Periodicity in Tree Rings from the Corn Belt
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thick Bh horizon that was penetrated by the conduit and comparison of the conduit sand with other outcrops suggests that it is associated with a pre-1886 event. The third possibility is that the conduit sand is associated with an event that took place before 1886 but later than 3060 years ago and that is distinct from the event that produced the crater (**1**). This suggests the occurrence of two events between 3740 and 1270 years ago. Comparison of site 1 with site 2 revealed similarities in the stratigraphy, composition, and nature of the liquefied sands. Comparison of the texture, color, and compaction of these sands supports the assumption of two temporally distinct events at site 1 and suggests that they are the same as those seen at site 2.

Although the number of earthquakes inferred at these sites is uncertain, definite field evidence indicates that one event occurred before 1886 with a strong possibility that at least two moderate to large earthquakes occurred near Charleston before 1886 but later than 3740 years ago (possibly between about 3000 and 1200 years ago). When the 1886 event is included, an initial average for a maximum recurrence interval of about 1500 to 1800 years is suggested for the Charleston seismogenic zone. Our results show that, with additional trenches and radiocarbon dating, tighter constraints can be developed for the number and timing of past events.

References and Notes

1. G. A. Bollinger, *Bull. Seis. Soc. Am.* **62**, 851 (1972); O. W. Nuttli *et al.*, *ibid.* **69**, 893 (1979).
2. C. E. Dutton, *U.S. Geol. Surv. Annu. Rep.* **9**, 203 (1889).
3. D. W. Rankin, Ed., *Geol. Surv. Prof. Pap. 1028* (1977); G. S. Gohn, Ed., *Geol. Surv. Prof. Pap. 1313* (1983).
4. L. Seeber and J. G. Armbruster, *J. Geophys. Res.* **86**, 7874 (1981); P. Talwani, *Geology* **10**, 654 (1982); C. M. Wentworth and M. Mergner-Keefer, *Geol. Surv. Prof. Pap. 1313* (1983), p. S1; J. C. Behrendt *et al.*, *ibid.*, p. J1.
5. Paleoseismology was a term first used in the United States by R. E. Wallace [in *Earthquake Prediction: An International Review*, D. W. Simpson and P. G. Richards, Eds. (American Geophysical Union, Washington, D.C., 1982), pp. 290–216; for a review see K. E. Sieh, in *ibid.*, pp. 181–207]. In this field we seek evidence of prehistoric earthquakes as they are preserved in shallow sediments. By dating suitably located organic materials on exposed trench faces, the historical record can be extended back in time and the recurrence rate estimated. Paleoseismic methods have been used extensively in the western United States [see K. E. Sieh, *J. Geophys. Res.* **83**, 3907 (1978); F. H. Swan, D. P. Schwartz, L. S. Cluff, *Bull. Seis. Soc. Am.* **70**, 1431 (1980)]. The first use of this technique in the central United States was by D. P. Russ [*Bull. Geol. Soc. Am.* **90**, 1013 (1979)].
6. Seismically induced liquefaction is usually associated with moderate to large earthquakes and is accompanied by forceful ejection of sand and water and the formation of sandblows and small craters. Liquefaction is caused by an increase in pore-water pressure during passage of seismically generated shear waves. If the pore-water pressure increases to a point equal to that of the confining pressure, the effective stress drops to 0 and the soil will enter a liquefied state (*8*). Well-sorted, cohesionless, water-saturated sands are most prone to liquefaction. For a detailed description of the mechanics of the liquefaction process see, for example, H. B. Seed and I. M. Idriss [in *Ground Motions and Soil Liquefaction During Earthquakes* (Earthquake Engineering Research Institute, Berkeley, Calif., 1982)]. D. P. Russ [*U.S. Geol. Surv. Prof. Pap. 1236* (1982), p. 95] argues that the approximate threshold of liquefaction in the New Madrid region is $m_b \geq 6.2$ (m_b, body wave magnitude). We assume a similar threshold for the Charleston region.
7. R. F. Scott and K. A. Zuckerman, in *The Great Alaska Earthquake of 1964* (National Academy of Sciences, Washington, D.C., 1973), vol. 7, pp. 179–189.
8. T. L. Youd, in *Proceedings of the World Conference on Earthquake Engineering 8*, San Francisco, 21–28 July 1984. In this study, field evidence of recurrence of liquefaction at locations in Japan and the United States is described.
9. J. M. Cox, thesis, University of South Carolina, Columbia (1984).
10. Site 1 is also being investigated by S. F. Obermeier *et al.* [*Science* **227**, 408 (1985)]. The outcrop studied by us is about 30 cm further into the plane of the wall. These are two of four sites where our detailed studies are under way.
11. K. E. Meisling, in *Geological Excursions in Southern California*, P. L. Abbott, Ed. (San Diego State University, San Diego, 1980), pp. 63–66.
12. Funded by a grant from the Nuclear Regulatory Commission following an initial effort funded by the U.S. Geological Survey (contract 14-08-001-21334). We thank several colleagues who visited the trenches and made valuable suggestions, in particular K. Sieh, K. Coppersmith, B. Voight, B. Ehrlich, L. Gardner, and D. Colquhoun. We thank D. Schwartz, K. Coppersmith, and B. Ehrlich for constructive reviews of the manuscript.

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Periodicity in Tree Rings from the Corn Belt

Abstract. *Previous tree-ring studies indicated that the total area affected by drought in the western United States has rhythmically expanded and contracted over the past 300 years, with a period near the 18.6-year lunar nodal and 22-year double-sunspot cycles. Recently collected tree-ring data from the U.S. Corn Belt for the years 1680 to 1980 were examined for evidence of either of these cycles on a regional scale. Spectral analysis indicated no periodicity in the eastern part of the Corn Belt, but a significant 18.33-year period in the western part. The period length changed from 17.60 to 20.95 years between the first 150 years and the last 151. High-resolution frequency analysis showed that the structure of the 18.33-year spectral peak was complex, with contributions from several frequencies near both the lunar nodal and double-sunspot periods. A* t*-test of difference of means in reconstructed annual precipitation weakly corroborated a previous finding of an association between drought area and the phase of the double-sunspot cycle. Both the high-resolution frequency analysis and the* t*-test results indicate that the periodic component of drought near 20 years is too weak and irregular to be of use in drought forecasting for the Corn Belt.*

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Evidence from tree rings of a 20-year rhythm in the total area of drought in the western United States (*1*) has been used to support the hypothesis that drought is linked to the 22-year Hale double-sunspot cycle, the 18.6-year lunar nodal cycle, or both (*2–5*). A convincing explanation of the physical mechanisms linking these solar and lunar cycles to climate is lacking, however, and the sparseness of tree-ring data for some parts of the western United States makes any assessment of the total area of drought conjectural. The largest gaps in coverage are in the grain-producing regions of the U.S. Great Plains, where droughts have been particularly devastating. In a previous study of tree growth in four regions on the fringes of the Great Plains, a period near 20 years was found only for central Iowa (*6*). Tree-ring data from other parts of the Corn Belt have since been collected and used to reconstruct a regional series of annual precipi-

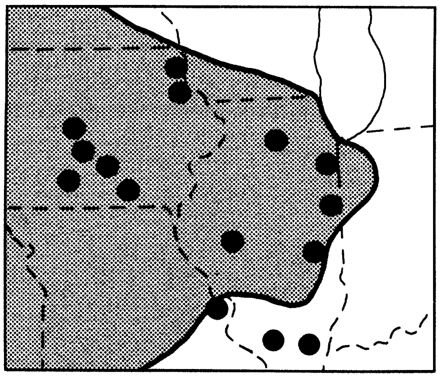


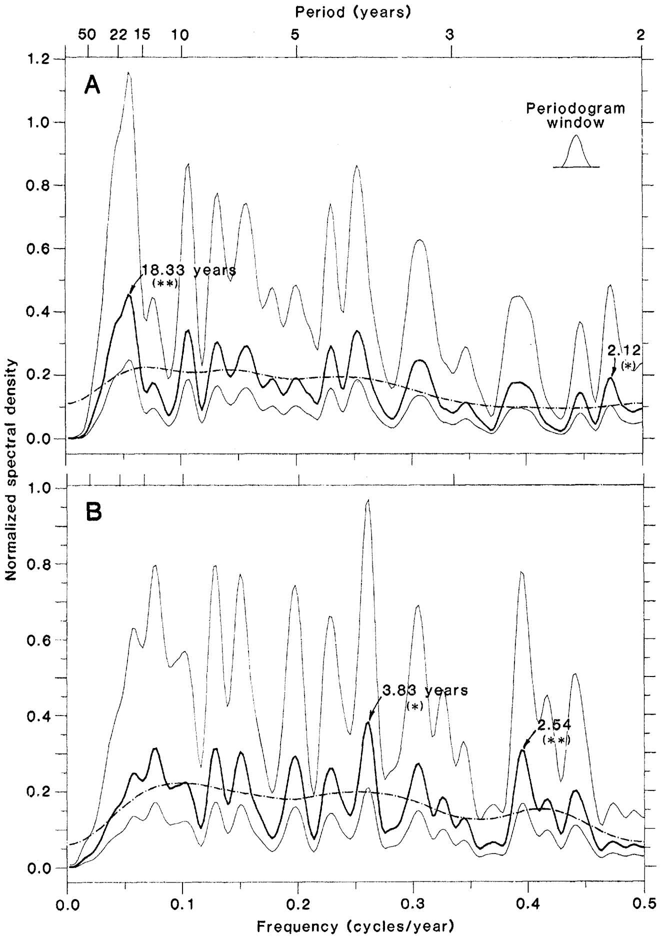
Fig. 1. Site locations of trees and boundaries of the grassland of central North America. Total number of trees for the 15 sites ranged from 37 in 1680 to more than 500 in the 20th century. All sites have at least one tree dating back to 1686, and all but two sites have trees dating to 1680. All samples were white oak (*Quercus alba*). Indices of annual ring width from these sites are highly correlated ($r > 0.80$) with annual (August to July) precipitation (*7*). Grassland boundaries are redrawn from Borchert (*8*).

tation, 1680 to 1980 [figure 2 of (*7*)]. The tree-ring data and precipitation reconstruction are examined here for periodicity and evidence of lunar or solar influence.

The tree-ring data are from 15 sites in the prairie "peninsula" that extends eastward from the Great Plains into the Midwest (Fig. 1). This peninsula is believed to be especially drought-prone when atmospheric circulation anomalies favor extreme drought over the much larger area of the Great Plains (*8*). Three time series, each covering the years 1680 to 1980, were examined: the mean tree-ring index for the seven Iowa sites, the mean index for the remaining eight sites, and the precipitation reconstruction, which is proportional to the mean tree-ring index for all 15 sites (*7*). The three series are referred to as Iowa, Illinois, and precipitation. All tree-ring data are available from the International Tree-Ring Data Bank at the University of Arizona, Tucson.

The tree-ring index is a ratio of ring width to the value of a fitted curve that approximates the trend in ring width with increasing age of the tree (*9*). Indexing, which is equivalent to high-pass filtering, places an upper limit on the range of periods over which climatic periodicity can be studied. The method used for indexing ring widths in our study was filtering by a cubic spline of specified frequency response (*10*), such that a sine wave with a period of 60 years would be reduced in amplitude by 50 percent. The reductions in amplitude at the key periods 22 and 18.6 years would be only 1.8 and 0.9 percent, respectively.

The mean Iowa and Illinois tree-ring series for 1680 to 1980 were subjected to spectral analysis to test for periodicity at the 18.6-year lunar nodal or 22-year double-sunspot periods. The highest peak in the sample spectrum for Iowa was at 18.33 years; this peak was significantly different [$\chi^2(10) = 21.2$, $P < 0.05$] (*11*) from the smooth underlying spectrum (Fig. 2A). The steep decline in the spectrum at periods longer than about 40 years is an artifact of data processing—conversion of ring widths to indices—but the waveform of the 18.33-year peak is at too short a period to be attributed to the indexing procedure. The absence of a corresponding peak in the Illinois spectrum (Fig. 2B) suggests that if climate is responsible for the 18.33-year spectral peak in the Iowa series, the climatic periodicity is restricted to the western Corn Belt.



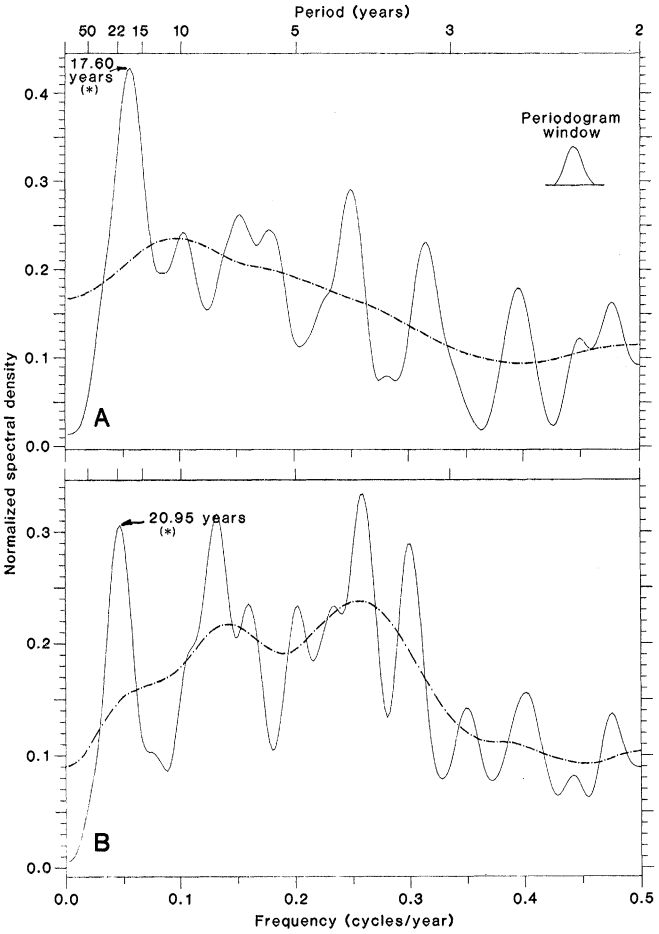


Fig. 2 (left). Estimated spectral density function (SDF) of Iowa (A) and Illinois (B) mean tree-ring indices, 1680 to 1980. Five percent of each end of the time series was tapered, the mean was subtracted, and the series was padded to a total length of 440 years by appending zeros. The periodogram was computed by the discrete Fourier transform with a fast-Fourier-transform algorithm. The SDF (dark line) was estimated by smoothing the periodogram (*11*) with an 11-weight raised-cosine filter. For a padded length of 440 years, spectral estimates near the lunar-nodal and sunspot periods were available at 17.60, 18.33, 19.13, 20.95, 22.00, and 23.16 years. Also shown are the 90 percent confidence band about the SDF (light lines) and a greatly smoothed periodogram (dashed line) against which spectral peaks were tested for significance [(*) $P = 0.10$ and (**) $P = 0.05$]. Significance levels of peaks are qualified by two considerations. First, the χ^2 test used is strictly appropriate for testing only at a prespecified period, not for "searching" for periodicity over a range of periods (*11*). Second, the choice of a much-smoothed version of the SDF (dashed line) as a null continuum was arbitrary; the procedure used to index ring widths clearly ruled out some simple theoretical alternatives such as "white noise" or "red noise." Fig. 3 (right). Estimated spectral density functions for the first half (1680 to 1829) (A) and the last half (1830 to 1980) (B) of the Iowa mean tree-ring index. The analysis procedure was as described in the legend to Fig. 2A, except that a 19-weight filter was used to smooth the periodogram. No peaks were significant at the 0.05 level of confidence.

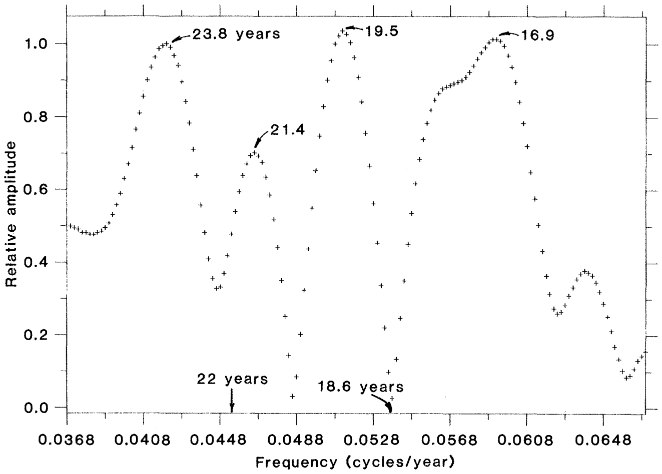


Fig. 4. Relative amplitudes of periodic components determined by HRFA of the Iowa mean tree-ring index, 1680 to 1980. Only the period range 15 to 27 years is plotted. The spacing between frequencies at which amplitudes of periodic components were calculated was $\Delta\omega = 0.0002$ per year. Amplitude squared is proportional to variance accounted for by the periodic component; amplitudes have been scaled relative to the peak at 19.5 years.

The periodicity in tree growth in Iowa has apparently been consistent over time, as illustrated by estimated spectra for the first and second halves of the 1680 to 1980 record (Fig. 3, A and B). The only peaks significant at the 0.10 level of confidence in these spectra were at 17.60 years (1680 to 1829) and 20.95 years (1830 to 1980). Neither of the peaks is at the lunar nodal or double-sunspot periods, however, and the slight shift in period over time indicates that the periodicity may not be explainable in terms of a simple hypothesis involving a single regular periodic signal.

Smoothed spectral estimates are useful for studying quasi-periodic phenomena or periodic phenomena whose power is spread over a broad range of frequencies, but could miss a periodic signal or a signal concentrated in a very narrow band of frequencies. A lunar nodal signal potentially falls in the later category. A recently developed method for examining the periodic structure of time series at a narrower frequency spacing than with spectral analysis is high-resolution frequency analysis (HRFA) (*12*). The effectiveness of HRFA in resolving periodic components in "noisy" series has been demonstrated in simulation experiments (*13*).

Amplitudes of periodic components for the period interval 15 to 27 years from HRFA of the 1680 to 1980 Iowa series are plotted in Fig. 4. The two largest amplitudes were at 19.5 and 16.9 years. Recall that the corresponding spectral peak (Fig. 2A) was at the intermediate period of 18.33 years. The third highest amplitude in HRFA was at 23.8 years, a period somewhat longer than the average double-sunspot cycle. The multiple peaks shown in Fig. 4 suggest that the Iowa tree-growth periodicity is a complex statistical phenomenon that cannot unequivocally be classified as a solar or lunar nodal signal.

Regardless of the cause of the near 20-year periodicity, its importance to Iowa tree growth and presumably to drought forecasting can be estimated by the percentage of tree-ring variance explained by sinusoids fitted to the line frequencies identified by HRFA. Least-squares fitting and removal of the 19.5- and 16.9-year periods reduced the total variance in the Iowa series by 7 percent; removal of the 19.5-, 16.9-, and 23.8-year periods reduced the total variance 10 percent. HRFA of the reconstructed Corn Belt precipitation series yielded similar results: the total variance due to the three most important frequencies was 9 percent. Even if the peaks identified by HRFA represented regular cycles, they would therefore allow prediction of perhaps a maximum of 10 percent of the variance of annual precipitation.

A phase linkage between tree-growth and lunar or solar cycles could be manifested by nonsinusoidal tree-growth variations, and so go undetected by spectral analysis or HRFA. Previous tree-ring studies indicated that the total area of drought in the western United States tended to peak about 2 years after alternate minima in the Hale sunspot series (*2*); another interpretation of the same data was that drought peaked in years of maximum lunar nodal tidal effect (*3*). We tested the precipitation series for a similar phase relation with sunspots by a *t*-test of difference of means for groups of years centered on 2 years after "odd" sunspot minima versus 2 years after "even" minima. Sunspot minima in 1976, 1954, and so on were designated as "odd," and alternate minima as "even." For a possible lunar relation, precipitation data centered on years of lunar maximum were tested against precipitation data centered on years of lunar minimum (Table 1). The means for the two groups from opposite phases of the lunar cycle were almost identical. The means for the two solar groups, on the other hand, were significantly different ($P < 0.05$), although the difference (3.8 cm) appears to be too small to be of use in drought prediction. As in previous tree-ring studies (*2*), relatively dry conditions followed odd (1976, 1954, 1933, and so on) sunspot minima. The *t*-test results therefore weakly corroborate the previous finding (*2*) of a phase relation between large-scale drought and the double-sunspot cycle. The three driest years in the precipitation series—1733, 1800, and 1934—were 0, +2, and +1 years from odd sunspot minima. These years could represent solar epochs during which spatially nonstationary drought shifted to the eastern part of the Great Plains.

Table 1. Test of difference of means (*15*) between reconstructed precipitation in years of odd versus even minima in the Hale double-sunspot series and maximum versus minimum lunar nodal tidal effect. Samples were 5-year averages of the precipitation series centered on key dates. Key dates for odd versus even sunspot minima were +2 years from minima in the annual mean sunspot number for 1711 to 1976 (*16*); minima in 1976, 1954, and so forth were designated as odd. Key dates for maximum lunar tidal effect were years of maximum lunar nodal tide (*17*); lunar minima were taken as halfway between maxima. The *t*-test was two-tailed.

Group	Sample size	Mean (cm)	Standard deviation (cm)
Odd sunspot minima	13	86.4	4.80
Even sunspot minima	12	90.2	3.92
$t(23) = -2.14$, $P = 0.043$			
Lunar maxima	16	89.4	3.85
Lunar minima	16	89.3	1.08
$t(29) = -0.14$, $P = 0.891$			

The lack of evidence for an 18.6-year lunar nodal signal in the results from spectral analysis, HRFA, and the *t*-test does not completely rule out the possibility of lunar nodal influence on drought in the Corn Belt. Any such influence, however, is either too weak to be detected from tree-ring data and our methods of analysis or is masked by the presence of other periodic or quasi-periodic signals. Complex hypotheses involving more than one lunar tidal component (*14*) have not been considered here; neither has possible interaction between solar and lunar signals. Ongoing tree-ring collections should eventually provide more suitable data for testing for a spatially nonstationary drought rhythm in the Great Plains and for testing complex hypotheses of solar or lunar-tidal influence on drought.

References and Notes

1. C. W. Stockton and D. M. Meko, *Weatherwise* **28** (No. 6), 244 (1975).
2. J. M. Mitchell *et al.*, in *Solar-Terrestrial Influence on Weather and Climate*, B. M. McCormac and T. A. Seliga, Eds. (Reidel, Dordrecht, Netherlands, 1979), pp. 125–143.
3. R. G. Currie, *J. Geophys. Res.* **86**, 11,055 (1981).
4. E. P. Bell, in *Variations of the Solar Constant*, S. S. Sofia, Ed. (NASA Conf. Publ. CP-2191, National Atmospheric and Space Administration, Washington, D.C., 1983), pp. 257–263.
5. C. W. Stockton, J. M. Mitchell, Jr., D. M. Meko, in *Weather and Climate Responses to Solar Variations*, B. M. McCormac, Ed. (Colorado Associated University Press, Boulder, 1983), pp. 507–515.
6. C. W. Stockton and D. M. Meko, *J. Climate Appl. Meteorol.* **22**, 17 (1983).
7. T. J. Blasing and D. Duvick, *Nature (London)* **307**, 143 (1984).
8. J. R. Borchert, *Ann. Assoc. Am. Geogr.* **40**, 1 (1950).
9. H. C. Fritts, *Tree Rings and Climate* (Academic Press, New York, 1976), pp. 261–268.
10. E. R. Cook and K. Peters, *Tree-Ring Bull.* **41**, 45 (1981).
11. The quantity $\nu g(\omega)/f(\omega)$ approximately follows a chi-squared distribution with ν degrees of freedom, where $g(\omega)$ is the spectral estimate at frequency ω and $f(\omega)$ is the theoretical population spectral value [P. Bloomfield, *Fourier Analysis of Time Series: An Introduction* (Wiley, New York, 1976), pp. 151–180].
12. M. M. Siddiqui and C. C. Wang, *J. Geophys. Res.* **89**, 7195 (1984).
13. G. W. Brier *et al.*, paper presented at the Second International Meeting on Statistical Climatology, Lisbon, September 1983.
14. W. H. Campbell, J. B. Blechman, R. A. Bryson, *J. Climate Appl. Meteorol.* **22**, 287 (1983).
15. W. C. Guenther, *Concepts of Statistical Inference* (McGraw-Hill, New York, 1973), pp. 342–345.
16. J. A. Eddy, *The Solar Output and Its Variation* (Colorado Associated University Press, Boulder, 1977), pp. 51–71.
17. R. G. Currie, *J. Geophys. Res.* **89**, 7215 (1984).
18. Research at Oak Ridge National Laboratory was sponsored by the National Science Foundation under interagency agreement BSR-8115316, A03, with the U.S. Department of Energy under contract DE-AC05-840R21400 with Martin Marietta Energy Systems, Inc., Publ. No. 2576, Oak Ridge National Laboratory. Research at the University of Arizona was sponsored by NSF grant ATM-8217951. The computer program for HRFA and helpful suggestions were provided by G. Brier.

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Competition for Phosphorus: Differential Uptake from Dual-Isotope–Labeled Soil Interspaces Between Shrub and Grass

Abstract. *Two species of* Agropyron *grass differed strikingly in their capacity to compete for phosphate in soil interspaces shared with a common competitor, the sagebrush* Artemisia tridentata. *Of the total phosphorus-32 and -33 absorbed by* Artemisia, *86 percent was from the interspace shared with* Agropyron spicatum *and only 14 percent from that shared with* Agropyron desertorum. *Actively absorbing mycorrhizal roots of* Agropyron *and* Artemisia *were present in both interspaces, where competition for the labeled phosphate occurred. The results have important implications about the way in which plants compete for resources below ground in both natural plant communities and agricultural intercropping systems.*

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The natural distribution of species is molded to a large extent by interspecific competition. Yet the nature of competition is known more by its manifestations than by its mechanisms. Competition among plants is normally inferred from their performance in experiments in which the competitive setting is manipulated in various ways. These changes include removing or adding neighbors, partitioning the roots or shoots of neighboring plants, or changing resource levels, as by fertilization (*1*). Apart from studies of competition for light or space above ground, it has seldom been possible to observe the manner in which plants compete. Sometimes mechanisms can be inferred from the physiological performance of individual plants tested in isolation (*2*), but it is difficult to make such inferences when plants are growing competitively in a field setting.

We report here a demonstration of differential competitiveness for a specific belowground resource, phosphate, when the actively absorbing roots of different species were intermingled. Experiments were conducted in field plots where sagebrush, *Artemisia tridentata* ssp. *vaseyana* (Rydb.) Beetle, was growing with two species of *Agropyron* bunchgrass. In this environment *Agropyron desertorum* (Fisch. ex Link) Schult. was much more effective in competing with *Artemisia* than was *Agropyron spicatum* (Pursh) Scribn. and Smith (*3*).

The field plots used had been established 6 years earlier as an evenly spaced matrix of transplanted shrubs and grasses. Each *Artemisia* shrub was surrounded by four grasses, with two of each *Agropyron* species on opposite sides. In these plots there was no overlap of the canopies, but the root systems of the grasses and shrubs were thoroughly intermingled (*4*). For the plant sets chosen, the grasses were similar in size.

Unlike nitrate and many other more diffusible soil nutrient ions, phosphate is almost immobile in soils and is accessible only when it is within a few millimeters of a root (*5*). The effective uptake zone of a root can be extended by root hairs and mycorrhizae, but competition for phosphate among roots can take place only when roots and their associated mycorrhizae are in close proximity (*5*).

To determine how effectively the shrub acquired phosphorous from soil space shared with each of its *Agropyron* neighbors, a dual-isotope technique was used (*6*). The isotopes ^{32}P and ^{33}P were injected separately into soil interspaces on opposite sides of the shrub and halfway between the shrub and each grass species (*7*). Because phosphate ions are quickly bound in these calcareous soils, they do not move appreciably by leaching or diffusion (*8*). Growing shoot tips of the *Artemisia* shrub were then sampled four times over a 56-day period (*9*). The ^{32}P/^{33}P ratio technique obviated the need to determine phosphorus isotope pools in the entire plants, which would have been nearly impossible because of the diffuseness of the root systems. The radioisotopes were virtually carrier-free, and the concentrations of the added phosphorus were below those levels shown to influence root or mycorrhizal growth (*7*). The two *Agropyron* grass species have very similar phenological patterns (*4*) and were in the same stage of their seasonal growing patterns.

A large stochastic element was expected, since individual roots would be contacted in the process of injecting the label. Root growth into the radioactive phosphate would also have had a random component. The results, however, were striking in their consistency among the replicate plant sets and over time. All eight replicate sets showed predominant uptake by the shrub on the *A. spicatum* side (Fig. 1A). There was a similar pattern of change in the rate of radioactive phosphate appearance in the shoots of *Artemisia* for isotopes absorbed from the two sides of the shrub. Thus the average ratio of isotope acquisition from the two sides remained about the same during the experiment (Fig. 1A). Over the 56 days, *Artemisia* obtained 86 percent of the total radioactive phosphorus from the interspace shared with *A. spicatum*.