Appendix B from K. Everard et al., “Plant Water Use Affects Competition for Nitrogen: Why Drought Favors Invasive Species in California”
(Am. Nat., vol. 175, no. 1, p. 85)

Data Collection and Parameter Estimation

Data Collection

Measurements of soil moisture were taken weekly from four replicates of the water addition plots at two depths, 15 and 60 cm, for both annuals and perennials, using two time-domain-reflectometry probes (SoilMoisture, Santa Barbara, CA). Soil nitrate and ammonium were measured in four replicates of the water addition experiment. Extractable soil nitrate was measured in a 0.5 M K₂SO₄ extract of a composite of four 2.5-cm diameter × 15-cm-long soil cores per plot taken on April 9, May 5, and June 1, 2001. Samples at 15–30- and 30–45-cm depths were taken only on May 5. Biomass estimates were taken at or close to peak production (May) by clipping, sorting to species, drying, and weighing aboveground biomass from two 0.1 × 1-m strips in each of the plots.

Soil Moisture Model Parameter Estimation

The first soil moisture measurements were taken at the beginning of April 2001, Julian day 88. The biomass estimates were taken at the end of the growing season in mid- to late May, and the nitrogen measurements were taken in April, May, and June. Because the soil moisture decreased throughout this part of the growing season, a mean soil moisture value between April and June was taken at each depth across each plant type both for consistency and in order to get a representative figure for the soil moisture throughout this period.

The measured volumetric soil moisture was converted to percentage saturation. The mean of the measurements from the two depths, 15 and 60 cm, was used; this gave the best fit to the model, and the results were qualitatively the same when these measurements were combined using a weighted-mean and root profile–adjusted method, as described by Miller et al. (2007). The parameters of the soil moisture model were estimated by use of simulations of the period April–December 2001. The field capacity $s_f$, onset of plant water stress $s_{ws}$, wilting point $s_w$, hygroscopic point $s_h$, maximum rate of transpiration $T_{max}$, saturated hydraulic conductivity $K_s$, and soil porosity $n$ were varied between simulations. The rooting depth $Z_r$ was taken as 600 and 1,500 mm for the annual and perennial species, respectively (Dyer and Rice 1999). The measured rainfall data were used (from Sedgwick Weather Station), and the starting soil moisture was set to the measured soil moisture on the first day. A grid search method was used; the range of parameter values explored was determined by both measurements from the field and values found in the literature. The simulated soil moisture values from each parameter set were compared with the measured soil moisture values by use of least squares, assuming a normal distribution of the errors. The set of parameters with the minimum sum of squares was taken as the best-fitting model. Figure B1 shows the simulated and measured soil moisture values for the best-fitting parameter estimates.
**Parameter Estimation for the Nitrogen Model**

The active-uptake parameters, $a_1$ and $a_2$, were estimated by use of the equilibrium solutions for the water addition and control plots. Since there is not a long enough time series for these data, a method similar to the soil moisture parameter estimation could not be used.

Soil moisture, inorganic nitrogen, and plant biomass are assumed to be at equilibrium. For each species, parameters with the subscript 1 refer to data from the control plots and those with subscript 2 refer to those from the water addition plots. Those without subscripts are assumed to be constant for a species and so remain the same between the two sets of plots.

We assume that the plant biomass is at equilibrium, and so equation (5) can be set to 0 for both the control and water addition plots, and the resulting equations can be solved for $a_1$ and $a_2$ as follows:

$$
\frac{\alpha_0 N_i T_{\text{max}}(s_i - s_w)}{W_i} \left[ \frac{T_{\text{max}}(s_i - s_w)}{s_w - s_w} + a_1 s_i^{e_1} \right] - m_P P_i = 0
$$

for $i = 1, 2$. Rearranging,

$$
a_1 s_i^{e_1} = \frac{m_P W_i}{\alpha_0 N_i} - \frac{T_{\text{max}}(s_i - s_w)}{s_w - s_w}
$$

for $i = 1, 2$. Taking logs gives

$$
\ln a_1 + a_2 \ln s_i = \ln \left( \frac{m_P W_i}{\alpha_0 N_i} - \frac{T_{\text{max}}(s_i - s_w)}{s_w - s_w} \right)
$$

for $i = 1, 2$. Combining these for $i = 1, 2$ gives

$$
a_2 = \frac{\ln K_1 - \ln K_2}{\ln s_1 - \ln s_2}, \tag{B1}
$$

where

$$
K_i = \frac{m_P W_i}{\alpha_0 N_i} - \frac{T_{\text{max}}(s_i - s_w)}{s_w - s_w}.
$$
Once we have this estimate for $a_2$, we substitute this back into equation (B1) and rearrange to obtain an estimate for $a_1$:

$$a_1 = \frac{m_P W_i / \alpha_N N_i - [T_{\text{max}}(s_1 - s_2)/(s_{\text{max}} - s_2)]}{s_1^2}.$$  \hspace{1cm} (B2)

The parameters necessary for these estimations were estimated from the data and the literature as follows. (1) For nitrogen in plant biomass, $P_i$, aboveground biomass (dry weight) was converted to nitrogen in biomass by use of root-shoot ratio and percentage of nitrogen in plant tissue. (2) For root-shoot ratio, values of 0.09 and 0.62 for the annual and perennial species, respectively, were estimated from Seabloom et al. (2003b). (3) For percentage of N in tissue, estimates of 47.5 and 43 mg g$^{-1}$ dry weight for the annual and perennial species, respectively, are from Garnier and Vancaeyzeele (1994). (4) For inorganic nitrogen in the soil $N_i$, measurements from the field were converted to milligrams per square meter from bulk density estimated from the soil porosity $n$, which was estimated from the soil moisture simulations and soil particle density from Brady and Weil (2002). Measurements by depth were combined by using the mean for consistency with the soil moisture estimations; both weighted means and a root profile–adjusted method gave qualitatively the same results. (5) The percentage of inorganic N that is dissolved, $\alpha_N$, was assumed to be 1 for nitrate and 0 for ammonium; the inorganic nitrogen values in table A1 include only nitrate. (6) For plant tissue death rate $m_P$, estimates of 0.016 and 0.005 day$^{-1}$ for the annuals and perennials, respectively, are from data in Aerts (1996), Craine et al. (1999), Ryser and Urbas (2000), Gill and Jackson (2000), and Seabloom et al. (2003b). (7) For inorganic nitrogen concentration in the water addition plots, estimates of 5,542 and 4,818 mg m$^{-3}$ in the annual and perennial plots, respectively, are from the Sedgwick data. (8) For soil moisture in the water addition plots, estimates of 0.36 and 0.359 in the annual and perennial plots, respectively, are from the Sedgwick data.

Calculation of the Growth Rate of Each Species as an Invasive for a Range of Growing Season Rainfall Rates

Rainfall during the growing season is supplemented by water that falls outside of the growing season. To account for this in estimating the growth rate of each species as an invasive for figure 3B, the total amount of water used during the growing season was calculated as (initial water in the soil minus final water in the soil) plus rainfall during the growing season. This is different for each species even if they have the same soil moisture, because they have differing rooting depths. The competitive indices were then calculated for each species, assuming that the out-of-season rainfall contributes a similar amount of water to the growing season each year.

Literature Cited Only in Appendix B


