, and have a prominent argillic B horizon where layer silicate clays accumulate (Rust 1983, Jones and DeByle 1985a, Cryer and Murray 1992).

In declining aspen stands, decreasing leaf fall leads to a decrease in organic matter accumulation and eventually a decrease in mollic horizon thickness (Cryer and Murray 1992). This may result in increased water infiltration through the soil profile and formation of an albic horizon. Conifer incursion can accelerate this process. In the theory of ecological succession proposed by Cryer and Murray (1992), as conifers invade declining aspen stands, the mollic horizon thins, the albic horizon thickens, and an argillic horizon forms. As the mollic horizon decreases and the albic horizon increases, soil pH, organic matter, exchangeable bases, cation-exchange capacity (CEC), and nutrients decrease.

Soils under mixed conifer/aspen stands are most often transition type soils with properties intermediate between Mollisols and Alfisols. In this case, soil properties are influenced by the vegetation that occupied the site for the longest period of time (Jones and DeByle 1985a).

The soils under pure aspen (both regenerating and declining) in the Burnt Flat Analysis Area consist of Argic Cryoborolls and Argic Pachic Cryoborolls (Table 1). In the mixed stands where severe aspen decline and appreciable conifer incursion has occurred, the soils are primarily transition soils classified as Mollic Cryoboralfs and Boralfic Cryoborolls. On Langdon Mountain (location 13) where conifer incursion is heaviest a Typic Cryoboralf may be found (Vulcan series). This soil had the lowest pH (6.1) of those measured. None of the properties (except perhaps pH and exchangeable K) of the surface 6-in. of soils in the tree interspaces reflected the presence of conifers (Tables 3 and 4).

Conifer incursion in the Burnt Flat Analysis Area corresponds to fire suppression in the area over the past several decades. Although soil profile alteration can occur after one generation of conifers (Jones and DeByle 1985a), conifer incursion in the Burnt Flat Analysis Area has decreased soil pH only slightly in some locations and no detectable loss of organic matter or nutrients has occurred in the surface 6-in of the soils. Soil samples were taken in the interspaces between trees where aspen suckering would most likely occur and may not accurately reflect soil properties directly under an individual conifer canopy. If so, a more detailed sampling radially outward from individual mature conifers may be needed to detect spatial trends in soil properties. Individual soil horizons need to be sampled and analyzed to fully characterize these soils. The surface 6-in. of soil was sampled because most of the lateral roots of aspen are concentrated near the soil surface (Schier and Campbell 1978). Lateral roots rather than vertical roots com-

Table 4. Comparison of forms of phosphorus in soils developed under aspen and mixed conifer/aspen stands. Samples from the Burnt Flat Analysis Area, Fishlake National Forest, Utah (n = 19).

Form of Phosphorus	Aspen	Mixed
Iron (Fe)-strip extractable	45 ± 2[1] a[2]	47 ± 5 a
Bicarbonate extractable	43 ± 3 a	38 ± 5 a
Organic	485 ± 40 a	493 ± 81 a
Noncrystalline Fe oxide-bound	419 ± 31 a	413 ± 40 a
Crystalline Fe oxide-bound	172 ± 8 a	152 ± 10 a
Calcium-bound	138 ± 48 a	116 ± 41 a

[1] Mean ± SE in mg/kg
[2] Means not followed by the same letter are significantly different ($p < 0.05$).

prise most of the aspen root system (Jones and DeByle 1985b). Most aspen suckers arise from lateral roots that are 5 to 25 mm in diameter (Schier 1982, Shepperd and Smith 1993).

The general absence of nutrient loss in the surface horizon of soils during conifer invasion in the Burnt Flat Analysis Area may be due to a precipitation distribution pattern that results in decreased rates of eluviation (transport) and illuviation (deposition) in these soils compared to other climatic conditions. Under Great Basin climactic conditions, most precipitation at these elevations arrives in the form of snow during winter and spring. During summer months, drier conditions often prevail for extended periods of time and most precipitation is from widely scattered convection activity. The rate of soil development may decrease relative to that under wetter conditions or where the precipitation distribution differs. Even though morphological changes are occurring in the soil profiles as conifer invasion proceeds, corresponding changes in chemical properties of the surface soil in tree interspaces are not found. Aspen loss from these areas need not be permanent if disturbances (e.g., fire, cutting) are restored to the landscape and if regenerating aspen are protected from excessive browsing. The soils in the Burnt Flat Analysis Area have not been altered to the point that burning of conifers is needed to increase soil pH and add nutrients back to the soil. Cutting should work as well.

It is unknown to what level soil pH can decrease and how much loss of organic matter and nutrients can be tolerated before aspen regeneration is suppressed. It appears that as long as some aspen root mass remains in the soil, regeneration is possible provided conditions can support regrowth.

Similar work in other areas with aspen, mixed conifer/aspen, and pure conifer stands, determining the spatial variability of soil properties in mixed conifer/aspen stands with respect to individual stand components, and entire soil profile sampling and analysis by horizon may lead to a more thorough understanding of the effects of aspen to conifer succession on soil genesis.

Literature Cited

Bartos, D.L. and N.V. DeByle. 1981. Quantity, decomposition, and nutrient dynamics of aspen litterfall in Utah. Forest Sci. 27:381–390.

Bremner, J.M. 1996. Nitrogen–total. p. 1085–1121. *In*: D.L. Sparks et al (eds.). Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, Wisc.

Buselli, E.M. 1994. Evaluation of several high-affinity, high-capacity sinks for multielement release from soils, mine spoils, and sediments. PhD Diss. Utah State Univ., Logan, Utah.

Chao, T.T. and L. Zhou. 1983. Extraction techniques for selective dissolution of amorphous iron oxides from soils and sediments. Soil Sci. Soc. Amer. J. 47:225–232.

Cryer, D.H. and J.E. Murray. 1992. Aspen regeneration and soils. Rangelands 14:223–226.

Jones, J.R. and N.V. DeByle. 1985a. Soils. p. 65–70. *In*: N.V. DeByle and R.P. Winokur (eds.). Aspen: ecology and management in the western United States. USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo. GTR RM-119.

Jones, J.R. and N.V. DeByle. 1985b. Morphology. p. 11–18. In: N.V. DeByle and R.P. Winokur (eds.). Aspen: ecology and management in the western United States. USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo. GTR RM-119.

Kuo, S. 1996. Phosphorus. p. 869–919. *In*: D.L. Sparks et al (eds.). Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, Wisc.

Lowther, J.R., P.J. Smethurst, J.C. Carlyle, and E.K.S. Nambiar. 1990. Methods for determining organic carbon in podzolic sands. Commun. Soil Sci. Plant Anal. 21:457–470.

Martin, R.E. and J.D. Dell. 1978. Planning for prescribed burning in the Inland Northwest. USDA Forest Service Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 67 p.

Mrowka, R. and R.B. Campbell, Jr. 1997. Cooperative management of the Monroe Mountain ecosystem. *In:* Diverse Forests, Abundant Opportunities, and Evolving Realities. Proceedings 1996 Society of Amer. Foresters Convention; 1996 Nov. 9–13; Albuquerque, N.M.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961–1010. *In*: D.L. Sparks et al. (eds.) Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, Wisc.

Rust, R.H. 1983. Alfisols. p. 253–281. In: L.P. Wilding et al (eds.) Pedogenesis and soil taxonomy: II. The soil orders. Elsevier Science Publ. B.V., Amsterdam, The Netherlands.

Schier, G.A. 1982. Sucker regeneration in some deteriorating Utah aspen stands: development of independent root systems. Can. J. Forest Res. 12:1032–1035.

Schier, G.A. and R.B. Campbell. 1978. Aspen sucker regeneration following burning and clearcutting on two sites in the Rocky Mountains. Forest Sci. 24:303–308.

Shepperd, W.D. and R.W. Smith. 1993. The role of near-surface lateral roots in the life cycle of aspen in the central Rocky Mountains. Forest Ecol. & Manage. 61:157–170.

Shuman, L.M. 1982. Separating soil iron- and manganese-oxide fractions for microelement analysis. Soil Sci. Soc. Amer. J. 46:1099–1102.

Sumner, M.E. and W.P. Miller. 1996. Cation exchange capacity and exchange coefficients. p. 1201–1229. *In*: D.L. Sparks et al (eds.). Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, Wisc.

Thomas, G.W. 1996. Soil pH and soil acidity. p. 475–490. *In*: D.L. Sparks et al (eds.). Methods of soil analysis. Part 3. Chemical methods. SSSA, Madison, Wisc.

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