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Evaluation of Soil Nutrients, pH, and Organic Matter in Rangelands Dominated by Western Juniper[2]

Abstract

Establishment of western juniper (*Juniperus occidentalis* Hook) in sagebrush-steppe of central Oregon appears to have affected the distribution of total N, organic matter, Ca, K, and pH. Compared to interspace soils and soils under juvenile trees, soil Ca, K, and pH were significantly higher under mature trees. Highest concentrations of total N and organic matter were found in upper soil layers under juvenile canopies. Thus, invasion of western juniper changes mineral cycling in microenvironments beneath the canopy. Further, these changes occur in such a way as to apparently enhance the competitiveness of western juniper with other herbaceous vegetation.

Introduction

Over the past 100 years, land management has influenced the composition and productivity of plant communities in central Oregon. During this period, western juniper (*Juniperus occidentalis*) has invaded rangelands previously supporting a more floristically diverse sagebrush-grassland (Caraher 1978). Although understory production of herbaceous and suffrutescent plants has apparently declined on these areas (Bedell and Bunch 1978), the mechanisms by which western juniper impacts associated vegetation has not been assessed. Alterations of microsites by recently established western juniper, as shown for other woody species (Doescher *et al.* 1984, Parker and Muller 1982, Barth 1980, Brotherson and Osayande 1980), may enhance the competitive ability of this species and provide new niches for understory species (Tiedemann and Klemmedson 1973b, Charley and West 1975).

The purpose of this study was to examine spatial variability in soil constituents on an area invaded by western juniper of different age classes. Loss of understory production following juniper invasion suggests a modification of microsite characteristics. We felt that changes in nutrient distribution under canopies of western juniper may be a significant factor contributing to the progressive site dominance of this species and the decline of associated plant species.

Study Area

The study site is located on a gentle northwest-facing slope at an elevation of 1300 meters. Soils of the area are classified as frigid Pachic Argixerolls and are approximately 60 cm in depth to weathered basalt. Cobbles increase with depth, reaching approximately 30% in the lower 30 cm of the profile. Basalt rock beneath is covered with soft $CaCO_3$ capping. In recent years, the area has been used for winter and early spring grazing by cattle.

Samples were collected in the Fall of 1982 from an area southeast of Prineville in Crook County, Oregon. Precipitation was collected in rain gauges and ranged between 300-350 mm annually.

Western juniper occurs as an almost continuous woodland on the study site. A single 0.2 ha block sampled adjacent to this study area contained 76 individual trees, 19 of which were less than 1 meter tall, and a tree canopy cover of 40% (Vaitkus 1986). The oldest tree established in 1895. Most (65%) of the trees (over 1 meter tall) established between 1900 and 1920, and have an average age of 63 years. Largest trees are 12-14 meters in height, with a crown radius of approximately 3 meters.

Understory vegetation is dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana*), Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Smith) and Sandberg bluegrass (*Poa sandbergii* Vasey). Low sage (*Artemisia arbuscula* Nutt.), squirreltail (*Sitanion hystrix* (Nutt.) Smith), downy brome (*Bromus

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tectorum L.), tailcup lupine (*Lupinus caudatus* Kell), and milkvetch (*Astragalus reventus* Gray) are commonly found throughout the area.

Juniper roots are a conspicuous feature of the surface soils of the area. These roots are characteristically dark red in color and appear to diminish in areas between trees. A conspicuous root mat, about 5 cm thick, extends outward from the bole of the tree approximately 2/3 the distance to the canopy edge of larger trees. No root mat is observed beneath small and intermediate sized trees (<8 meters).

Materials and Methods

To examine spatial relationships of soil nutrients, pH, and organic matter, the soil surface was stratified into four zones. These zones were selected to represent a horizontal vegetation gradient away from the bole of individual juniper trees.

The first zone was an area adjacent to the bole of large, mature junipers (>80 years old). Individual trees were between 12 and 14 meters tall and had a canopy radius between 2.0 to 3.0 meters. This zone was either devoid of other vegetation or dominated by annual grasses such as downy brome. This zone was designated the MB zone because it occurred near the bole of mature trees.

The second zone was 1/2 to 2/3 the distance from the bole of large junipers toward the canopy edge. The vegetation of this zone was dominated by high seral perennial grasses, such as Idaho fescue and bluebunch wheatgrass. This zone was designated the MG zone because it occurred under the canopy of mature trees in a zone dominated by perennial grasses.

The third zone was located in the interspace areas between mature junipers and was characterized by considerable bare soil and small Sandberg bluegrass plants. No noticeable litter accumulation was evident in this zone which was designated the I zone because it occurred in the interspaces between trees.

The fourth zone was adjacent to the bole of small juvenile junipers (<40 years old). Individual trees were 2-3 meters tall and had a canopy radius of 0.75-1.5 meters. High seral perennial grasses such as Idaho fescue and bluebunch wheatgrass dominated this area. It was assumed that this zone reflected initial stages of juniper establishment and would provide a comparison of temporal changes in soil constituents relative to mature trees. Samples were removed from soils directly below the perennial grasses. This zone was designated the J zone because of its location under juvenile trees.

Zones associated with five large and five juvenile, randomly selected western juniper trees were sampled. Within each zone, surface litter was removed, pits were excavated, and mineral soil collected at depths of approximately 0-8 cm, 8-16 cm and 16-24 cm. These depths were selected to ascertain the presence of vertical chemical patterns in the zone of greatest root volume. Five soil samples at each depth/zone combination were extracted (Brotherson and Osayande 1980). Soils were sieved through a 4 mm screen, thoroughly mixed, and obvious root material and organic debris removed before analysis (Charley and West 1975).

Soil analysis was performed at the Oregon State University Soil Testing Laboratory. Total N was determined using the Micro-Kjeldahl method (Bremner and Edwards 1965); OM was estimated utilizing the wet oxidation-titration method of Walkley and Black (1934); P was determined by the sodium bicarbonate method of Olsen and Dean (1965); Ca, Mg, and Na were determined by the ammonium acetate method of Peech *et al.* (1947); K was determined by a modification of the technique used by Pratt (1965); and pH was measured using a 1:2 soil:water ratio and a glass electrode (Jackson 1958).

Analysis of variance with a split-plot design was used to test significant differences ($\alpha = 0.05$). Zones were analyzed as main plots and soil sampling depths were analyzed as subplots. Where interactions existed, two-way interaction means were separated using a protected least significant differences (LSD) procedure. Where no interactions were detected, LSD was used to separate main-effect means (Steel and Torrie 1980).

Results

Total N, Ca, K, pH, and OM levels were significantly different between zones and between depths within zones. These soil constituents also exhibited a significant zone x depth interaction. The following relationships were noted:

1. Concentrations of Ca were greatest in surface soils (0-8 cm) near the bole of large juniper trees (MB zone) and declined with distance from the bole in the MG and I zones (Table 1). There were no significant differences in concentration with distance from the bole at the 16-24 cm soil depth. Calcium concentrations near the bole of juvenile trees (J zone) were similar to those in the MG and I zones, but were always lower than in the MB zone.

Presence of juniper canopies strongly influenced surface concentration of Ca. Ca concentrations in the MB and MG zones at the 0-8 cm sampling depth were greater than at the 8-16 cm and 16-24 cm depths. In the J zone, Ca concentrations at the 0-8 cm depth were greater than at the 8-16 cm depth, but not different from the 16-24 cm depth. Calcium concentrations showed no depth related patterns in the I zone.

2. Highest levels of organic matter in the mineral soil were found predominately in the zones beneath juniper canopies (Table 2). Levels of organic matter were highest in the 0-8 cm depth under the J zone compared to the other zones. Next greatest surface levels were found near the boles of large juniper trees (MB zone) and became progressively lower in the MG and I zones. Results at the 8-16 cm depth showed no clear patterns. Differences between zones were nonsignificant at the 16-24 cm sampling depth.

Soil depth also significantly influenced OM content of the soil. Organic matter levels were highest at the 0-8 cm depth in all zones and declined with increasing soil depth.

3. Total N levels of surface soils were greater in the J zone than those found in the MB, MG and I zones (Table 3). No differences in surface levels of total N were detected between the MB and MG zones and the MB and I zones. At the 8-16 and 16-24 cm sampling depths, no differences in levels of total N were found among zones.

Total N levels showed depth dependent patterns. Highest total N levels were found near the surface in all zones, and were lowest at the deepest sampling depths.

4. Concentrations of K were greatest in surface soils in the MB and MG zones and least in the I zone (Table 4). Surface concentrations of K in the J zone did not differ from either the MG or I zones, although concentrations in the MG zone were greater than in the I zone. The pattern of K concentration became less distinct with depth.

In the MB, MG and J zones, concentrations of K at 0-8 cm were higher than those found at the 8-16 cm and 16-24 cm sampling depths. Potassium concentrations did not differ with depth in the I zone.

TABLE 1. Mean Ca concentration (cmol (p^+) Kg^{-1}) at three depths in a *Juniperus occidentalis* woodland.

Soil Depth	Zone			
cm	MB	MG	I	J
0-8	19.8^{Aa*}	16.1^{Ba}	12.4^{Ca}	14.56^{Ba}
8-16	15.7^{Ab}	14.2^{ABb}	12.6^{BCa}	12.34^{Cb}
16-24	14.9^{Ab}	14.3^{ABb}	13.20^{ABa}	12.86^{Bab}

EMS (zone comparison) = 1.38
EMS (depth comparison) = 1.86
*Identical capital letters indicate nonsignificant differences (α=.05) among MB, MG, I, and J soil zones at a particular soil depth. Identical lower case letters denote nonsignificant differences among soil depths within MB, MG, I, and J zones.

TABLE 2. Mean OM concentrations (% D.W.) at three depths in a *Juniperus occidentalis* woodland.

Soil Depth	Zone			
cm	MB	MG	I	J
0-8	5.9^{Aa*}	5.1^{Ba}	4.2^{Ca}	6.8^{Da}
8-16	4.3^{ABb}	3.7^{Ab}	3.8^{Aab}	4.5^{Bb}
16-24	3.6^{Ac}	3.5^{Ab}	3.4^{Ab}	3.9^{Ac}

EMS (zone comparison) = .24
EMS (depth comparison) = .18
*Identical capital letters indicate nonsignificant differences (α=.05) among MB, MG, I, and J soil zones at a particular soil depth. Identical lower case letters denote nonsignificant differences among soil depths within MB, MG, I, and J zones.

TABLE 3. Mean total N (% D.W.) concentrations at three depths in a *Juniperus occidentalis* woodland.

Soil Depth	Zone			
cm	MB	MG	I	J
0-8	$.17^{ABa}$	$.19^{Aa}$	$.15^{Ba}$	$.28^{Ca}$
8-16	$.14^{Ab}$	$.14^{Ab}$	$.13^{Aab}$	$.16^{Ab}$
16-24	$.13^{Ab}$	$.13^{Ab}$	$.12^{Ab}$	$.14^{Ab}$

EMS (zone comparison) = .0006
EMS (depth comparison) = .0005
*Identical capital letters indicate nonsignificant differences (α=.05) among MB, MG, I, and J soil zones at a particular soil depth. Identical lower case letters denote nonsignificant differences among soil depths within MB, MG, I, and J zones.

Magnesium, Na, P and pH did not exhibit a zone x depth interaction. Separation of main effect means for these constituents revealed the following relationships:

1. Concentrations of Mg and Na increased with soil depth (Table 5), but did not differ among zones.

2. Concentrations of P decreased with soil depth (Table 5), but did not differ among zones.

3. Highest pH values were found in the MB zone (Table 6). Intermediate pH values were detected in the MG zone while lowest levels were found in the I and J zones. Levels of pH in the J zone did not differ from the I zone. No differences in pH were detected with increasing soil depth.

Discussion

Examination of soil constituents in a western juniper community provided insight into possible changes in mineral cycling brought about by invasion of this species. Soil constituents such as total N, total S, K, and organic matter have been found to accumulate at the soil surface beneath non-halophytic shrubs (Tiedemann and Klemmedson 1973a, Charley and West 1975, Doescher *et al.* 1984). Our findings, however, indicated several unique patterns of total N and Ca accumulations associated with establishment of western juniper.

A strong accumulation of total N was detected at the 0-8 cm depth in the J zone in comparison to the MB, MG and I zones. The reason for this high N accumulation in the surface horizon under juvenile trees (J zone) is not entirely clear. The enhancement may be related to the young age of the junipers and sampling of soils dominated by high seral perennial grasses. Accumulation of grass litter and the absence of tree litter may result in higher total N levels in soils of the J zone. In contrast, litter, especially under large junipers, may be slow to decompose and not allow for the accumulation of total N in surface soils. Visual observation of the detritus at the bottom of the litter mat in both the MB and MG zones revealed recognizable plant material. Juniper foliage as well as bunchgrass tillers were found essentially intact. Feeder roots of juniper at the soil/litter interface may serve as efficient collectors of mineralized nitrogen. Nitrogen accumulations in ecosystems dominated by western juniper may actually be associated with litter and/or biomass of juniper trees.

TABLE 4. Mean K concentration (mg Kg^{-1}) at three depths in a *Juniperus occidentalis* woodland.

Soil Depth	Zone			
cm	MB	MG	I	J
0-8	777.4^{Aa}	685.6^{ABa}	481.8^{Ca}	572.4^{BCa}
8-16	662.0^{Ab}	589.0^{ABb}	490.8^{Ba}	509.2^{ABab}
16-24	637.4^{Ab}	561.4^{ABb}	497.8^{ABa}	473.6^{Bb}

EMS (zone comparison) = 20055.8
EMS (depth comparison) = 2438.2
*Identical capital letters indicate nonsignificant differences ($\alpha = .05$) among MB, MG, I, and J soil zones at a particular soil depth. Identical lower case letters denote nonsignificant differences among soil depths within MB, MG, I, and J zones.

TABLE 5. Main effect means for concentrations of Mg (cmol (p^+) Kg^{-1}), Na (cmol (p^+ Kg^{-1}), and P (mg Kg^{-1}) at soil depths of 0-8 cm, 8-16 cm, and 16-24 cm. No differences were detected between zones.

	Soil Chemical		
Soil Depth	Mg	Na	P
0-8 cm	6.7^{a*}	.17^{a}	15.9^{a}
8-16 cm	7.10^{a}	.17^{a}	14.5^{ab}
16-24 cm	7.7^{b}	.19^{b}	13.5^{b}

EMS (Mg) = .45
EMS (Na) = .0007
EMS (P) = 7.94
*Identical letters indicate nonsignificant differences ($\alpha = .05$) at a particular soil depth.

TABLE 6. Main effect means for levels of soil pH between MB, MG, I, and J. No differences were detected between soil depths.

	Zone			
	MB	MG	I	J
pH levels	6.6^{A*}	6.4^{B}	6.3^{C}	6.3^{C}

(EMS = .0087)
*Identical letters indicate nonsignificant differences ($\alpha = .05$) at a particular soil depth.

Increased levels of Ca beneath juniper canopies may result from two processes: 1) mineral washing in stem flow (Young *et al.* 1984); and/or 2) decomposition of needles which are probably high in Ca, as has been found for

Juniperus scopulorum (Hart and Parent 1974). These changes could enhance the competitiveness of western juniper by altering soil chemical dynamics in favor of western juniper. For instance, increased Ca concentrations coupled with alterations in soil pH under canopy soils may affect growth of herbaceous vegetation. Observations of plant species under canopies of large western junipers have shown distinct spatial segregation with distance from the bole of individual trees (Vaitkus 1986). These understory patterns likely result from changes in soil nutrients under western juniper, as well as other microenvironmental alterations resulting from establishment of this species.

Conclusions

Distribution of soil constituents in arid regions provides insight into functional roles vegetation has on ecosystem processes. Results support hypotheses proposed by Archer *et al.* (1985). which state that, in arid environments invaded by shrubs (in their case—*Prosopis glandulosa* Torr.), autogenic alterations induced by the shrub alter microsite conditions to the benefit of woody vegetation. For western juniper, redistribution of soil constituents may be one such autogenic process which enhances its competitiveness.

Based upon comparisons between four sampling zones, our evidence suggests a potential decrease in total soil N under juniper canopies during the time between establishment and maturity. Redistribution of N pools may also have occurred. In addition, alterations in soil nutrients, such as Ca, may promote the persistence of western juniper and the reduction in understory vegetation. How these factors influence plant succession and competitive interactions between western juniper and herbaceous species will be addressed in future research.

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