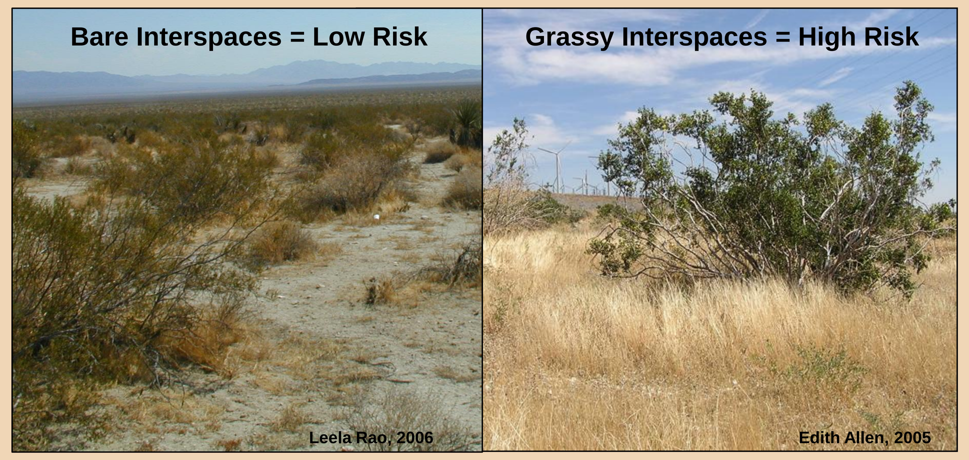

Modeling the effects of nitrogen deposition, precipitation variability, and soil texture on winter annual production and fire risk in the desert

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Problem

Fires in the arid regions of Southern California have recently increased in frequency due to increased numbers of above-normal precipitation years and increased cover of exotic annual grasses (Brown and Minnich, 1986; Brooks and Minnich, 2006). Fires alter the ecosystem by reducing the diversity and density of shrubs, which then impacts the associated fauna (McLaughlin and Bowers, 1982; Brown and Minnich, 1986).

The threshold of biomass necessary to carry fire ranges from 0.7 to 1.5 tons ha^{-1} of fine continuous fuel (Anderson, 1982; Scifres and Hamilton, 1993; Minnich and Dezzani, 1998), although the exact amount of native forb and exotic grass biomass needed to carry fire in the desert is still unknown. Due to its persistence on the landscape, exotic grass litter increases the length of the fire season and thus increases the probability that an ignition will occur (Brooks et al., 2004).

Annual vegetation in the desert is limited by water (Noy-Meir, 1973) and regulated by nitrogen (Romney et al., 1978; Gutierrez et al., 1988). A nitrogen deposition gradient exists across Joshua Tree National Park in Southern California (Figure 1) potentially increasing fire risk in more polluted locations through N fertilization of the nutrient poor interspaces.

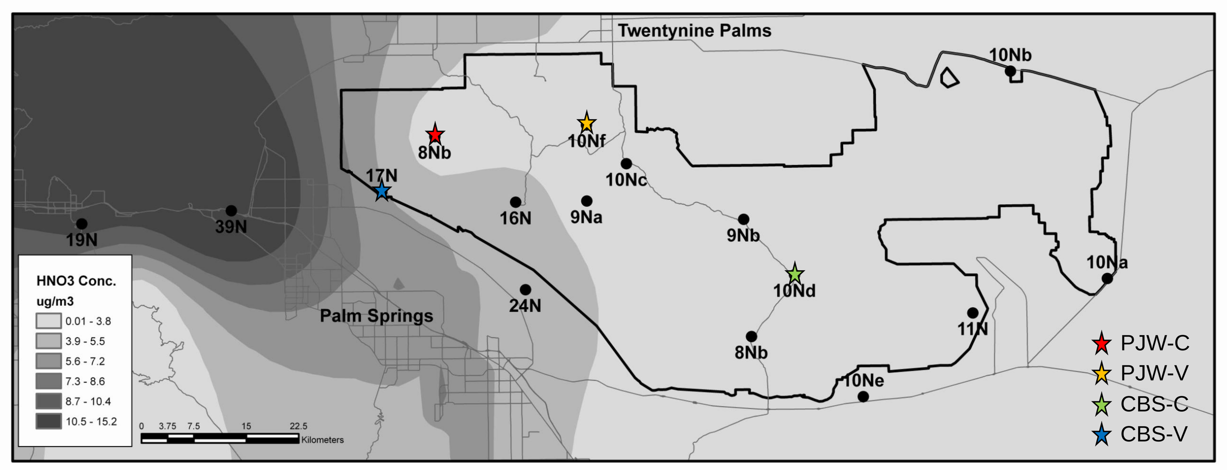

Figure 1. Atmospheric nitric acid concentration observed across Joshua Tree National Park during July 2005 (Rao et al., *in review*). Sampling points are labeled with the calculated annual N deposition using the inferential method. Starred locations are the calibration and validation sites used in the DayCent production model development (PJW = piñon-juniper woodland; CBS = creosotebush scrub).

Objectives

1. Determine the extent to which the biogeochemical process model DayCent can model annual production and nutrient cycling in two desert vegetation types, low elevation creosotebush scrub (CBS) and high elevation piñon-juniper woodland (PJW), under a range of N-fertilization scenarios.
2. Use DayCent to gain an understanding of how fire risk in the desert will change with increasing N deposition, precipitation, and soil clay contents.

Methods

The daily version of the Century model, DayCent (Parton et al., 1998; Parton et al., 2001) was calibrated for one creosotebush scrub (CBS) and one piñon-juniper woodland (PJW) site in Joshua Tree N.P. The model was validated on a second CBS and PJW site in the Park with the same vegetation but different soils (Table 1), climate, and background N deposition. For the simulations, a "spin-up" to equilibrium was run for at least 1900 years. N deposition was then added to the model and increased linearly to current values over a period of 100 years. The simulation was ended when the weather file corresponded to the year 2008. The model was calibrated on production and SOM C, and validated on production, SOM C, SOM N, inorganic N, aboveground C:N, soil C:N.

A N fertilization experiment has been conducted at these four Joshua Tree N.P. sites since 2003, with plots fertilized with 0, 5, and 30 kg ha^{-1} N each winter. To determine the ability of the model to accurately predict annual vegetation response to N fertilization, the field fertilization experiment was simulated and measured production compared to simulated production.

Fire risk was determined by calculating the probability of annual biomass exceeding the fire threshold as N deposition increases. After a spin-up for 1000 years at 1 kg ha^{-1} N dep., deposition was increased every 100 years up to 15 kg ha^{-1}. This risk analysis was conducted for both vegetation types, six precipitation regimes (9-43 cm MAP), and six soil textures (1-14% clay).

Table 1. Soil properties for the calibration and validation sites modeled with DayCent.

Site	Sand-Silt-Clay	% Rock	Bulk Density	Field Capacity[1]	Wilting Point[1]	Hydraulic Conductivity[2]
CBS-Calibration	83-11-6	29	1.63	0.1599	0.0561	0.0039
CBS-Validation	88-10-2	25	1.61	0.0947	0.0268	0.0081
PJW-Calibration	78-13-9	11	1.39	0.1616	0.0607	0.0024
PJW-Validation	71-25-4	42	1.63	0.1046	0.0311	0.0042

[1]Volumetric; [2]cm s^{-1}

Calibration & Validation

Table 2. Comparison of observed and simulated soil and vegetation nutrient parameters from the creosotebush scrub calibration (C) and validation (V) sites.

Parameter Description	[1]CBS-C ± SD	[2]CBS-C Sim.	[3]CBS-V ± SD	[2]CBS-V Sim.
Aboveground C:N	23.40 ± 6.66	23.65 ± 6.18	N/A	24.44 ± 6.71
Total Soil Organic Matter C (g/m^2)	915.55 ± 356.96	935.32 ± 19.55	866.97 ± 332.86	541.68 ± 22.99
Total Soil Organic Matter N (g/m^2)	100.8 ± 52.1	72.84 ± 1.19	141.60 ± 43.77	43.68 ± 1.37
Annual N mineralization (g/m^2)	2.46	1.57 ± 0.65	4.58	1.75 ± 0.61
Soil mineral N 0-10 cm (g/m^2)	0.575 ± 0.087	0.502 ± 0.140	0.834 ± 0.373	0.480 ± 0.161
Soil mineral N 10-30 cm (g/m^2)	0.324 ± 0.191	0.083 ± 0.060	N/A	0.084 ± 0.059
Soil mineral N 30-45 cm (g/m^2)	0.118 ± 0.137	0.028 ± 0.022	N/A	0.018 ± 0.024
Soil mineral N 45-60 cm (g/m^2)	0.051 ± 0.025	0.016 ± 0.019	N/A	0.003 ± 0.012
Soil mineral N 60-90 cm (g/m^2)	0.100 ± 0.049	0.128 ± 0.083	N/A	0.050 ± 0.026
Soil mineral N 90-120 cm (g/m^2)	0.106 ± 0.064	0.454 ± 0.210	N/A	0.104 ± 0.082
Soil mineral N >120 cm (g/m^2)	?	15.695 ± 0.269	?	22.295 ± 0.428
Soil C:N	9.62 ± 1.73	12.86 ± 0.04	6.21 ± 1.98	12.28 ± 0.20

[1]Soil data collected from deep cores; soil mineralization is potential from lab incubation
[2]Simulated values are the average from the last 25 years of the simulation ± 1 standard deviation
[3]Soil C and N data collected from surface cores (0-5 cm) and extrapolated to 20 cm based on proportional decrease in depth observed in deep cores from CBS-C; surface cores (0-5) taken each July for mineral N and extrapolated to 10 cm depth; soil mineralization is potential from lab incubation

Table 3. Comparison of observed and simulated soil and vegetation nutrient parameters from the piñon-juniper woodland calibration (C) and validation (V) sites.

Parameter Description	[1]PJW-C ± SD	[2]PJW-C Sim.	[3]PJW-V ± SD	[2]PJW-V Sim.
Aboveground C:N	33.79 ± 7.48	21.42 ± 5.90	N/A	23.89 ± 4.62
Total Soil Organic Matter C (g/m^2)	1121.93 ± 245.41	966.72 ± 30.13	939.04 ± 633.33	529.54 ± 12.73
Total Soil Organic Matter N (g/m^2)	109.18 ± 38.69	54.24 ± 2.60	92.48 ± 62.04	31.04 ± 1.10
Annual N mineralization (g/m^2)	1.68	1.18 ± 0.49	1.42	1.06 ± 0.31
Soil mineral N 0-10 cm (g/m^2)	0.553 ± 0.207	0.539 ± 0.171	0.734 ± 0.396	0.179 ± 0.121
Soil mineral N 10-30 cm (g/m^2)	0.135 ± 0.091	0.105 ± 0.085	N/A	0.047 ± 0.038
Soil mineral N 30-45 cm (g/m^2)	0.068 ± 0.056	0.026 ± 0.018	N/A	0.011 ± 0.013
Soil mineral N 45-60 cm (g/m^2)	0.031 ± 0.036	0.012 ± 0.008	N/A	0.003 ± 0.006
Soil mineral N 60-90 cm (g/m^2)	0.023 ± 0.093	0.080 ± 0.111	N/A	0.069 ± 0.067
Soil mineral N 90-120 cm (g/m^2)	0.022 ± 0.006	0.092 ± 0.175	N/A	0.416 ± 0.179
Soil mineral N >120 cm (g/m^2)	?	10.108 ± 0.469	?	21.830 ± 0.283
Soil C:N	12.09 ± 6.98	17.78 ± 0.29	11.47 ± 3.56	16.96 ± 0.18

[1]Soil data collected from deep cores; soil mineralization is potential from lab incubation
[2]Simulated values are the average from the last 25 years of the simulation ± 1 standard deviation
[3]Soil C and N data collected from surface cores (0-5 cm) and extrapolated to 20 cm based on proportional decrease in depth observed in deep cores from CBS-C; surface cores (0-5) taken each July for mineral N and extrapolated to 10 cm depth; soil mineralization is potential from lab incubation

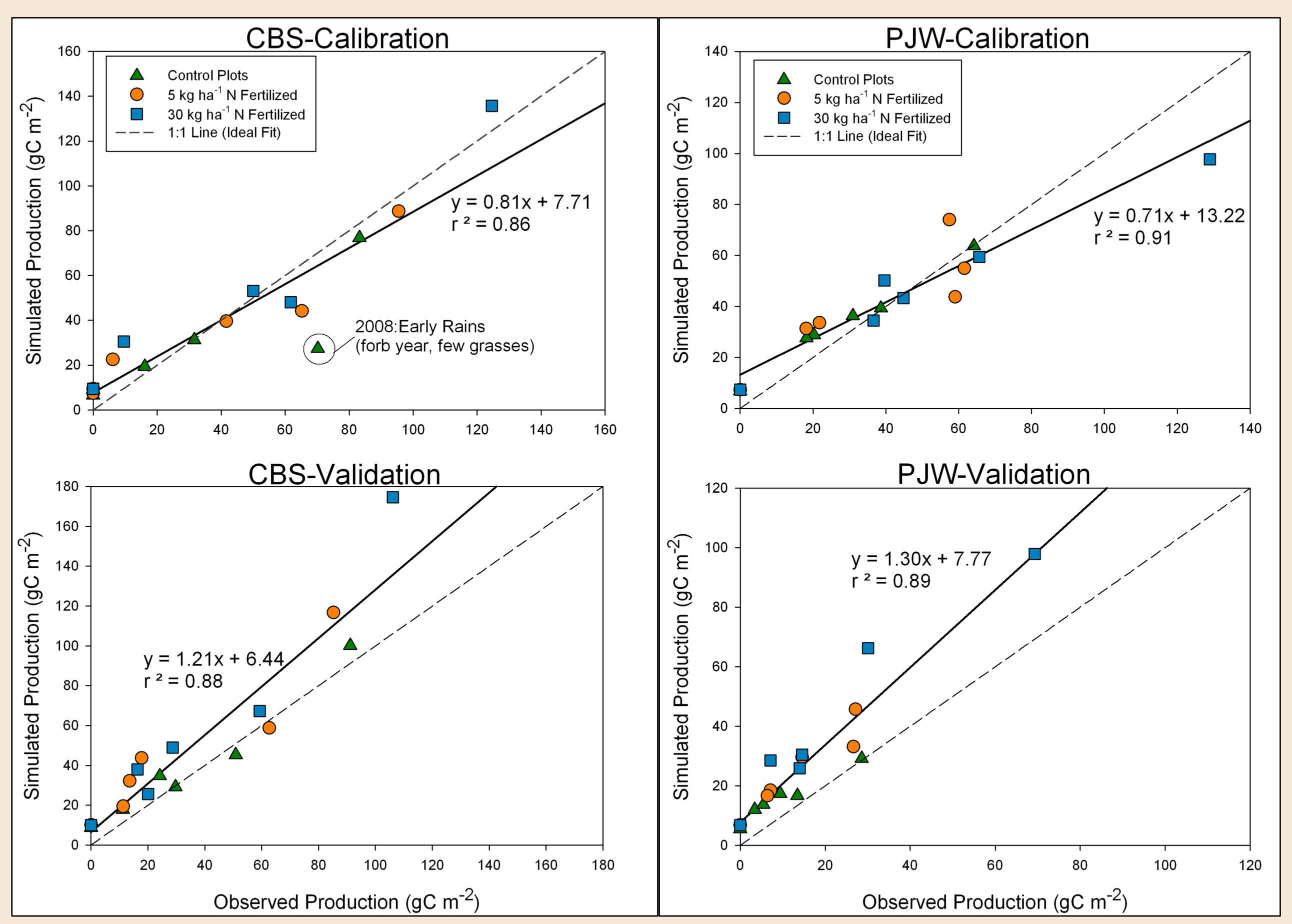

Figure 2. Regressions of observed versus simulated production for the calibration and validation sites in each vegetation type. Each regression was run on peak interspace production for all control and fertilized plots combined. Plots were fertilized each winter and production measured the following spring from December 2002-April 2008. In 2007 there was insufficient precipitation for germination in the field, although DayCent simulated a small amount of production in that year. The CBS-Calibration site outlier resulted from the inability of DayCent to model shifts in community composition. In 2003-2005 CBS-C was dominated by grasses, but in 2008, after two years of drought and no germination, the vegetation was dominated by forbs that have a different growth pattern and tissue chemistry than the grasses.

Fire Risk Analysis

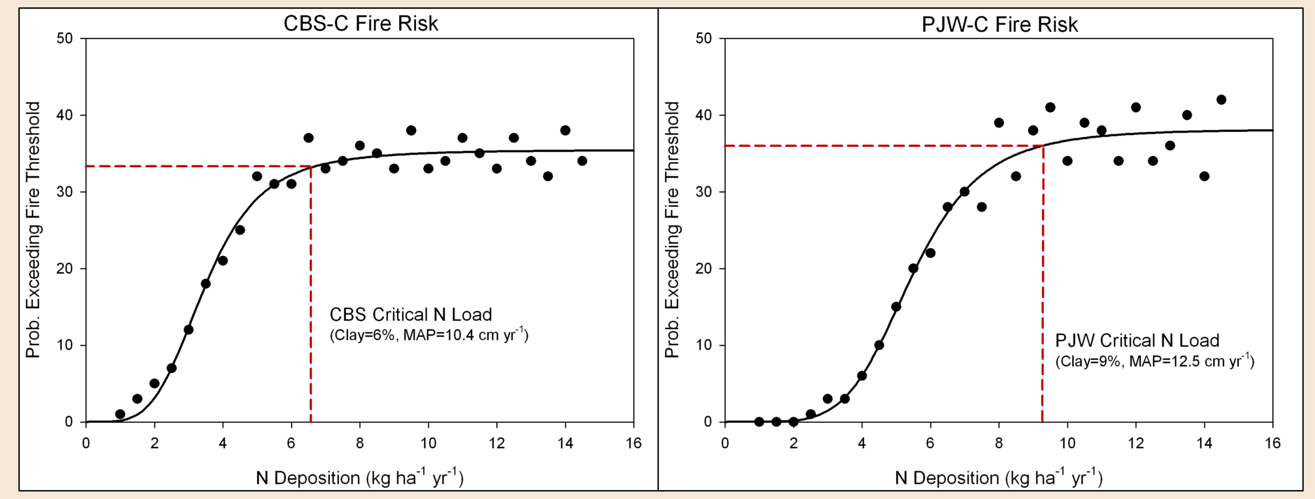

Figure 3. Fire risk for each vegetation type was calculated as the probability that annual biomass would exceed the fire threshold (1 ton ha^{-1}) under a given N deposition load. For the calibration CBS site, the maximum probability of exceeding the fire threshold is at 6.5 kg ha^{-1} of N deposition, indicating that above this critical load the vegetation is N saturated and precipitation is the primary determinant of whether the fire threshold will be reached. The PJW-C critical load is at 9.2 kg ha^{-1}, suggesting that the vegetation at this site is less plastic in its response to N fertilization, a finding supported by a greenhouse study on the biomass response of the exotic grasses from the CBS (*Schismus* sp.) and PJW (*Bromus madritensis*) sites to N fertilization (Rao 2008). Differences in the maximum probability of exceeding the fire threshold at the two sites is due to the difference in mean annual precipitation.

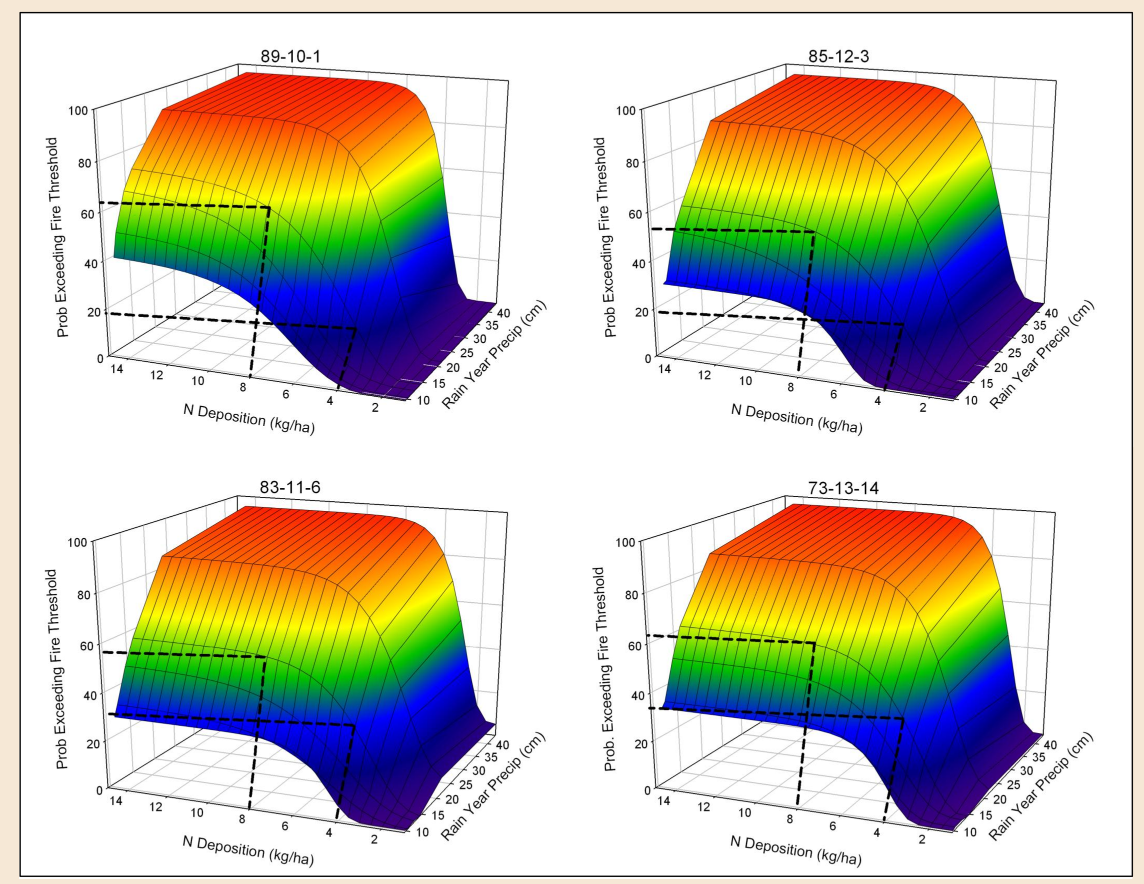

Figure 4. Fire risk analysis for CBS across four soil textures (1-14% clay) and 6 precipitation regimes. Dashed lines indicate that the current fire risk for Palm Desert, CA (MAP=14.4 cm, N dep.=8 kg ha^{-1}) ranges between 52 and 64%. If N deposition were decreased to 4 kg ha^{-1}, fire risk would decrease to 17-35% across the landscape, signifying a significant reduction in fire risk.

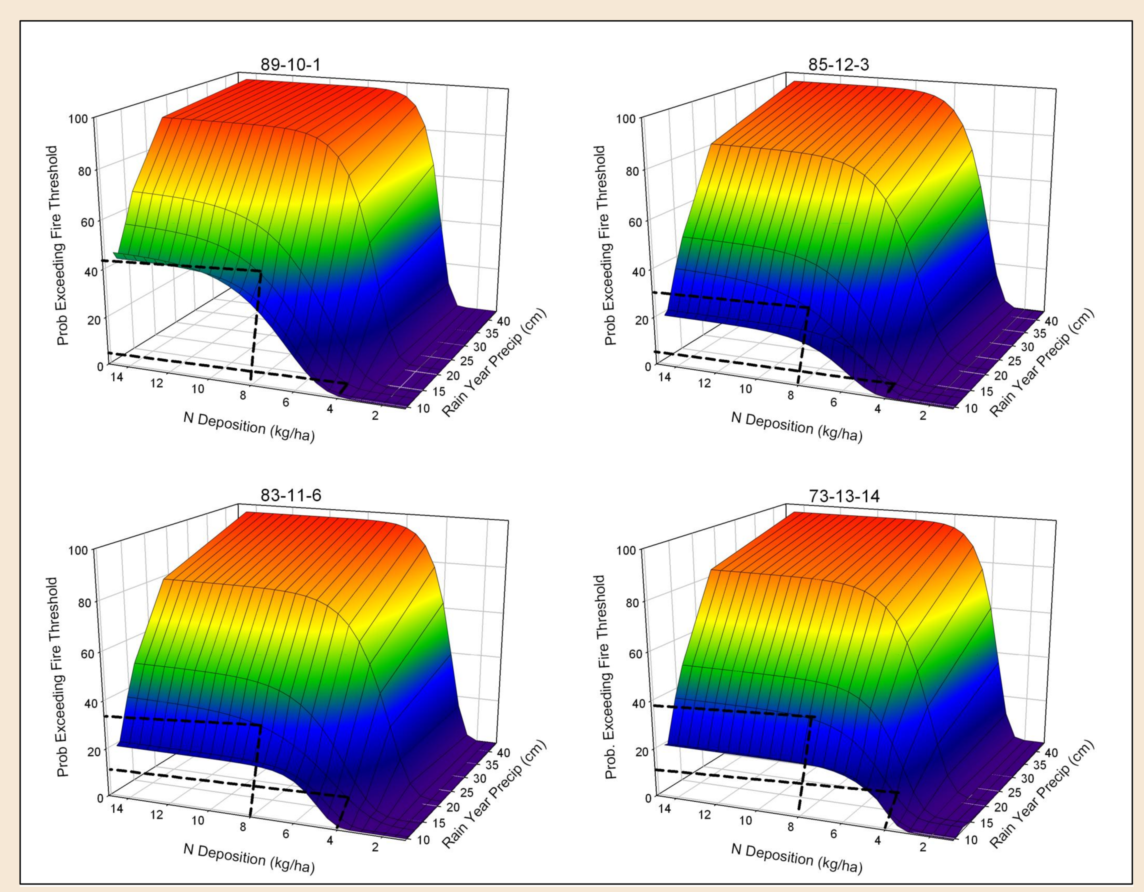

Figure 5. Fire risk analysis for PJW across four soil textures (1-14% clay) and 6 precipitation regimes. Dashed lines indicate that the current fire risk for Yucca Valley, CA (MAP=12.5 cm, N dep.=8 kg ha^{-1}) ranges between 29 and 45%. Halving N deposition would decrease fire risk to 1-11%, indicating a significant reduction in fire risk, although the fuel load provided by the trees and shrubs in this ecosystem would still keep the baseline fire risk higher than in creosotebush scrub (Brooks and Minnich 2006).

Conclusions

- The biogeochemical process model, DayCent, can be successfully applied in a risk based approach to determining critical loads for N deposition for its effects on increasing fire in the desert.
- At current N deposition loads, creosotebush scrub sites in more polluted regions of Southern California deserts are likely to exceed the fire threshold in years of average to above-average rainfall.
- Interspace winter annuals in piñon-juniper woodlands are less responsive to N fertilization than the annuals in creosotebush scrub, but fire risk is likely to remain high in piñon-juniper woodlands due to greater shrub and tree cover in this vegetation type.
- Fifty percent reductions in N deposition will result in a substantial reduction of interspace fuels and thus fire risk in both ecosystem types, such that fires will likely occur only in years of above-average rainfall.
- Calibration and validation of the DayCent model for two vegetation types from Joshua Tree N.P. indicates that the model, developed for grasslands, falls short in three primary areas when simulating this extreme desert environment.
  1. The model is sensitive to low clay contents resulting in sub-optimal modeling of soil nutrient cycling and production in very sandy soils, most likely due to premature drying of the soils resulting in reduced mineralization rates.
  2. DayCent cannot limit germination in years of extremely low rainfall, resulting in increased production (greater than + 1 SD of observed production) even in years of moderately low rainfall.
  3. DayCent can only model one species or generalized annual vegetation community at a time. Because DayCent cannot model shifting species mixtures (e.g., forb dominance to grass dominance), soil nutrients and some years of annual production may not be modeled accurately.
- Despite model problems, DayCent accurately predicts the relative response of production to fertilization in these desert ecosystems.

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