Edaphic Parameters Associated with Shore Juniper Decline

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ABSTRACT

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In the absence of evidence of a biotic agent as the primary cause of decline of shore juniper (*Juniperus conferta*), abiotic factors were examined to determine their roles in contributing to decline. Six of 20 edaphic components measured in 20 landscape plantings were significantly interrelated to decline index in a multivariate principal axis factor analysis. These parameters were calcium, clay + silt content, magnesium, nitrate, phosphorus, and zinc. Where soil horizons could be distinguished, parameters of the A+B horizon were better indicators of decline than those of the C horizon. Supportive evidence for the involvement of these components was provided by tissue nutrient analysis from landscape plantings and from greenhouse studies of nutrient deficiencies and water stress in which nitrogen deficiency and, in one case, both water excesses and deficiencies, induced symptoms resembling decline.

Additional key words: abiotic stress.

Shore juniper, *Juniperus conferta* Parl., is a low-growing shrub that has increased in popularity as a landscape plant in North Carolina during the past several years. The numbers of shore juniper specimens submitted to the North Carolina Plant Disease and Insect Clinic also increased during this period. Many of these plants showed symptoms of a previously undescribed decline. Symptoms of decline included chlorosis of the older needles that progresses to necrosis, beginning at the soil line and advancing up the plant stem. Stunting, root necrosis, and small, tan foliar lesions were observed less frequently. Research was undertaken to determine the etiology of shore juniper decline (SJD).

A root and crown rot, wilting, stunting, and death were reported to be caused by either *Phytophthora cinnamomi* Rands, *P. nicotianae* Dast. var. *nicotianae* (Breda de Haan) Tucker, *Pythium irregulare* Buisman, or *P. sylvalicum* Campbell & Hendrix (7). In repeated, replicated greenhouse experiments, inoculation of 1-yr-old plants with *P. cinnamomi*-infested oat grains produced symptoms resembling those of decline after 6–8 wk (4,5). Plant size indices and root and shoot fresh weights were also significantly smaller in *P. cinnamomi*-inoculated plants than in those inoculated with sterile oat grains or not inoculated. Because root necrosis is generally associated with *P. cinnamomi* infection but not with SJD, *P. cinnamomi* was not considered a primary cause of SJD.

A binucleate, Rhizoctonialike fungus was consistently recovered from surface-disinfested needles of shore juniper. Inoculations of shore juniper with 13 of these isolates under conditions of several variations of relative humidity, host water potential, inoculum placement, wounding, and inoculum substrate failed to produce decline symptoms (4). Inoculations with eight other fungi, as well as naturally infested debris, also failed to induce decline symptoms (4). Populations of plant parasitic nematodes at decline sites were considered too low to be a probable contributing factor in SJD (4; D. M. Benson, *unpublished*).

In the absence of a detectable biotic agent as the primary cause of SJD, investigations were undertaken to examine abiotic agents as causes of or factors contributing to SJD. The sensitivity of shore juniper to low dosages of ozone, alone and in combination with NO_2 and SO_2, has been reported elsewhere (4). The roles of certain edaphic components in SJD are discussed in this article.

MATERIALS AND METHODS

Edaphic components study. Twenty landscape plantings of shore juniper representing different severity levels of SJD were selected in Wake County, NC. Plantings had been in place a minimum of 3 yr. At each site, 20 plants, approximately one plant per square meter, were rated for SJD as follows: 1 = no symptoms, 2 = chlorosis on the basal third of the plant, 3 = chlorosis and some necrosis on the basal third, 4 = lower third of plant necrotic, 5 = lower third of plant necrotic and chlorosis of the middle third, 6 = basal third necrotic and some necrosis of the middle third, 7 = basal two-thirds necrotic, 8 = lower two-thirds necrotic and chlorosis of the top third, 9 = lower two-thirds of plant necrotic and some necrosis of the upper third, and 10 = plant dead.

Approximately 500 cm^3 each of surface soil (A+B horizons) and subsoil (C horizon) were collected at each site. Where soil was homogeneous to a depth of 30 cm, only one sample was taken. When the C horizon was encountered in the first 30 cm, A+B and C horizons were collected separately. Depth of the A+B horizon was recorded. Soil color was determined by the Munsell soil color book (Munsell Products, Baltimore, MD 21233). Color code letters were converted to numeric values as follows: 1 = 1 YR, 2 = 2.5 YR, 3 = 4 YR, 5 = 7.5 YR, and 6 = 10 YR. Thus, the higher numbers indicate decreasing soil redness. Soil mottles were rated by the following scale: 0 = none, 1 = few, 2 = moderate, 3 = abundant, and 4 = numerous. The proportion of sand and clay + silt was determined by wet sieving 10 g of soil (oven dry weight, 60 C for 24 hr). Sand retained by a sieve with a 53-μm opening was collected, oven-dried 24 hr at 60 C, and weighed. The proportion of clay + silt was determined by subtraction. Acidity, pH, cation exchange capacity, base saturation, percent organic matter, and weight per volume (bulk density) were determined by the Agronomic Division, North Carolina Department of Agriculture (NCDA). Exchangeable and extractable anions and cations (calcium, copper, magnesium,

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manganese, nitrate, total nitrogen, phosphorus, potassium, and zinc) were determined spectrophotometrically and soil reaction electrometrically by NCDA.

Approximately 50 g (fresh weight) of actively growing (terminal shoots) juniper tissue was collected at each site. Actively growing tissue is considered the most accurate indicator of nutrient status for conifers (17). Levels of tissue nutrients (Bo, Ca, Cu, Fe, Mg, Mn, N, P, K, and Zn) were determined spectrophotometrically by the Agronomic Division, NCDA.

A multivariate factor analysis (principal axis method—no rotation) was performed for all 20 variables for all data together and for single C horizon and A+B horizon samples separately. Variables unrelated to decline rating in this preliminary factor analysis were omitted from the final factor solutions. Factor loadings greater than or equal to 0.35 indicated interrelationship among variables within a factor (3,11,12).

Nutrient deficiency study. Roots of 9-mo-old rooted shore juniper cuttings were rinsed with distilled water and potted in distilled water-washed sand in 7.5-cm square plastic pots in clay saucers. Plants were watered alternately with distilled water and Hoagland's solution deficient in specific nutrients (9). The resulting treatments were the complete nutrient complement and the complete nutrient complement minus Ca, Fe, Mg, N, P, K, S, or micronutrients (B, Cu, Mn, Mo, and Zn). Height and width of each plant were recorded at 0, 4, 8, and 12 wk after potting, and plant size indices $[(h + w)/2]$ were calculated (7). Treatments were replicated four times in a complete randomized block design, and the experiment was repeated once.

TABLE 1. Factor analysis (principal axis method—unrotated) of soil variables in undifferentiated soils from six landscape plantings of shore juniper

Variable	Factor 1	Factor 2	Factor 3	Communality
Decline rating	0.85*[a]	0.16	0.42*	0.93
Acidity	−0.96*	0.24	0.15	1.00
Base saturation	0.99*	−0.11	−0.04	1.00
Calcium	0.97*	−0.17	−0.08	0.97
Clay + silt	0.74*	0.64*	0.10	0.96
Color	−0.83*	−0.04	0.48*	0.93
Log magnesium	0.87*	−0.04	0.05	0.76
Nitrate	−0.52*	0.80*	−0.28	0.99
Phosphorus	−0.87*	−0.40*	−0.15	0.93
pH	0.96*	−0.04	−0.11	0.94
Variance	0.75	0.13	0.06	
Cumulative variance	0.75	0.88	0.94	

[a] Values marked by an asterisk indicate interrelationship within a factor, as their loading is ⩾0.35 (3,13,14).

Water stress study. In a preliminary experiment, xylem water potentials, as measured by a hydraulic press, of 2-yr-old unwatered plants decreased after 12 days when compared to those of plants watered regularly (6). Plants growing in saturated soil moisture tended toward a more gradual decrease in xylem potential.

To study water stress effects on shore juniper, three watering regimes were established. Two-year-old shore juniper plants in a 1:1:1 (v/v) mixture of pasteurized soil, sand, and peat in 3.7-L plastic containers were watered as needed, placed in saucers of water, or subjected to cycles of no water for 12 days followed by a thorough watering on the 13th day. Plants were observed for chlorosis, necrosis, and wilting. Treatments were replicated five times in a complete randomized block design, and the experiment was performed four times.

RESULTS

Edaphic components study. Junipers at any one site were generally homogeneous in decline rating. Mean decline ratings per site ranged from 1.2 to 8.6. Soils from all survey sites had been previously disturbed. Most sites had apparently been filled, in many cases with parent material after road or building construction.

For sites in which soil horizons could not be distinguished (highly disturbed, undifferentiated soils), decline rating and the nine soil variables included in the factor analysis were highly interrelated in Factor 1, which accounted for 75% of the overall variance (Table 1). Decline rating was not related to other variables in Factor 2. Factor 3, which accounted for 6% of the overall variance, indicated an interrelationship between decline rating and soil color. As indicated by the communality figure, this three-factor solution accounted for 93% of the variance in decline rating. Coefficients for linear correlations among variables are given in Table 2. A significant inverse relationship between decline rating and phosphorus was found. In addition, decline rating was directly related ($P<0.05$) to base saturation, calcium, and clay + silt.

For sites in which the horizons could be distinguished, the set of variables interrelated with decline ratings in the surface soil was different from the set of variables interrelated with decline ratings in the subsoil (Tables 3 and 4). Estimates of communality indicated that the surface soil accounted for more of the variance in decline rating (75%) than did the subsoil (66%). In the surface soil data, Factor 1 accounted for 40% of the overall variance and indicated an interrelationship among decline rating and five of the six soil variables included. All soil variables were interrelated with decline rating in Factor 2, which accounted for 35% of the overall variation

TABLE 2. Linear correlations of soil variables with disease rating from landscape plantings of shore juniper in disturbed and differentiated soils

	Linear correlation with decline rating[a]			
Variable	Undifferentiated soils (6 sites)	Surface soils (14 sites)	Subsoils (14 sites)	Undifferentiated soils plus surface soils (20 sites)
Acidity	−0.72			
Base saturation	0.81*			
Calcium	0.79*		−0.40*	0.03
Cation exchange capacity			−0.38	
Clay + silt	0.80*	−0.39	−0.30	−0.22
Color	−0.58			
Magnesium		−0.42*	−0.33	−0.15
Log magnesium	0.64			
Manganese		0.22		
Nitrate	−0.46			−0.16
Nitrogen		0.35	−0.34	
Organic matter			−0.35	
Phosphorus	−0.83**	−0.25	−0.55**	−0.33
Potassium			−0.15	
pH	0.70			
Zinc		0.57**		0.43*

[a] Correlation coefficient for disease rating and a given variable are significant at 10% (*) and 5% (**) where marked.

(Table 3). A direct linear correlation was found between zinc and the decline rating ($P < 0.05$) and an inverse linear correlation between magnesium and the disease rating ($P < 0.10$) (Table 2).

Clay + silt, magnesium or log magnesium, nitrate or total nitrogen, and phosphorus were the only variables consistently interrelated to decline rating in factor analyses of all three types of soil samples. A greater proportion of variation in decline rating was explained by the surface soil data than by the subsoil data; therefore, data from the surface soil were used with data from the sites where horizons could not be distinguished to determine an overall factor solution for all sites sampled. The decline rating was interrelated with six soil variables in all four factors (Table 5). A total of 95% of the variance in decline rating was accounted for by the four factors. Means and ranges of these edaphic parameters are given in Table 6.

TABLE 3. Factor analysis (principal axis method—unrotated) of soil variables in surface soils from 14 landscape plantings of shore juniper

Variable	Factor 1	Factor 2	Factor 3	Communality
Decline rating	−0.42*[a]	0.71*	0.25	0.75
Clay + silt	0.92*	−0.01	−0.19	0.89
Magnesium	0.80*	−0.27	0.40*	0.87
Manganese	0.54*	0.76*	−0.22	0.92
Nitrogen	0.36*	0.84*	−0.30	0.93
Phosphorus	0.81*	−0.04	0.35*	0.78
Zinc	−0.20	0.76*	0.47*	0.84
Variance	0.40	0.35	0.11	
Cumulative variance	0.40	0.75	0.85	

[a] Values marked by an asterisk indicate interrelationship within a factor, as their loading is ⩾0.35 (3,11,13).

TABLE 4. Factor analysis (principal axis method—unrotated) of soil variables in the subsoils from 14 landscape plantings of shore juniper

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Decline rating	−0.69*[a]	0.06	0.11	0.40*	0.66
Calcium	0.85*	−0.11	−0.19	0.42*	0.95
Cation exchange capacity	0.74*	−0.26	−0.36*	0.48*	0.97
Clay + silt	0.50*	−0.42*	0.60*	−0.05	0.79
Magnesium	0.63*	0.28	0.36*	−0.29	0.69
Nitrogen	0.63*	0.71*	0.30	0.03	0.98
Organic matter	0.60*	−0.76*	0.18	−0.10	0.98
Potassium	0.60*	0.54*	−0.35*	−0.36*	0.91
Phosphorus	0.22	0.63*	−0.49*	−0.38*	0.83
Variance	0.40	0.23	0.13	0.10	
Cumulative variance	0.40	0.63	0.76	0.86	

[a] Values marked by an asterisk indicate interrelationship within a factor, as their loading is ⩾0.35 (3,11,13).

TABLE 5. Factor analysis (principal axis method—unrotated) of soil variables in the surface soils and undifferentiated soils from 20 landscape plantings of shore juniper

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Decline rating	−0.37*[a]	0.43*	0.70*	0.35*	0.95
Calcium	0.81*	0.44*	0.23	−0.07	0.91
Clay + silt	0.75*	−0.37*	0.28	0.22	0.82
Magnesium	0.56*	−0.53*	0.46*	−0.04	0.81
Nitrate	0.45*	0.55*	−0.50*	0.43*	0.94
Phosphorus	0.87*	0.22	−0.16	−0.19	0.87
Zinc	−0.07	0.83*	0.31*	−0.31*	0.89
Variance	0.38	0.26	0.17	0.07	
Cumulative variance	0.38	0.64	0.81	0.88	

[a] Values marked by an asterisk indicate interrelationship within a factor, as their loading is ⩾0.35 (3,11,13).

When data from surface soils and undifferentiated soils were combined, zinc was the only soil variable to be directly correlated to decline rating in a linear relationship ($P < 0.10$) (Table 2).

All tissue nutrients examined were significantly interrelated to decline rating (Table 7). Calcium was directly correlated to decline rating and phosphorus and potassium were inversely correlated with decline rating in linear relationships ($P < 0.05$) (Table 8). Means and ranges of tissue nutrient data are also presented in Table 8.

Nutrient deficiency study. After 4 wk, the percentage increase in the plant size indices for plants growing in N-deficient medium was significantly less than the percentage increases of the control and the plants growing in the other nutrient-deficient media (Fig. 1). Eight weeks after transplanting, percentage increases in plant size indices for plants growing in N- and P-deficient media were significantly less than for control plants receiving all nutrients. Basal chlorosis was evident on N-deficient plants 8 wk after transplanting, and by 12 wk, chlorosis had progressed to necrosis. The percentage increase in the plant size indices of N-, P-, and

TABLE 6. Means and ranges of soil parameters in surface soils and undifferentiated soils from 20 landscape plantings of shore juniper

Variable	Mean	Range
Calcium (ppm)	62.1	5.0 − 87.3
Clay + silt (%)	39.8	6.4 − 83.0
Magnesium (ppm)	12.8	6.6 − 23.3
Nitrate (ppm)	1.8	0.0 − 9.6
Phosphorus (ppm)	30.8	2.0 −100.0
Zinc (ppm)	11.2	1.2 − 68.9

TABLE 7. Factor analysis (principal axis method—unrotated) of shore juniper tissue nutrient levels and decline rating from 20 landscape plantings

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Decline rating	−0.57*[a]	0.37*	0.00	−0.64*	0.87
Boron	−0.06	−0.59*	0.55*	0.44*	0.85
Calcium	−0.78*	0.36*	0.45*	0.14	0.95
Copper	0.68*	0.47*	−0.31	0.23	0.82
Iron	0.37*	0.44*	0.65*	0.28	0.82
Magnesium	−0.52*	0.56*	0.29	−0.38*	0.82
Manganese	−0.53*	0.56*	−0.05	−0.37*	0.73
Nitrogen	0.71*	0.16	0.54*	0.05	0.82
Phosphorus	0.74*	0.03	0.39*	−0.27	0.77
Potassium	0.83*	0.29	0.01	−0.23	0.83
Zinc	0.42*	0.45*	−0.47*	0.51*	0.85
Variance	0.36	0.08	0.16	0.13	
Cumulative variance	0.36	0.54	0.70	0.83	

[a] Values marked by an asterisk indicate interrelationship within a factor, as their loading is ⩾0.35 (3,11,13).

TABLE 8. Linear correlation of shore juniper tissue nutrient levels and decline rating and means and ranges of tissue nutrient levels

Variable	Correlation with decline rating[a]	Mean	Range
Boron	0.04	60 ppm	26–64
Calcium	0.68*[b]	0.67 %	0.44–1.04
Copper	−0.13	8 ppm	3–14
Iron	0.08	59 ppm	34–101
Magnesium	0.24	0.12 %	0.10–0.16
Manganese	0.21	330 ppm	99–850
Nitrogen	−0.33	2.11 %	1.39–3.04
Phosphorus	−0.49*	0.32 %	0.22–0.46
Potassium	−0.44*	1.47 %	0.94–1.95
Zinc	0.23	37 ppm	18–118

[a] 1 = Healthy plant, 10 = dead plant.
[b] r = 0.44 at 5%.

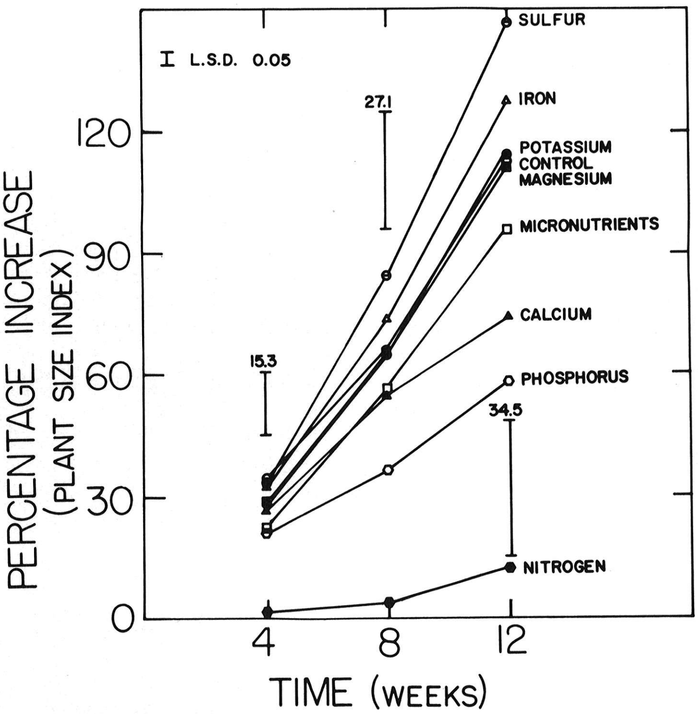

Fig. 1. Effect of eight different nutrient-deficient media on the percentage size increase in shore juniper plants for 12 wk.

Ca-deficient plants was significantly less than that of control plants after 12 wk.

Water stress study. Junipers from which water was withheld for cycles of 12 days developed the first SJD-like symptoms after 8 wk. Plants maintained under saturated soil moisture conditions developed chlorosis of the older needles after 10 wk, and chlorotic needles subsequently became necrotic. Control plants did not develop chlorosis or necrosis. When this experiment was repeated three additional times, no symptoms developed in any watering regime.

DISCUSSION

Many decline phenomena are precipitated by interactions among predisposing, inciting, and contributing factors (13,16). Factor analysis is a "useful interpretive procedure" for determining interrelationships in diseases of complex etiology (16). It has been used to relate nematode populations (14) and Hypoxylon canker incidence on trembling aspen (2) to soil properties. Factor analysis has been used to characterize disease progress curves (3,11,12) and components of Septoria resistance in wheat (10). In our study, factor analysis was used to indicate potentially fruitful areas of research on the etiology of SJD and as additional evidence for the contribution of soil properties to SJD.

Six of 20 edaphic components examined were interrelated to the decline index in a multivariate factor analysis. Supportive evidence for the involvement of these components in SJD was provided by greenhouse studies of nutrient deficiencies and water stress, in which SJD-like symptoms were produced by nitrogen deficiency and by water deficiency or excess. Further supportive evidence was provided by tissue nutrient analysis, which indicated suppressed levels of nitrogen, phosphorus, and potassium in decline plants and an elevated level of calcium in decline plants compared with that in asymptomatic plants. Although the precise roles of these components have not been established, deficiencies of nitrogen and phosphorus can cause chlorosis, leading to necrosis of the older leaves of other plant species (1,8,15).

Foliar symptoms of SJD were produced by dissimilar causal agents—*P. cinnamomi*, nitrogen deficiency, and, in one instance, water stress. Thus, chlorosis of the older needles progressing to necrosis may be considered a general response of shore juniper to stress. Diagnosis of shore juniper problems from examination of foliage alone would be difficult without additional information. Our data suggested that soil nutrient levels, soil clay + silt content, and possibly water stress may be involved in SJD. Because data presented indicated that edaphic factors may have a strong role in SJD, poor soils should be avoided for landscape plantings of shore juniper. Further research is needed to determine if SJD could be alleviated with fertilization and irrigation.

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