Soil heating, nitrogen, cheatgrass, and seedbed microsites

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Abstract

Heat-induced changes in the soil-solution and post-wildfire erosion can create chemically and texturally diverse seedbed microsites. We quantified organic carbon, extractable NH_4^+ after incubation (aerobic and anaerobic), and emergence of cheatgrass (*Bromus tectorum* L.), by particle size fractions, in unburned and simulated burned sagebrush (*Artemisia tridentata* spp. *tridentata* Nutt.) subcanopy soil. For all particle size fractions, significantly ($P \leq 0.05$) more extractable NH_4^+ and significantly less extractable NO_3^- were measured in heated material as compared to unheated material. Heated treatments had significantly more NH_4^+ and significantly less NO_3^- mineralized after 11 days aerobic incubation than after unheated treatments; net N mineralized tended to be higher for all particle fractions in heated treatments than in unheated treatments. Emergence of cheatgrass under aerobic conditions was significantly retarded in all heated treatments. Elevated NH_4^+ to NO_3^- ratios in the soil-solution following heating does not explain suppression of cheatgrass emergence. Nitrogen mineralization, before and after simulated burning, is adequate in all particle size fractions to support the needs of germinating seeds. Nitrogen mineralization was not enhanced by the presence of growing cheatgrass plants.

Key Words: nitrate, ammonium, nitrogen mineralization, sagebrush

In sagebrush (*Artemisia*) plant communities in the Great Basin, water ultimately controls plant competition; however, NO_3^- and possibly NH_4^+ in the seedbed soil-solution are the catalysts driving competition among seedlings for moisture. Considerable soluble NO_3^- can be lost from the soil following wildfires (White et al. 1973, Klemmedson 1976). Conversely, post-wildfire seedbeds often have elevated levels of NH_4^+ (Christensen 1973, DeBano et al. 1979). Elevated levels of NH_4^+ combined with depressed soil nitrification following wildfires (Dunn et al. 1985) leads to greater NH_4^+ to NO_3^- ratios than generally occur in the seedbed of sagebrush communities (Charley and West 1977). Increased uptake of NH_4^+ relative to NO_3^- can be deleterious to newly establishing plants and may impact their competitive ability (Gigon and Rorison 1972, Marschner 1986).

Barre soil surfaces following wildfires are susceptible to increased movement of soil by wind and water that can lead to considerable loss of nitrogen (DeBano and Conrad 1978, Fletcher et al. 1978). On previously burned sagebrush landscapes in northeastern California and northwestern Nevada, the winnowing action of wind and water creates texturally variable deposits. Deposits range from fine-textured water-laid sediments to well-sorted fine and fine sand eolian deposits to coarse-textured lag deposits. These texturally diverse seedbeds, which may also vary in nitrogen status, could differentially influence the recruitment of plants (Harper et al. 1965, Collis-George and Hector 1966).

Our purpose was to:

- quantify extractable NO_3^- and NH_4^+ and nitrogen mineralization, before and after simulated burning, among particle size fractions separated from big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.) subcanopy soil;
- determine if alteration of extractable NH_4^+ to NO_3^- ratios, as a consequence of soil heating, influences the emergence of cheatgrass (*Bromus tectorum* L.) and;
- determine the influence of cheatgrass growth on nitrogen mineralization before and after simulated burning.

Materials and Methods

Soil Collection and Preparation

The soil sampling area was from a sagebrush-grass plant community 30 km north of Reno, Nev. The soil is a fine-loamy, mixed, mesic, Durixerollic Haplargid and developed in granitic colluvium. Elevation is 1,555 m and average annual precipitation is 25 cm. Soil was collected July 1992 from sagebrush subcanopies, 0 to 10 cm, and included the litter layer. Three replicate samples were collected from areas approximately 100 m apart. From each area, soil was composited from 5 adjacent sagebrush subcanopies.

The 3 soil samples were each sieved through a 0.833 mm mesh and the <0.833 -mm fraction was homogenized and saved. We chose to remove material larger than 0.833 mm because it was mostly undecomposed sagebrush litter. The <0.833 -mm material was split; one-half was untreated, the other half artificially burned to simulate soil conditions following a wildfire. The heat treatment consisted of placing approximately 500 g of material in a ceramic crucible which was placed in a pre-heated 300°C muffle furnace for 15 minutes. Previous research has shown that this artificial treatment produces a soil-solution chemistry closely matching the immediate post-wildfire soil-solution chemistry beneath sagebrush subcanopies in similar soil (unpublished research, USDA-ARS, Reno, Nev.). Heated and unheated treatments were separated into the following size fractions using a stacked set of sieves and 10 minute shaking time on a mechanical shaker: 0.425–0.833 mm, 0.300–0.425 mm, 0.180–0.300 mm, and <0.180 mm. Another portion of each was left unsieved (<0.883 mm or whole fraction).

Analytical

The following attributes were determined on each size fraction of both heated and unheated treatments: organic carbon (Walkley-Black method, Nelson and Sommers 1982); extractable NH_4^+ and NO_3^- (10-g material shaken for 30 minutes with 30 ml of 0.15% KCl, NH_4^+ determined by flow injection analysis, NO_3^- and NO_2^- determined by ion chromatography); organic N (Kjeldahl method, Bremner and Mulvaney 1982); pH on a saturated paste.

Nitrogen mineralization was evaluated by aerobic and anaerobic methods (Keeney 1982). For both methods, 500-ml glass beakers were filled with 250 g of material. For the aerobic procedure, all materials were moistened with deionized water to -0.033 MPa as

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Table 1. Selected attributes of pre-incubated material from particle size fractions of heated and unheated big sagebrush subcanopy soil.

Particle fraction (mm)	Extractable NH_4^+		Extractable NO_3^-		Organic C		Total N		C/N	
	Unheated	Heated	Unheated	Heated	Unheated	Heated	Unheated	Heated	Unheated	Heated
	mg kg ⁻¹									
0.425–0.883	4.0c ¹	7.4c	35.9a	0.0c	45130a	45530a	1382ab	1650ab	32.7a	33.1a
0.300–0.425	4.4c	11.4b	20.2a-c	2.6bc	45100a	41570a	1740ab	1513ab	25.9ab	27.2ab
0.180–0.300	4.0c	11.1b	26.8ab	1.2bc	36400a	28930a	2228a	1417ab	17.6ab	20.4ab
<0.180	4.0c	11.1b	12.7a-c	1.2bc	25030a	22970a	1351b	1642ab	20.7ab	14.1b
whole	4.0c	17.2a	28.4a	0.0c	37500a	45400a	1926ab	1824ab	19.9ab	25.2ab

¹Within soil attributes, particle fraction $\times$ heat treatment means followed by the same letter are not significantly different at the $P \leq 0.05$ level.

determined by a pressure plate membrane apparatus. To produce anaerobic conditions, water was added until it just completely covered the soil surface. Approximately 1 g of fresh soil was added to the heated treatment before incubation. This was necessary to re-introduce soil microorganisms killed during heating.

Cheatgrass Emergence and N Mineralization Experiment

To determine the influence of cheatgrass growth on N mineralization and the influence of simulated soil burning and cheatgrass emergence, seed treatments were superimposed on the mineralization treatments: minus seeds or plus seeds. The plus seed treatment consisted of 20 seeds of cheatgrass buried approximately 1 cm. The seed was >95% germinable as tested on moistened paper. Samples were incubated at 25° C under continuous fluorescent lighting for 11 days. Beakers were covered with parafilm, the anaerobic treatments sealed, the aerobic treatment loosely covered. At the end of the incubation period, the following parameters were measured: (a) emergence of cheatgrass; (b) organic carbon, extractable NH_4^+ and NO_3^- , and organic nitrogen as above; and (c) total nitrogen in emerged cheatgrass (leaves and roots) using an H_2O_2 modification of the Kjeldahl method (Isaac and Johnson 1976). Unemerged seeds were inspected to see if any had germinated; none had. Plant nitrogen was considered part of the mineralized pool.

$\text{NH}_4^+/\text{NO}_3^-$ Cheatgrass Germination Experiment

To determine if elevated $\text{NH}_4^+/\text{NO}_3^-$ ratios influence cheatgrass germination, post-heating levels were used as a guideline in a controlled experiment. Forty seeds of cheatgrass (4 replications) were placed on ashless filter paper in petri dishes and the following solutions ($\mu\text{g ml}^{-1}$) were added until the paper was saturated: 0 $\text{NH}_4^+ + 0 \text{NO}_3^-$, 5 $\text{NH}_4^+ + 100 \text{NO}_3^-$, 100 $\text{NH}_4^+ + 0 \text{NO}_3^-$, 100 $\text{NH}_4^+ + 100 \text{NO}_3^-$, 400 $\text{NH}_4^+ + 100 \text{NO}_3^-$, 400 $\text{NH}_4^+ + 0 \text{NO}_3^-$. Ammonium was added as Cl^- salt and nitrate as Na^+ salt. Seeds were counted after 5 days and considered germinated if the radicle had emerged at least 1 cm. The pH of the test solutions was similar for heated and unheated treatments (5.8–6.1), thus formation of NH_3 was minimal.

Statistics

The experimental design was a completely random design with 3 replications. The preincubation data were analyzed using a 2-way analysis of variance with particle size and heat treatment as the 2 factors for each soil attribute. The postincubation data set used a 3-way analysis of variance with particle size, heat treatment, and incubation treatment as the 3 factors for each soil attribute. Duncan's new multiple range test was used for multiple comparisons. Significance was judged at the $P \leq 0.05$ level.

The germination experiment was a completely random design with 4 replications. Data were analyzed using a 1-way analysis of variance, where treatments consisted of selected combinations of NH_4^+ and NO_3^- solutions.

Results and Discussion

Attributes of Pre-incubated Material

Most particle fractions of the heated treatments contained significantly more extractable NH_4^+ and less extractable NO_3^- than similar size fractions of unheated treatments (Table 1). The 300° C temperature in the simulated burning was higher than that reported to volatilize NO_3^- in soil (White et al. 1973, Raison 1979). Significantly elevated levels of NH_4^+ after wildfires has been reported by others (Christensen 1973, Khanna and Raison 1986).

There were no significant differences in the amount of organic C between heated and unheated treatments (Table 1). This is surprising because the temperature of the simulated burn should have volatilized considerable organic C (Hosking 1938). Perhaps removal of plant litter by sieving before the simulated burn in part explains this finding.

Nitrogen content of particle size fractions varied considerably and was surprisingly high in the coarsest fractions (Table 1). For the unheated treatments, the <0.180-mm particle fraction contained the lowest N content of all size fractions and significantly less than the 0.180 to 0.300-mm size fraction. However, there were no significant differences among the size classes for the heated treatments. Published literature shows variability in N content among particle size fractions. Nitrogen content tends to be lowest in sand fractions, increasing to a maximum in the fine silt fraction, and then decreasing somewhat in the clay fraction (Anderson et al. 1981, Catroux and Schnitzer 1987). Swift and Posner (1972) and Shiel (1986) reported N content decreased with an increase in fineness of particle size.

For individual particle fractions, there were no significant differences in N content between heated and unheated treatments (Table 1). This finding was not expected since N can be volatilized at the burn temperatures we used (DeBell and Ralston 1970, White et al. 1973). The length of simulated burning may have been insufficient to volatilize significant N or the nature of organic N in the soils tested may be recalcitrant to temperatures of 300° C.

There were no significant differences in C/N ratios between heated and unheated soils (Table 1). There was a trend toward decreasing C/N ratios with decreasing particle size, which is supported by the findings of others (Shiel 1986, Catroux and Schnitzer 1987). The magnitude of C/N ratios in the soils studied are much higher than generally reported for surface horizons of temperate agricultural soils (Stevenson 1959). As compared with other studies of sagebrush subcanopy soils, our C/N ratios are higher than those of Burke (1989) and Bolton et al. (1990) and are considerably lower than those of Doescher et al. (1984).

Changes in N Status Concomitant With Incubation

There were no significant differences in any measured attribute between with or without seed treatments (see methods), therefore, these data are not presented. These findings address one of our objectives; N mineralization is not enhanced by the presence of cheatgrass plants that are growing. The plus and minus seed treat-

Table 2. Net extractable NH_4^+ and NO_3^- in particle size fractions of heated and unheated big sagebrush subcanopy soil after 11 days of aerobic and anaerobic incubation.

Particle fraction (mm)	NH_4^+				NO_3^-			
	Aerobic		Anaerobic		Aerobic		Anaerobic	
	Unheated	Heated	Unheated	Heated	Unheated	Heated	Unheated	Heated
	mg kg ⁻¹							
0.425–0.883	11.9i ¹	66.1a	61.8ab	44.7d-g	199.2a	24.6c-e	-35.9f	0.0c-f
0.300–0.425	-1.9i	60.5a-c	48.7b-e	37.2e-h	184.1ab	42.8c	-20.2ef	-2.6c-f
0.180–0.300	-0.1i	46.9c-f	35.8e-h	33.0f-h	144.8b	34.0cd	-26.8f	-1.2c-f
<0.180	0.2i	49.8b-e	43.5d-h	30.3h	209.0a	42.6c	-12.7d-f	-1.2c-f
whole	3.6i	52.5a-d	47.4c-e	31.8gh	174.0ab	40.1c	-28.4f	0.0c-f

¹Within soil attributes, particle fraction $\times$ heat treatment $\times$ incubation treatment means followed by the same letter are not significantly different at the $P \leq 0.05$ level.

ments were pooled for subsequent statistical analyses (Table 2 and 3).

Significantly more NH_4^+ was mineralized in heated treatments than the unheated control under aerobic incubation conditions, with coarse particle fractions in heated samples having significantly higher net mineralization of NH_4^+ than finer fractions (Table 2). Enhanced mineralization and release of NH_4^+ following wildfires has been reported in different plant communities (Hobbs and Schimel 1984, Khanna and Raison 1986).

For heated treatments, significantly more NH_4^+ was mineralized aerobically than anaerobically (Table 2). Since nitrification should be inhibited under anaerobic conditions, one would expect higher NH_4^+ . Our findings suggest that either the rate of mineralization is slower under saturated conditions, perhaps due to decreased numbers of heterotrophic organisms in heated soils, and/or there is considerable denitrification under anaerobic incubations.

Under aerobic conditions, slightly less NO_3^- was mineralized in heated treatments than in unheated treatments (Table 2). Bell and Binkley (1989), using an aerobic procedure, reported a distinct trend toward lower levels of mineralized NO_3^- in heated soils than in unheated control soils. Given that considerable ammonification occurred in heated soils (Table 2), it appears that nitrification is slower in heated treatments. Nitrifying bacteria are especially susceptible to heat, whereas, ammonifiers can withstand heat because of thick cell walls or spore formation (Ahlgren and Ahlgren 1965, Raison 1979). Although we added fresh soil to the heated treatments to replace microorganisms killed by heat, the numbers may have been insufficient or the kinetics of microbial growth may have been too slow to rapidly convert NH_4^+ to NO_3^- .

Net total N mineralized under aerobic conditions was slightly greater for all particle sizes, in heated treatments compared to unheated treatments (Table 3). Percent N mineralized tended to decline with decreasing particle size for both heated and unheated treatments and aerobic and anaerobic incubation (Table 3). This is generally opposite of that reported in the literature (Chichester

1969, Catroux and Schnitzer 1987). In general, greater proportion of N was mineralized in heated soils than unheated soils.

Cheatgrass Emergence

In the aerobic environment, heated treatments consistently retarded cheatgrass emergence as compared to unheated treat-

Table 4. Percent emergence of cheatgrass from particle size fractions of heated and unheated big sagebrush subcanopy soil after 11 days aerobic and anaerobic incubation.

Particle fraction (mm)	Aerobic		Anaerobic	
	Unheated	Heated	Unheated	Heated
0.425–0.833	97.1a ¹	16.7c	1.7c	5.0c
0.300–0.425	97.1a	15.0c	3.3c	3.3c
0.180–0.300	88.3a	11.7c	0.0c	8.3c
<0.180	90.0a	46.7b	3.3c	3.3c
whole	95.0a	8.3c	0.0c	3.3c

¹Within soil attributes, particle fraction $\times$ heat treatment $\times$ incubation treatment means followed by the same letter are not significantly different at the $P \leq 0.05$ level.

ments (Table 4). For aerobic incubations, percent emergence was negatively correlated with the ratio of net mineralized NH_4^+ to net mineralized NO_3^- (Fig. 1).

Nitrate and NH_4^+ can stimulate germination while excessive NH_4^+ can inhibit germination of certain seeds (Hendricks and Taylorson 1974). Lack of NO_3^- or the excess of NH_4^+ in heated soils did not contribute to depression of cheatgrass emergence for there were no significant differences in cheatgrass germination among the following test solutions in $\mu\text{g ml}^{-1}$ (mean % germination): 0 NH_4^+ , 0 NO_3^- (85); 5 NH_4^+ , 100 NO_3^- (91); 100 NH_4^+ , 0 NO_3^- (93); 100 NH_4^+ , 100 NO_3^- (85); 400 NH_4^+ , 100 NO_3^- (84); 400 NH_4^+ , 0 NO_3^- (87).

Considerable quantities of organic acids can be produced by

Table 3. Net N mineralized and percent of total N mineralized in particle size fractions of heated and unheated big sagebrush subcanopy soil after 11 days of aerobic and anaerobic incubation. For treatments with emerging cheatgrass, total plant N was added to the mineralized and total N-pool.

Particle fraction (mm)	Net mineralized N				Percent N mineralized			
	Aerobic		Anaerobic		Aerobic		Anaerobic	
	Unheated	Heated	Unheated	Heated	Unheated	Heated	Unheated	Heated
	mg kg ⁻¹							
0.425–0.883	56.1ab ¹	57.8a	40.0c-g	34.8d-h	3.1bc	4.5a	2.8b-e	3.2b
0.300–0.425	41.8b-f	57.2a	33.3e-h	28.4f-h	2.2b-g	3.2b	1.9c-g	2.0d-g
0.180–0.300	35.4d-h	44.9a-e	21.8h	25.4gh	2.1c-g	3.0b-d	1.3g	2.0d-g
<0.180	48.9a-d	49.6a-d	31.0e-h	23.3h	1.6fg	3.1bc	1.8c-g	2.8b-e
whole	43.8a-c	50.4a-c	30.4c-h	24.7h	2.6b-f	3.2b	1.7fg	1.7fg

¹Within soil attributes, particle fraction $\times$ heat treatment $\times$ incubation treatment means followed by the same letter are not significantly different at the $P \leq 0.05$ level.

Fig. 1. Percent emergence of cheatgrass regressed against the ratio of net mineralized (mg kg^{-1}) NO_3^- to NH_4^+ . Data are for aerobic incubations only.

heating sagebrush subcanopy soils (Blank and Young 1990). Organic acids at levels less than measured in the previous study have been shown to inhibit seed germination (Mayer and Evenari 1953, Adkins et al. 1985). Blank and Young (1990), however, reported no significant differences in the germination of needle-and-thread grass (*Stipa comata* Trin. & Rupr.), Indian ricegrass [*Oryzopsis hymenoides* (R. & S.) Ricker], and cheatgrass between seeds grown in soil collected from sagebrush subcanopies following wildfire and a similar unburned control soil. The germination trials, however, were conducted several weeks after the wildfire, at which time, compound(s) responsible for suppression of cheatgrass germination may have disappeared.

Conclusions

We suspected that seedbed microsites with varying soil textures caused by postwildfire soil erosion would differ in nitrogen fertility, and therefore, in their ability to function as safesites for germination. Our laboratory experiments, however, indicate that there is sufficient inorganic N and N mineralization capacity following simulated burning, even in medium sand-sized fractions, to supply the N needs of newly germinating seeds.

Artificially heated sagebrush subcanopy soils significantly depressed emergence of cheatgrass as compared to unheated controls. This finding is contrary to the observation of cheatgrass being an aggressive colonizer following wildfires (Stewart and Hull 1949). However, Young and Evans (1978) related that cheatgrass recruitment beneath sagebrush subcanopies was depressed the first year following a wildfire. They attributed this finding to caryopses loss due to intense heat. At this time we cannot offer a plausible mechanism, whereby heated soil retards the emergence of cheatgrass but are investigating the phenomenon further.

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