

1991

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McPherson, Guy R.; Rasmussen, G. Allen; Wester, David B.; and Masters, Robert A., "Vegetation and Soil Zonation Associated with *Juniperus Pinchotii* Sudw. Trees" (1991). *Publications from USDA-ARS / UNL Faculty*. 1071.
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VEGETATION AND SOIL ZONATION ASSOCIATED WITH *JUNIPERUS PINCHOTII* SUDW. TREES

Guy R. McPherson¹, G. Allen Rasmussen², David B. Wester³, and Robert A. Masters⁴

ABSTRACT.—Herbaceous vegetation pattern and soil properties around individual *Juniperus pinchotii* Sudw. trees were studied on a grazed and a relict grassland in western Texas. Herb standing crop and soil samples were obtained under the canopy, at canopy edge, and beyond the canopy edge of three to five trees on each of four dates. Standing crop was lowest midway between the bole and canopy edge. Soil organic matter was highest under juniper canopies on both sites. Soil pH and P were not related to distance from tree bole on either site. Herbaceous pattern from under the canopy to canopy edge apparently depended primarily on individual tree size. However, trees had little influence on herbaceous vegetation pattern 3–5 m beyond canopy edge, a response attributed to distance-independent interaction between *J. pinchotii* and herbaceous vegetation. Given a shallow soil underlain by indurated caliche and tree densities ranging from 288 (relict size) to 2123 (grazed site) trees/ha, the interaction between *J. pinchotii* and herbaceous vegetation did not change over a distance of 3–5 m from tree canopy edge in our study area.

Key words: *Juniperus pinchotii*, redberry juniper, vegetation pattern, soil nutrients, herbivory, relic area, competition.

Zones of herbaceous vegetation around *Juniperus* trees have been reported for several species in the western United States (Arnold 1964, Clary 1973, Springfield 1976, Everett et al. 1983, Schott and Pieper 1985). The most commonly recognized vegetation zones are: (1) under woody plant canopies, where *Juniperus* litter and shade alter micro-environment; (2) in a transition zone, where *Juniperus* roots compete with herbaceous plants for water and nutrients; and (3) in the interstice between trees, where trees do not influence herbaceous vegetation. In contrast, a zonation pattern was not detected around *J. virginiana* in Oklahoma (Engle et al. 1987) or *J. monosperma* in New Mexico (Armentrout and Pieper 1988). In these studies, herbaceous vegetation beyond tree canopies did not change with increased distance from trees.

Woody species influence soil properties primarily by rooting and litterfall characteristics (Barth 1980). Chemical constituents from surrounding soil are taken up by tree roots and concentrated in biomass. Litterfall transfers much of this biomass to the area beneath the canopy where it accumulates, and decomposition releases chemical constituents to

the underlying soil. Soluble salts (Fireman and Hayward 1952, Sharma and Tongway 1973), nitrogen and phosphorus (reviewed by Tiedemann 1987), and zinc, iron, and magnesium (Hibbard 1940, Follett 1969, Barth 1980) have been implicated in this process.

Juniperus pinchotii Sudw. (nomenclature follows Correll and Johnston 1970), a sprouting evergreen conifer commonly found on limestone or gypseous soils, occupies about 2.4 million ha of rangeland in western and central Texas (Adams 1972). Throughout its range, *J. pinchotii* migrated quickly onto prairies during the expansion of the cattle industry (1870–1920) (Hall and Carr 1968, Adams 1975). Western Texas populations of *J. pinchotii* previously restricted to buttes and escarpments have subsequently expanded into adjacent grasslands and have become a major vegetation component (Ellis and Schuster 1968). The primary objective of this study was to determine the effects of individual *Juniperus pinchotii* trees on herbaceous vegetation and soil properties at a grazed and a relict site in western Texas.

STUDY AREAS

Two western Texas study sites were used.

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Flattop Mountain, an isolated butte 11 km northwest of Snyder (101°10'W, 33°00'N), has not been grazed by livestock but is accessible to wildlife species and supports relict vegetation (McPherson 1987). Nine km southeast of the butte is an area with considerable historic grazing pressure. The grazed site is contiguous with the Llano Estacado High Plains; the relict site is a High Plains outlier (Brown and Schuster 1969). Average annual precipitation is 472 mm (Dixon 1975). Dominant soil on both sites is a shallow (about 50 cm) clay loam of the Lea-Slaughter complex (fine-loamy, mixed, thermic Petrocalcic Paleustolls and clayey, mixed, thermic, shallow Petrocalcic Paleustolls) (Dixon et al. 1973, Dixon 1975). These sites represent environmental settings whose primary extrinsic difference is domestic livestock grazing. The sites may also have intrinsic soil differences.

METHODS

On each site, 20 *Juniperus* plants were selected randomly, except for the requirements that they were (1) beyond the shading influence of other junipers; (2) between 1.0 and 4.0 m tall; and (3) at least 5 m from roads, shallow soil (gravel present at surface), or visibly disturbed areas. Standing crop of herbaceous vegetation was estimated around three to five randomly selected trees on each site in July (corresponding to peak standing crop) and October (to assess autumn productivity) 1984 and 1985, years in which study sites received 42 and 96% of long-term growing season precipitation (420 mm), respectively (McPherson 1987). Transects were established in the cardinal directions from the stem, ending 3 m beyond the canopy edge. Rectangular quadrats (0.10 m²) were located at midpoint between canopy edge and stem (location 1), at canopy edge (location 2), and at 1.0-m intervals beyond the canopy edge (locations 3–5). Two quadrats were randomly located along each of 10 randomly located 5-m permanent transects in the interstice between trees (at least 5 m from nearest *Juniperus* plant; location 1). Standing crop in quadrats was harvested to a 2.5-cm stubble height and separated by species. Herbage samples were oven-dried at 60 C for 48 h and weighed.

Two complete soil horizons were exposed and profiles described to the depth of indurated caliche on each site (McPherson 1987).

Soil samples were collected from the 0–10-cm soil layer halfway between bole and canopy edge, at canopy edge, and at 1, 2, and 3 m along a southward transect from five randomly selected trees on each site in May 1986. Determination of calcium carbonate equivalent followed Richards (1954); organic matter content (OM) was determined by wet digestion (Prince 1955). Samples were analyzed for nitrogen (N), potassium (K), phosphorus (P), exchangeable calcium (Ca), sodium (Na), and magnesium (Mg) following Onken et al. (1980). Soluble salt and pH determination followed McLean (1982).

Species occurring with less than 5% frequency on all sites and dates were removed from the data set (Gauch 1982), leaving 57 species for subsequent analyses. Standing crop values were log transformed (Steel and Torrie 1980). Analysis of variance, Fisher's protected LSD, and reciprocal averaging ordination (RA) were used to analyze the effect of *Juniperus* trees on herbaceous vegetation and soil properties. Variability from tree to tree was taken into account by considering trees as blocks in a randomized complete block design in the analysis of variance. The "treatment effect" in this analysis was quadrat distance from tree bole.

RESULTS

Herbaceous Vegetation

Strong interactions ($P < .01$) between tree (block) and quadrat distance from tree (treatment) were exhibited by 56 of 57 species on all dates and sites (a tree- \times -distance interaction was not present [$P > .05$] for *Bouteloua curtipendula* [Michx.] Torr. on the relict site on any date). Tree- \times -distance interactions were also exhibited by plant guilds (cool-season grasses, warm-season grasses, forbs) and for total standing crop.

With only one grazed site and one relict site, it is not possible to statistically test the effect of site. Within a site, apparent differences in aboveground biomass between years (Table 1) were attributable to differences in precipitation (about twice as great in 1985 as 1984). (For elaboration of site and year effects on herbaceous production, see McPherson and Wright 1990.) However, vegetation composition within each site was similar on all sampling dates (Table 1). Ordination results

TABLE 1. Standing crop (g/m²) of selected herbaceous species on grazed and relict grassland at six locations around *Juniperus pinchotii* trees in western Texas, July and October 1984 and 1985 (each number is mean of four cardinal directions and three to five trees).

Species ¹	GRAZED SITE											
	July 1984						October 1984					
	Location ²						Location					
	1	2	3	4	5	I	1	2	3	4	5	I
GRASSES												
ARSP	0	6	90	192	173	270	0	401	125	113	124	156
BOCU	6	29	24	193	16	23	0	141	107	38	63	53
BUDA	0	2	4	2	2	6	0	6	4	6	6	5
TRMU	0	2	6	58	4	34	0	72	24	61	64	52
STNE	121	61	0	0	0	0	0	0	0	0	0	0
SIHY	0	11	0	0	0	0	70	0	0	0	0	0
Other grasses	2	13	4	10	6	15	0	122	46	57	60	27
FORBS												
CRDI	0	0	2	20	51	98	0	37	111	73	96	80
SICA	8	28	0	0	0	0	146	0	11	158	0	6
ZIGR	0	4	2	24	2	39	12	60	12	7	13	65
EVNU	0	4	17	34	8	43	0	8	15	21	27	30
LEER	0	0	37	2	6	14	0	2	8	2	0	23
CADR	0	4	6	6	4	8	2	11	6	38	63	37
ERMO	0	0	0	0	0	0	0	0	0	0	0	0
Other forbs	71	94	96	139	120	149	16	126	99	98	276	158
TOTAL	208	258	288	680	392	699	246	986	568	672	792	692
RELICT SITE												
GRASSES												
ARSP	0	2	2	161	73	113	0	4	0	4	0	52
BOCU	248	217	436	285	333	830	26	116	157	95	122	184
BUDA	0	2	14	23	15	18	0	8	2	0	2	0
TRMU	0	13	25	19	0	60	0	42	0	19	22	30
STNE	123	19	13	0	0	0	0	0	0	34	0	39
SIHY	0	0	0	0	0	0	62	7	0	0	0	0
Other grasses	56	155	59	171	2	82	8	120	156	107	59	31
FORBS												
CRDI	0	0	0	0	0	0	0	0	0	0	0	0
SICA	6	0	0	0	0	0	30	2	0	0	20	5
ZIGR	0	0	0	0	0	0	0	0	0	0	0	0
EVNU	0	0	0	0	6	0	0	0	0	0	0	0
LEER	0	0	0	0	0	0	0	0	0	0	0	0
CADR	0	0	0	0	0	0	0	0	0	0	0	0
ERMO	0	0	0	0	0	0	0	0	0	0	0	0
Other forbs	13	10	13	25	75	62	8	26	25	19	24	49
TOTAL	446	418	562	684	504	1165	134	325	340	278	249	390

were also similar on each sampling date. Because ordination diagrams, which included all sampling dates, contained too many points to plot adequately, only results from the October 1985 sampling date are shown.

Effects of *J. pinchotii* on herbaceous vegetation pattern were recognizable at several

scales (landscape, community, and individual tree). Evaluation of pattern at the landscape level involved ordinating all trees on both sites (Fig. 1). The first ordination axis indicates a site effect: all quadrats from the relict site were assigned negative first axis scores, and most quadrats from the grazed site were

TABLE 1 continued. Data for 1985.

Species ¹	GRAZED SITE											
	July 1985						October 1985					
	Location						Location					
	1	2	3	4	5	I	1	2	3	4	5	I
GRASSES												
ARSP	2	61	393	586	347	570	0	16	64	211	188	228
BOCU	114	198	19	27	49	186	8	79	0	0	0	209
BUDA	0	12	18	13	19	41	17	8	8	7	22	7
TRMU	8	118	50	54	83	127	4	114	34	85	172	181
STNE	0	0	0	0	0	0	0	0	0	0	0	0
SIHY	120	2	0	0	0	0	126	0	0	0	0	0
Other grasses	0	114	38	134	118	80	2	187	82	184	204	13
FORBS												
CRDI	0	109	190	145	230	127	0	50	131	68	118	30
SICA	390	2	0	0	13	0	0	4	0	0	0	0
ZIGR	0	65	0	0	0	94	0	36	119	53	31	48
EVNU	0	13	38	24	71	100	0	24	34	65	33	45
LEER	14	37	132	83	101	82	169	476	436	152	212	20
CADR	8	12	26	43	127	57	0	44	20	7	133	43
ERMO	10	312	79	36	13	46	57	57	90	63	85	67
Other forbs	145	185	292	273	211	474	77	174	150	158	134	184
TOTAL	811	1240	1275	1418	1382	1984	460	1269	1168	1053	1332	1075
RELICT SITE												
GRASSES												
ARSP	0	107	135	83	183	88	0	16	21	7	113	254
BOCU	0	463	417	351	379	595	91	356	609	615	830	605
BUDA	0	45	35	55	44	26	5	15	8	11	18	45
TRMU	0	47	46	42	33	2	57	274	43	54	60	23
STNE	25	796	247	186	277	25	0	0	0	0	0	10
SIHY	245	117	57	0	0	27	252	66	1	0	0	0
Other grasses	0	74	106	54	64	173	38	280	177	226	82	162
FORBS												
CRDI	0	0	2	0	0	0	0	0	0	0	0	0
SICA	131	145	41	16	0	9	3	39	3	0	0	3
ZIGR	0	0	0	0	0	0	0	0	0	0	0	0
EVNU	0	0	0	0	3	0	0	0	0	0	0	0
LEER	0	0	0	0	0	0	0	0	0	0	0	0
CADR	0	0	0	0	0	0	0	6	2	0	0	0
ERMO	191	123	74	138	84	134	223	180	117	42	111	139
Other forbs	53	91	255	139	349	186	50	52	43	79	69	35
TOTAL	645	2008	1415	1064	1416	1265	719	1284	1024	1034	1283	1276

¹Species abbreviations are: ARSP = *Aristida* sp., BOCU = *Bouteloua curtipendula*, BUDA = *Buchloe dactyloides*, TRMU = *Tridens nutticus*, STNE = *Stipa neomexicana*, SIHY = *Sitanion hystrix*, CRDI = *Croton dioicus*, SICA = *Simsia calva*, ZIGR = *Zinnia grandiflora*, EVNU = *Evolvulus nuttallianus*, CADR = *Calylophus drummondianus*, ERMO = *Erigeron modestus*.

²Locations are midway between tree bole and dripline (1), at dripline (2), 1, 2, and 3 m from dripline (3-5, respectively), and in interstices (I).

assigned positive first axis scores. Exceptions were quadrats under tree canopies (location 1 and, to a limited extent, location 2) on the grazed site.

Ordination of quadrats along the second axis (Fig. 1) indicates a gradient from tree bole

to interstice representing tree influence on herbaceous vegetation. Location 1 quadrats (under the tree canopy) were ordinated together, as were quadrats beyond the canopy edge (locations 3-5, I). Quadrats at the canopy edge (location 2) were ordinated

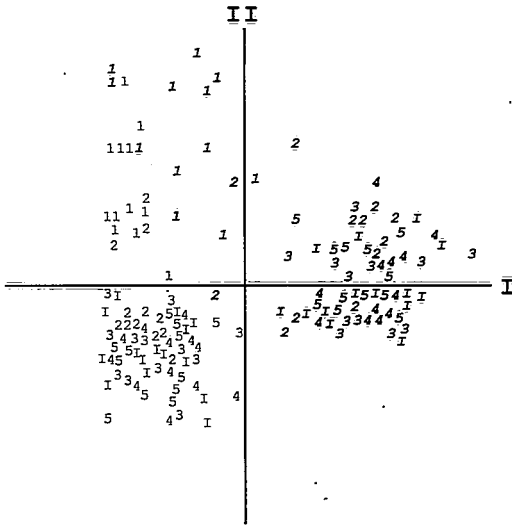


Fig. 1. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on grazed (bold type) and relict (normal type) semiarid grasslands. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location I is in interstice between trees.

between quadrats under the tree and those beyond the canopy edge.

Ordination of all trees on the relict site (Fig. 2) and the grazed site (Fig. 3) reflects community-level analyses. On both sites, axis I reflected a distance gradient from tree bole to interstice. Quadrats under the canopy and at canopy edge were assigned negative first axis ordination scores, whereas other quadrat locations were generally assigned positive scores. Additionally, quadrats at locations 3–5 were ordinated together with quadrats from the interstitial zone. Axis II reflected tree-to-tree variation. Small trees (height, stem diameter, and crown volume) were ordinated more positively on this axis than were large trees (data not shown). Ordinations did not indicate any effect of compass direction on herb response.

Ordination of a single tree on each site further elucidated the tree's influence on herbaceous vegetation beneath the canopy (Figs. 4, 5; in each case, axis III was plotted against axis I to reduce arch distortion associated with the plot of axes I and II). The ordination revealed that quadrats under the tree (location 1) were readily distinguishable from remaining quadrats. Quadrats 1, 2, and 3 m

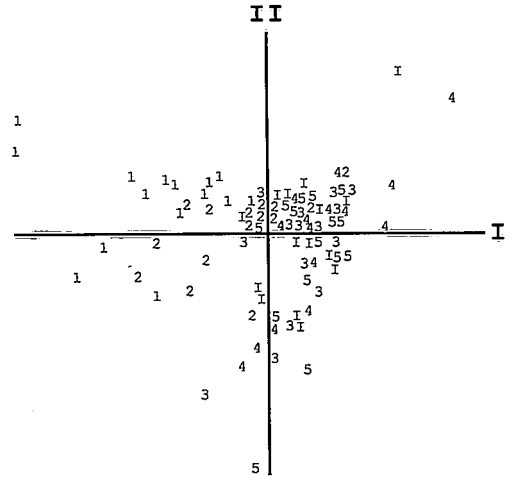


Fig. 2. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on a relict semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location I is in interstice between trees.

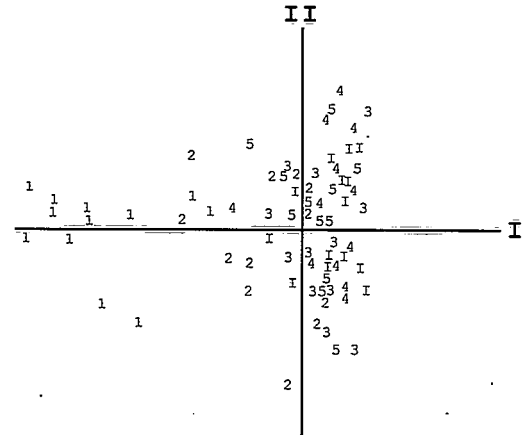


Fig. 3. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on a grazed semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location I is in interstice between trees.

from the tree (locations 3, 4, and 5) tended to be ordinated together. Quadrats at canopy edge (location 2) were assigned ordination scores intermediate between these two groups.

Soil Properties

Organic matter, soil P, and pH differed ($P < .05$) between sites; however, trees influenced few of the measured soil properties.

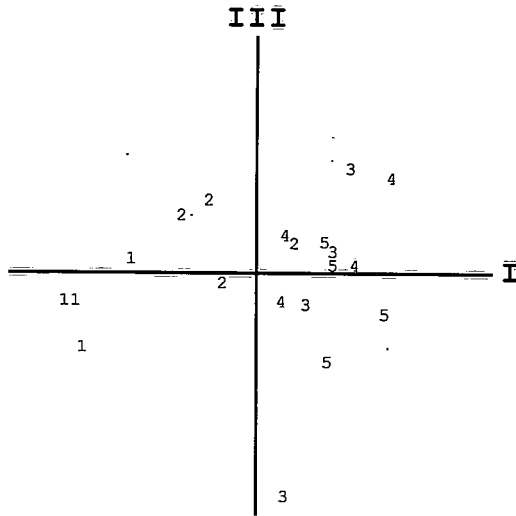


Fig. 4. Reciprocal averaging ordination around a *Juniperus pinchotii* Sudw. tree on a relict semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively.

Organic matter was higher ($P < .05$) under trees than at or beyond canopy edge on both sites (Table 2). Potassium and salinity were slightly higher at the edge of the canopy than at other locations on the relict site. Other soil properties were unaffected by distance from tree bole.

DISCUSSION

These data indicate that site differences reflecting differences in environment and possibly grazing history had a relatively large impact on soils and herbaceous vegetation. Although parent material and physical environment appeared similar for the two sites, these sites may have differed with respect to localized precipitation patterns or geochemical processes. It is also noteworthy that these two study areas have different histories with respect to livestock grazing. Livestock grazing can influence these soil properties (Whitehead 1970, Kleiner and Harper 1972, Bauer et al. 1987).

Our data indicate that *J. pinchotii* trees had minimal impact on most soil properties, results which differ markedly from those reported for *Juniperus* species in the western U.S. (for a review see Tiedemann 1987). For example, Barth (1980), Thran and Everett

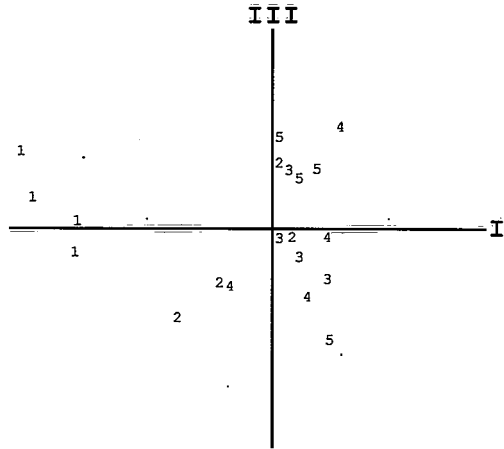


Fig. 5. Reciprocal averaging ordination around a *Juniperus pinchotii* Sudw. tree on a grazed semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively.

(1987), and Klopatek (1987) found 1.5–5.5 times more soil N under pinyon or juniper trees than in interstices. Concentrations of soil P, K, Mg, Ca, and Na followed similar patterns. However, Brotherson and Osayande (1980) reported no differences in P or cations and only a slight difference in N (0.049 vs. 0.044%) under *J. osteosperma* trees and in open areas. Mean soil N was 0.015% in our study area, which is probably growth-limiting. Tiedemann (1987) indicated that 0.05–0.5% total N is sufficient for grassland and shrubland soils. Differences in soil organic matter at different distances from the bole probably resulted from deposition and subsequent decomposition of *Juniperus* foliage.

Herbs in location 1 and, to a lesser extent, location 2, were protected from grazing by *Juniperus* trees. *Juniperus pinchotii* is a closed-canopy species that does not self-prune lower branches. This growth form offers protection from grazing under canopies. At each site, *J. pinchotii* had little influence on herbaceous vegetation or soil properties beyond the tree crown. Our results indicate less tree influence on herbaceous vegetation than commonly reported for *Juniperus* species in the western U.S. That there was no discernible pattern in herbaceous vegetation 1–3 m past the tree canopy and beyond into the interstitial zone does

TABLE 2. Soil properties of grazed and relict grassland at five locations around *Juniperus pinchotii* trees in western Texas.

Soil property	Site ²	Location ¹				
		1	2	3	4	5
OM (%)	R	4.2aA ³	3.4b	3.3bA	3.4bA	3.4bA
	G	3.5aB	2.9b	2.5cB	2.5cB	2.5cB
K (ppm)	R	490.0b	568.0a	437.0b	435.0b	460.0b
	G	461.0	593.0	494.0	451.0	661.0
Salinity (ppm)	R	358.0ab	374.0a	318.0b	325.0b	342.0b
	G	315.0	329.0	297.0	310.0	316.0
P (ppm)	R	6.5A	7.0A	6.2A	7.8A	7.5A
	G	19.9B	17.3B	18.3B	17.7B	17.1B
pH	R	8.0	7.8A	7.9A	7.8	7.9A
	G	8.0	8.2B	8.1B	8.0	8.1B

¹Locations are midway between tree bole and dripline (1), at dripline (2), and 1, 2, and 3 m from dripline (3, 4, and 5, respectively).

²R = relict site, G = grazed site.

³Means within a row followed by the same lowercase letter are not significantly different ($P > .05$) according to Fisher's protected LSD. Means within a column for each soil property followed by the same uppercase letter are not significantly different ($P > .05$) according to Fisher's protected LSD.

not imply that herbaceous vegetation has not reacted to the presence of *J. pinchotii* trees, but rather that this response is distance-independent. That is, it is likely that interaction between *J. pinchotii* and herbaceous vegetation is similar 1 m from the tree canopy and 5 m beyond the tree canopy. Personal observations of mechanically uprooted *J. pinchotii* trees have revealed that the root system of these trees is laterally extensive. Furthermore, soils of our study areas were less than 50 cm deep and were underlain by indurated caliche (McPherson et al. 1988); these conditions are conducive to lateral root growth. Plummer (1958) and Arnold (1964) also reported *Juniperus* roots in openings between trees, and Johnsen (1962) found many juniper roots up to 16 m from trees. Lateral roots in the latter study commonly exceeded tree heights by threefold. Therefore, the concept of "interstitial zone" may have meaning only in an "aboveground" sense in our study area (where average juniper density is 2123 trees/ha on the grazed site and 288 trees/ha on the relict site [McPherson et al. 1988]). At these tree densities, there may be no zone underground where root occupancy between *J. pinchotii* and herbaceous vegetation is minimal. This interpretation is supported by *J. pinchotii* trees in our study area ranging in age from less than 10 yr to 120 yr old (McPherson 1987). Although *J. pinchotii* is increasing in density in the area, it is not a recent invader of the site, and the older, larger trees are well established and are assumed to have extensive lateral root systems.

The presence of tree- \times -quadrat location interaction in our study is of considerable interpretational importance. This interaction indicates that the response of most herbs to distance from *J. pinchotii* depends upon particular characteristics of the tree in question, and precludes general statements about herbaceous pattern related to distance from *J. pinchotii* plants. Contrary to most other studies, we found little discernible zonation beyond the tree canopy. We attribute this interaction to the effect of tree size on vegetation *immediately* beneath the tree (our trees ranged from 1 to 4 m tall). This zone increases with increasing tree size, so that the variation in herbaceous vegetation between locations 1 (midway between tree bole and canopy edge) and 2 (at canopy edge) is strongly influenced by tree size (see Schott and Pieper [1985] for a detailed study on the effect of tree size/age characteristics on resulting subcanopy micro-environment and vegetation). The importance of differences in microclimate associated with compass directions (Arnold 1964, Everett et al. 1983, Armentrout and Pieper 1988) apparently was masked by other factors in our study.

Existence of herbaceous zonation patterns beyond the tree canopy depends upon species and age of *Juniperus* involved, composition of surrounding herbaceous vegetation, and environment (Arnold 1964, Everett et al. 1983, Engle et al. 1987, Armentrout and Pieper 1988). In arid and semiarid environments there is often a reduction in intensity of competition with improvement of soil water status

(see Fowler [1986] for a review). We suggest that herbaceous zonation beyond the tree canopy is more likely to develop around western junipers in drier environments (e.g., *J. osteosperma* in Everett et al. 1983) than around eastern junipers in more mesic environments (e.g., *J. virginiana* in Engle et al. 1987) because limiting moisture in the former setting intensifies species interactions. Superimposed on this "environmental" effect is the influence of herbaceous species composition (e.g., Armentrout and Pieper 1988). This interpretation is consistent with the observation that *J. pinchotii* is a stabilized hybrid between two western junipers (*J. deppeana* and *J. monosperma*) (Hall 1963, Hall and Carr 1968, Adams 1972, 1975) which, by virtue of its increasing density in western and central Texas grasslands, is evidently well adapted to a moisture regime more favorable than that experienced by its progenitors.

It is noteworthy that effects of *J. pinchotii* on herbaceous vegetation pattern were recognizable at several scales (landscape, community, and individual tree). Arnold (1964) first described herbaceous vegetation patterns around *Juniperus* using a single tree. Subsequent research (e.g., Clary 1973, Springfield 1976, Everett et al. 1983, Schott and Pieper 1985) increased the sample size but still focused on the impact of individual trees on herbaceous vegetation patterns. Our study indicates that patterns detectable at the level of individual trees may also be identified at much larger scales.

ACKNOWLEDGMENTS

We thank Sheila Merrigan, Colleen Schreiber, and Jeff Mosley for their assistance with data collection. Mykal Ryan assisted with data entry. This study is a contribution of the College of Agricultural Sciences, Texas Tech University, Publication Number T-9-570.

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Received 20 March 1991

Accepted 5 August 1991