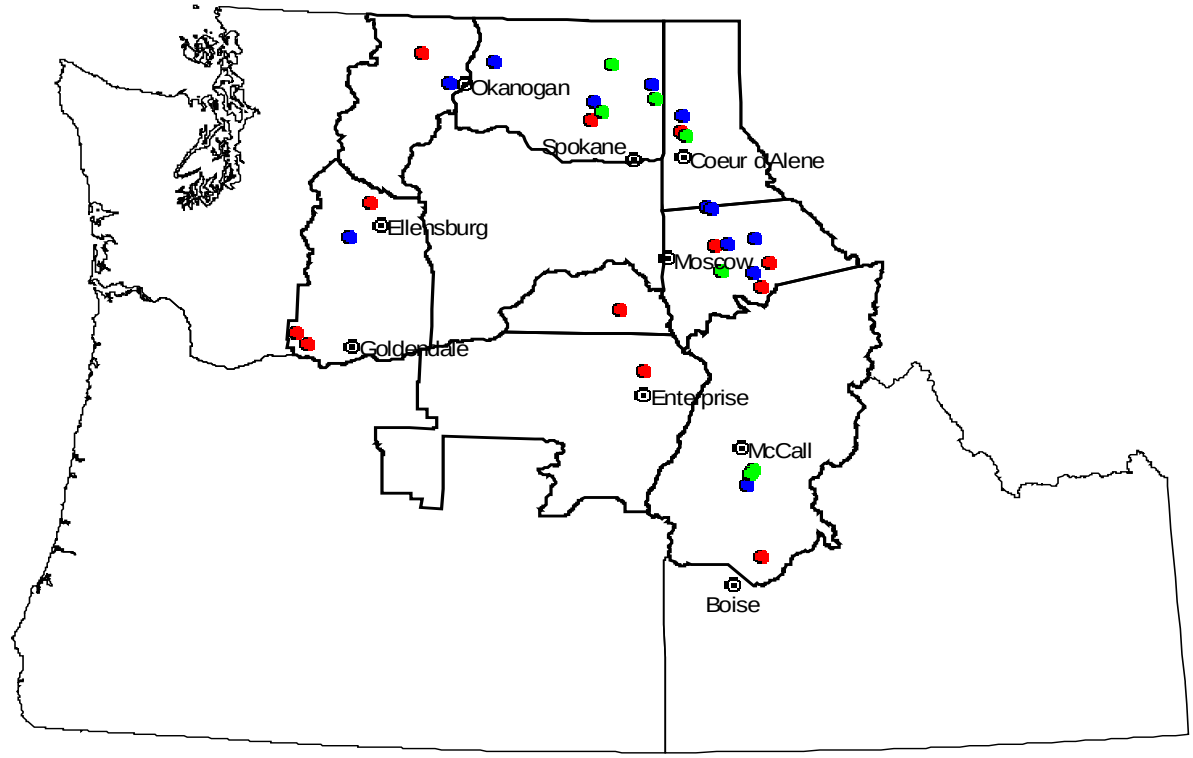
The Forest Health/Nutrition Experiment: 8-year Growth and Mortality Responses for Individual Species

Peter Mika

2006 IFTNC Annual Meeting

IFTNC Forest Health / Nutrition Experimental Locations (1994-1996)



Design of the experiment

- Sites stratified by 4 rock types and 3 vegetation types
- A core N and K 4-treatment experiment at all sites
- Additional fertilizer treatments tailored to site conditions
- Large experimental plots to monitor mortality

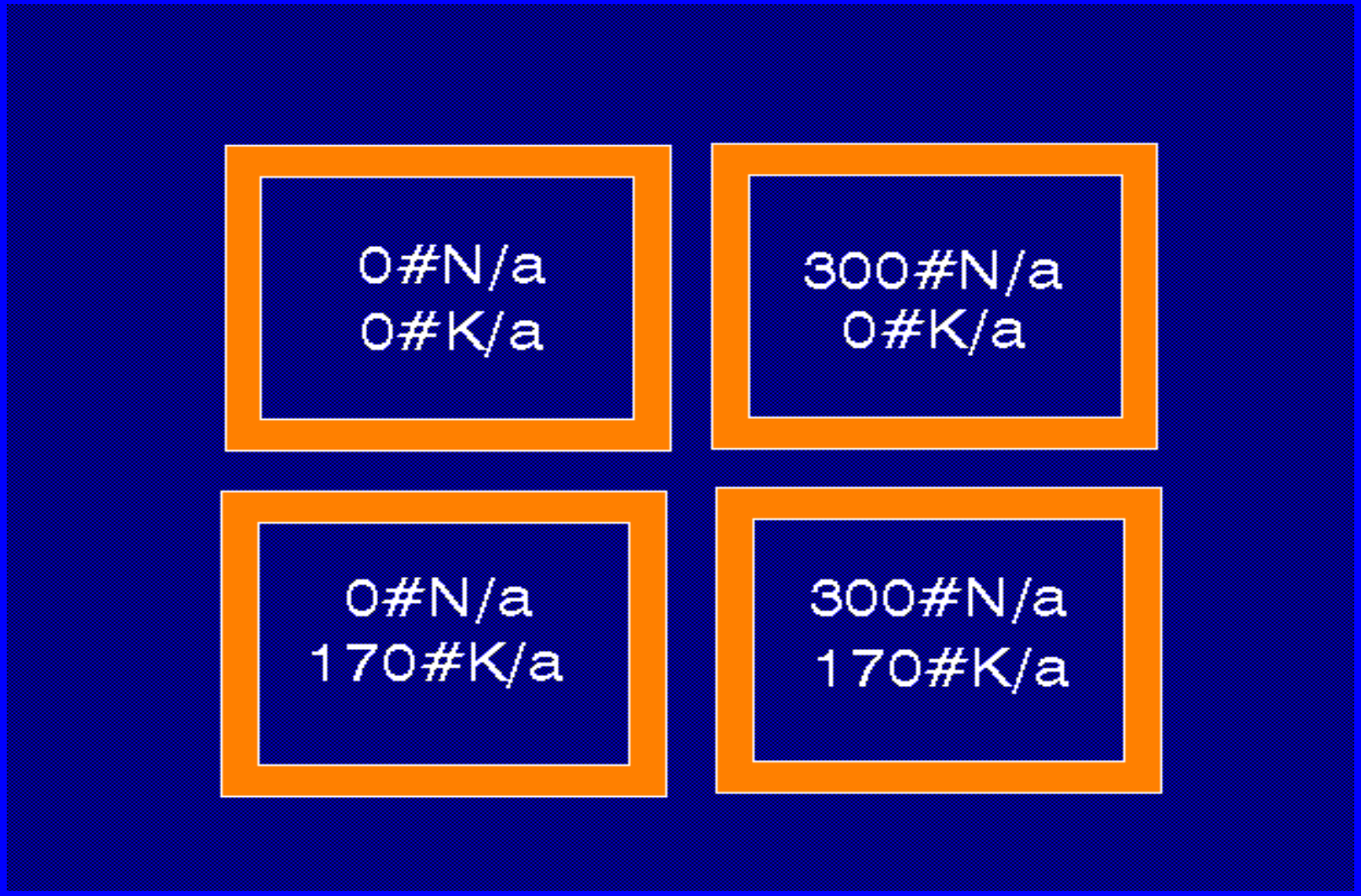
Sites Established: 1994-1996

by Rock Type and Vegetation Series

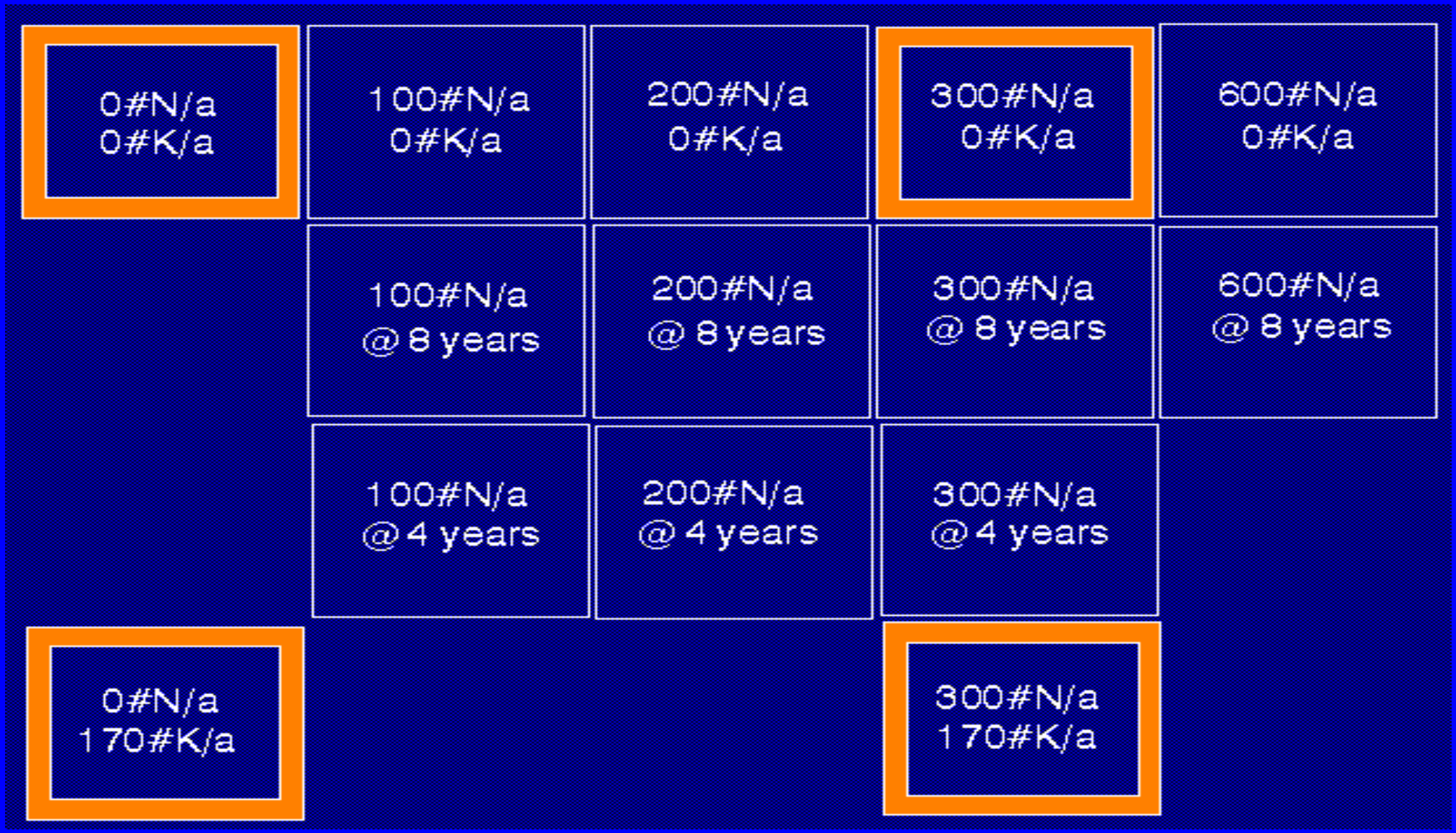
	Douglas-fir	Grand fir	Cedar/ Hemlock	TOTAL
Granite	K,B (1) K (2) N,B (1)	K (4)	K (2)	10
Basalt	N (1) R (2)	K (3)	N (1) R (2)	9
Metamorphic		K (1)	K (3)	4
Mixed	N (2)	K (2)	K (1) N (3)	8
TOTAL	9	10	12	31

N-Rate (N), Repeated N-Rate (R), N-K Response Surface (K), Bark Beetle (B)

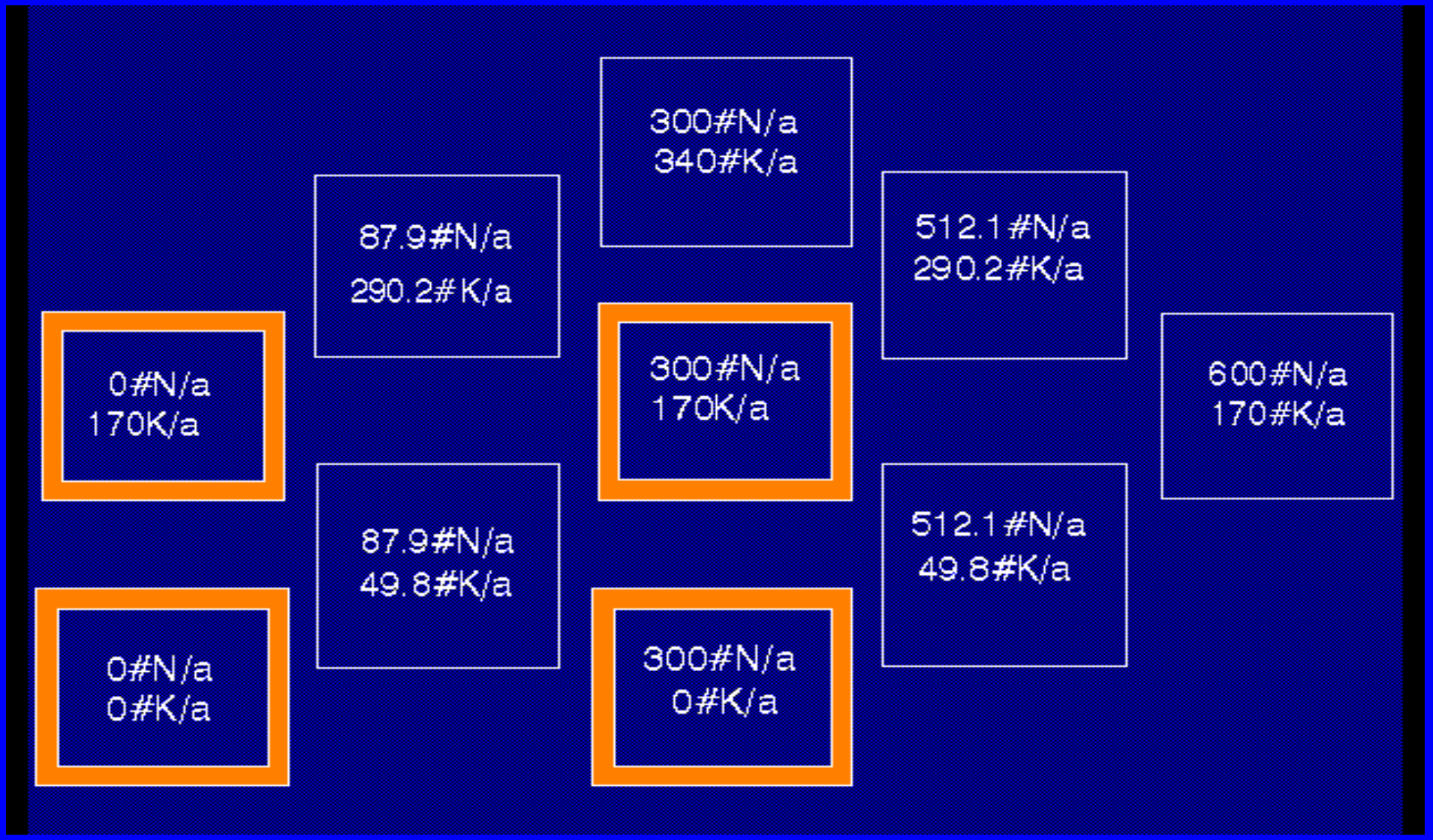
Core Design



Nitrogen Rate Design



N-K Response Surface Design



Topics for Today:

- Fertilizer Effects on Species-specific 8-year BA and Volume Growth
  - N and K Effects: N and K response surface
  - S and Micronutrient (B, Cu, Mo, Zn) Effects : ANOVA comparison of means
  - Repeated N effects : ANOVA comparison of means
- Fertilizer Effects on Species-specific 8-year Tree and BA Mortality
  - N and K Effects: N and K response surface
  - S and Micronutrient (B, Cu, Mo, Zn) Effects: ANOVA comparison of means
  - Repeated N effects : ANOVA comparison of means

Species-specifc Growth Analysis: N and K

Only plots with ≥1.0 ft^2/a live BA at year 8 of a species were used

(DF: 29 sites, 326 plots GF: 21 sites, 188 plots PP: 19 sites, 155 plots)

Dependent variable = relative growth rate (RGR)

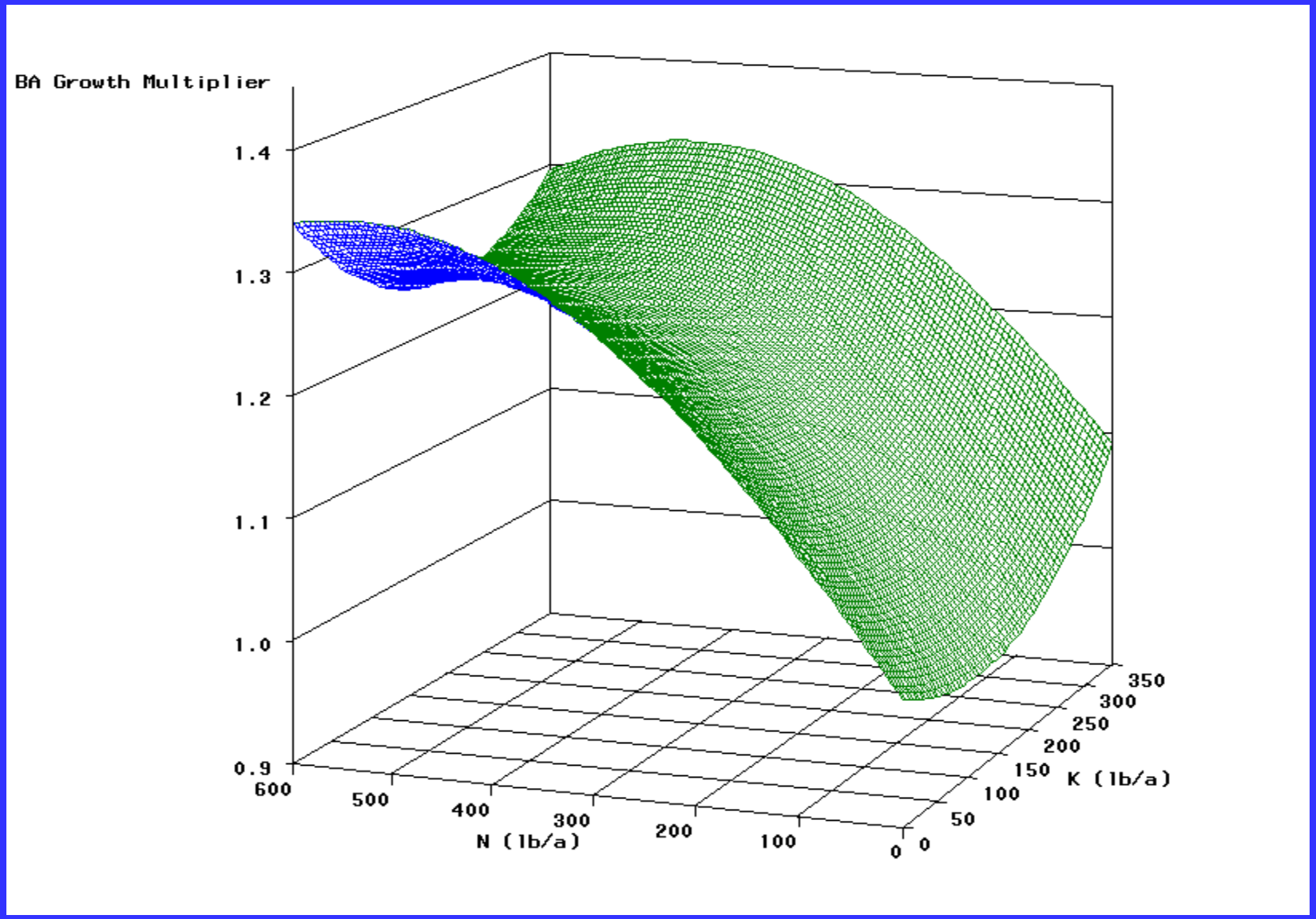
= 8-year growth/initial size (ie. 8-year BA growth/initial BA)

N and K fertilizer effects estimated using a multiplicative species-specific quadratic response surface model:

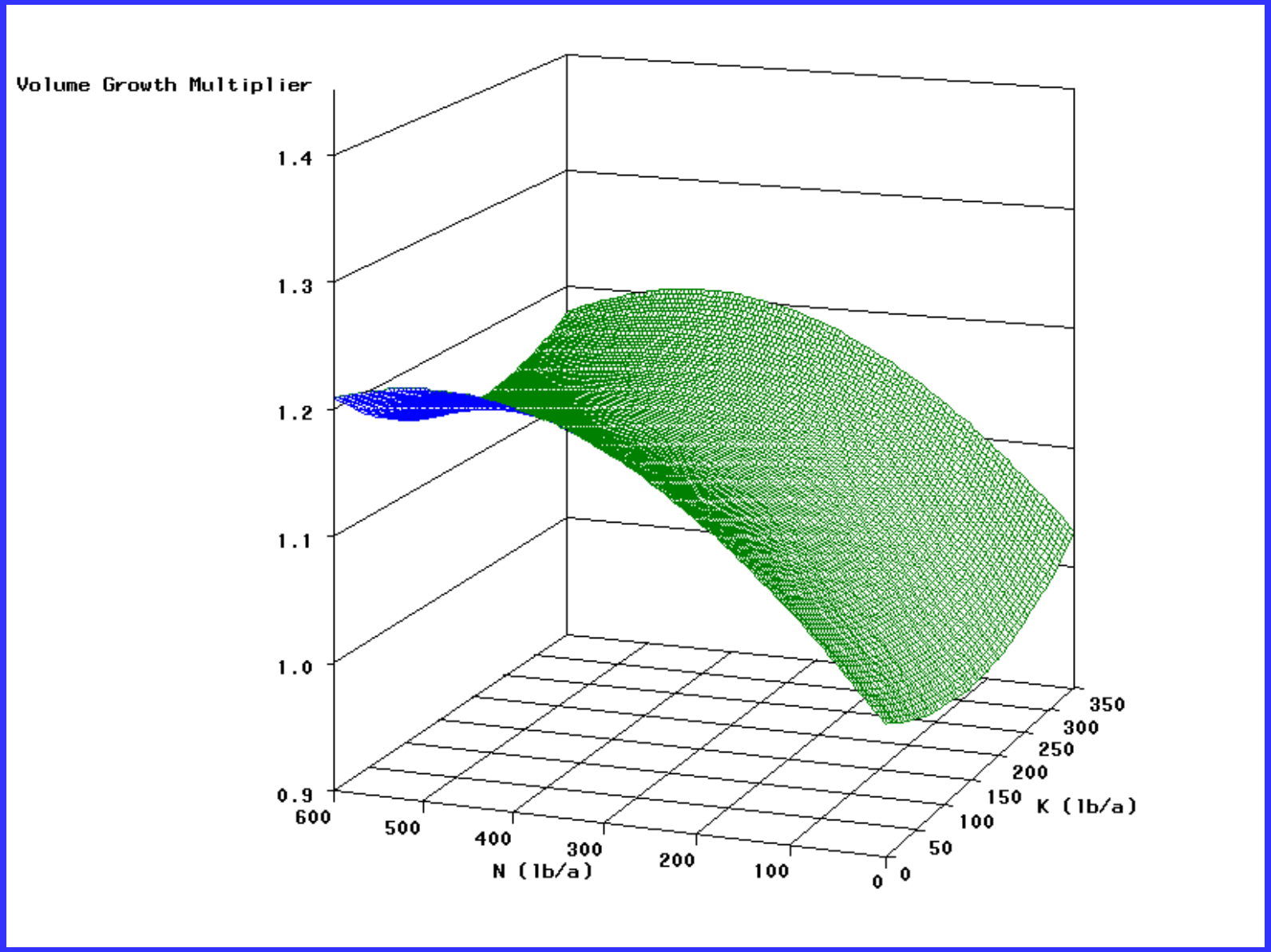
$$\ln(RGR) = \mu + Site + \beta01 * BA_0 + \beta02 * BAMort_8 + \beta1 * N + \beta2 * N^2 + \beta3 * K + \beta4 * K^2 + \beta5 * NK$$

Graphed response = fertilizer growth effect as a proportion of control growth (a growth multiplier)

N and K fertilizer effects on 8-year gross BA growth



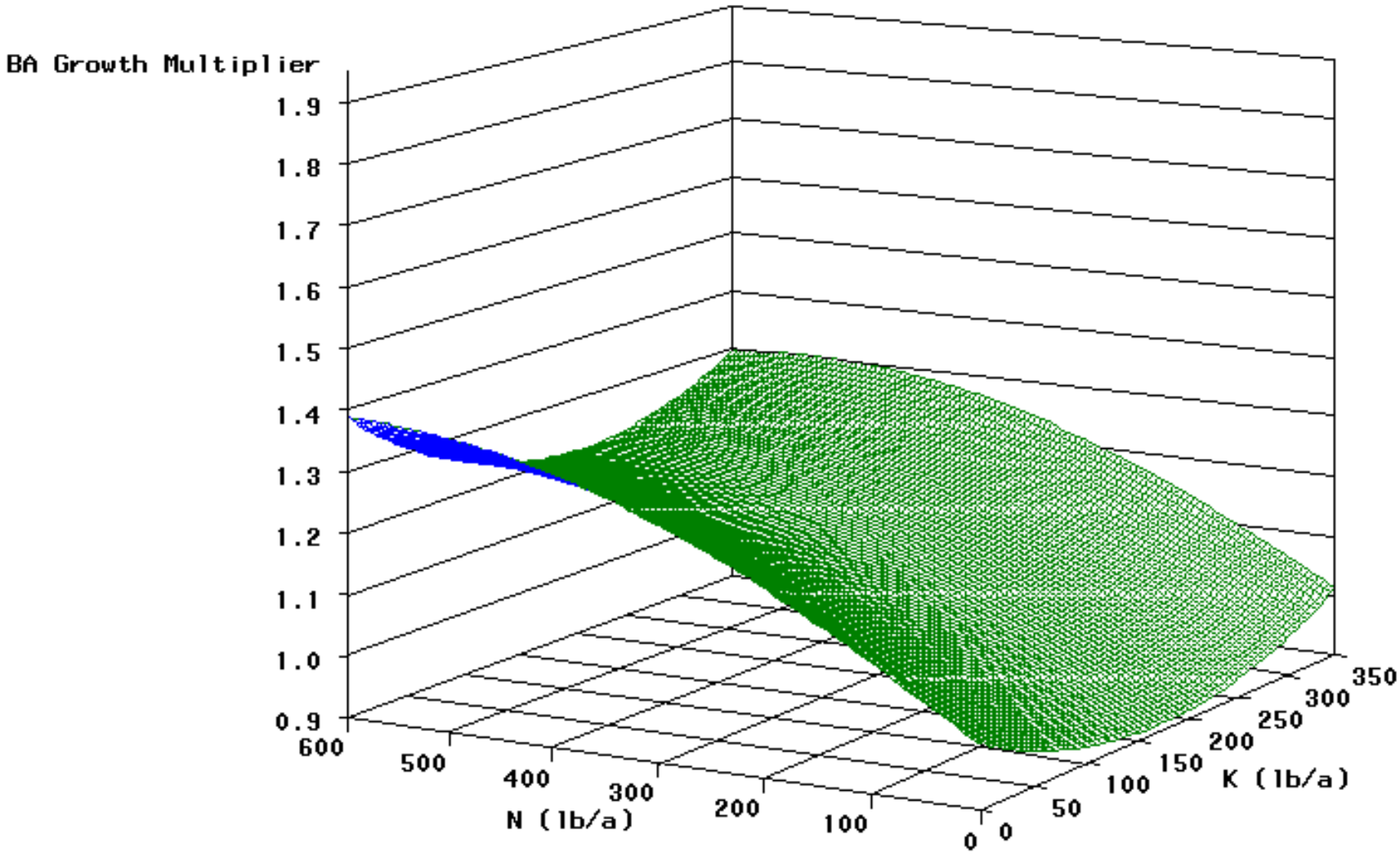
N and K fertilizer effects on 8-year gross Volume growth



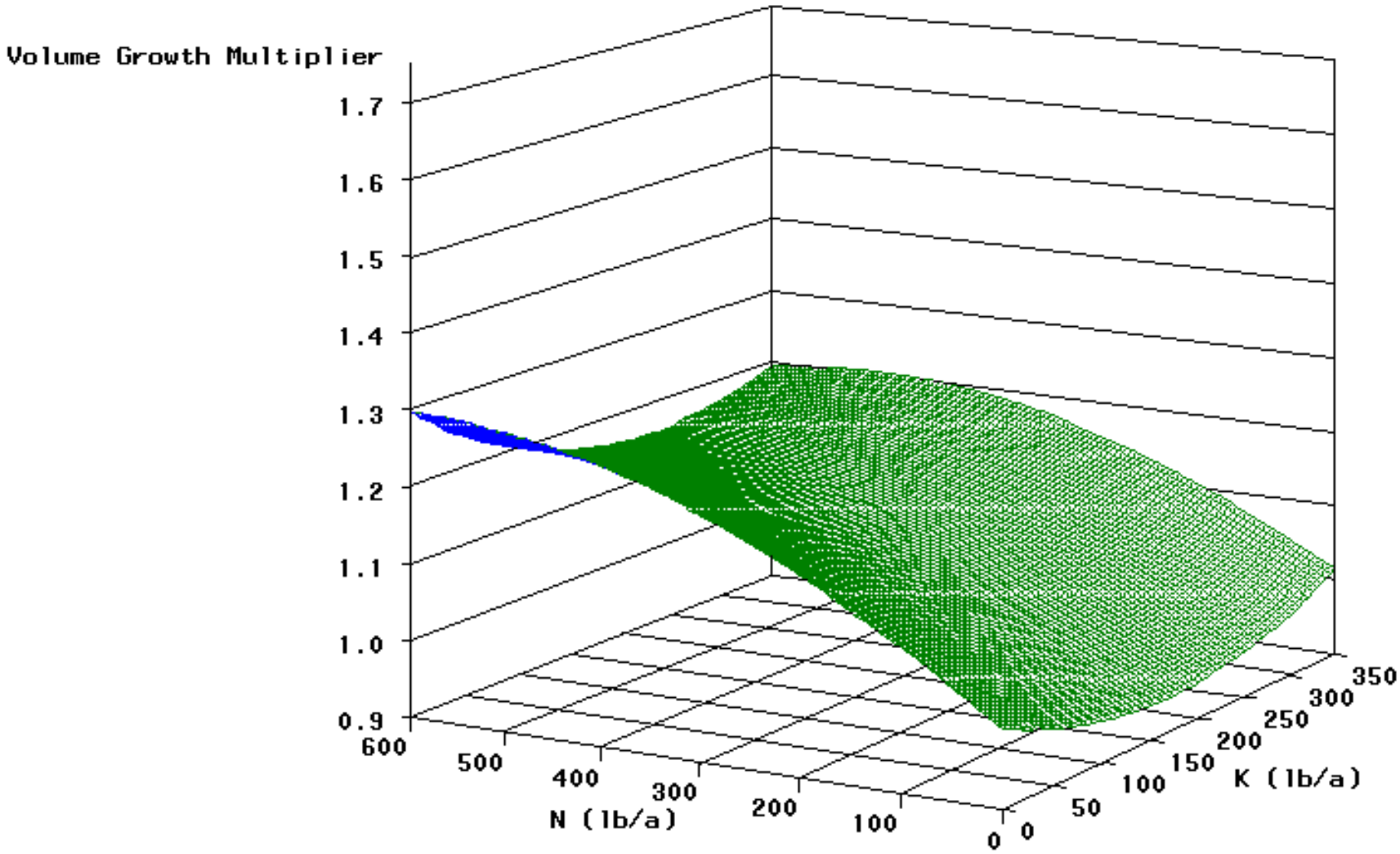
Foliar Chemistry Vector Analysis Results: N and K

Species	Results	Prognosis:
DF	N deficiency even for high N rates K dilution	Growth response to N even at high N rates No growth response to K
GF	N deficiency but only for moderate N rates K deficiency?	Growth response to low N rates but negative response to high N rates Perhaps some growth response to K
PP	N deficiency but only for moderate N rates K dilution	Growth response to low N rates but declining response at high N rates No growth response to K

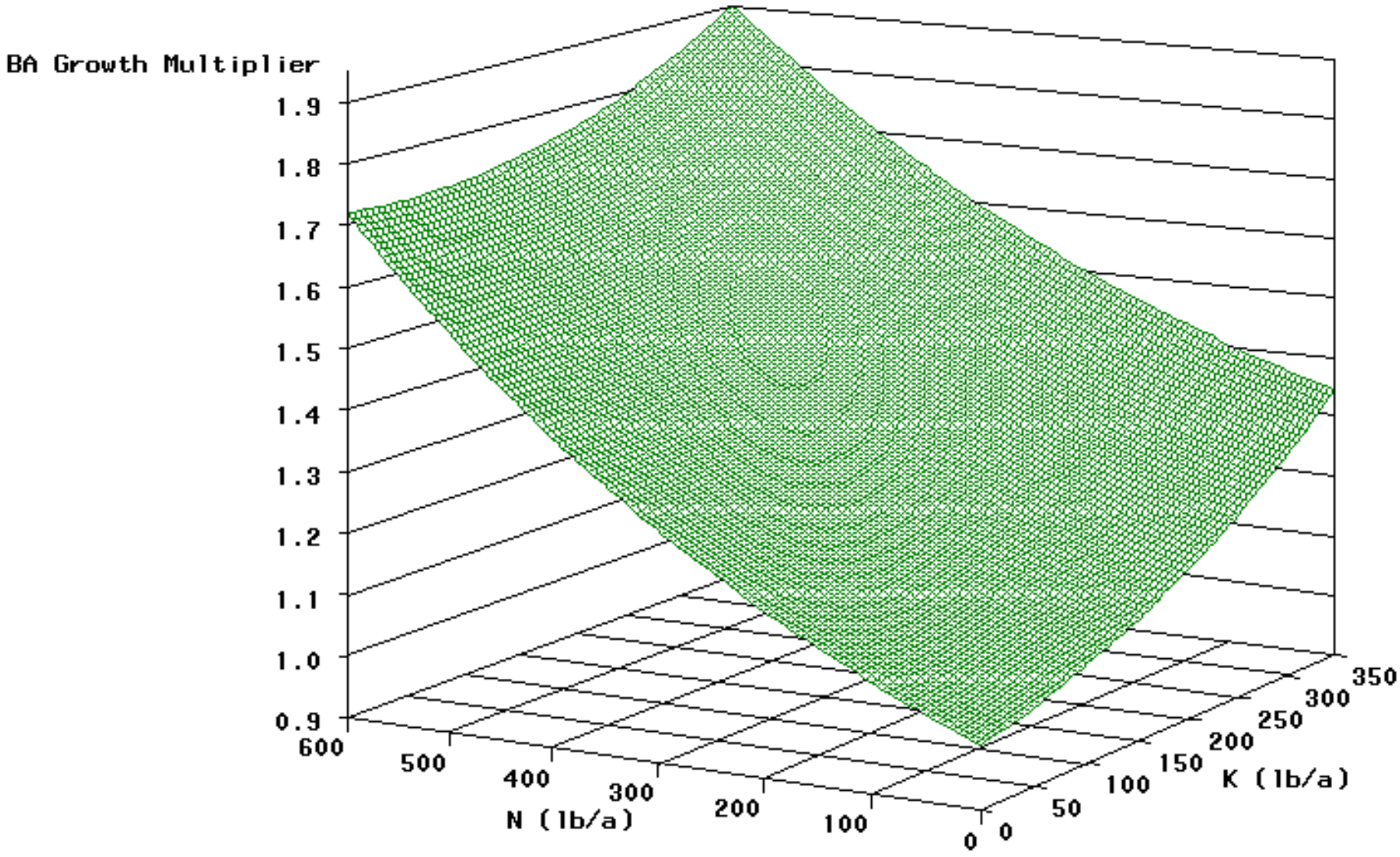
N and K Fertilizer Effects on 8-Year Gross BA Growth
Species= DF



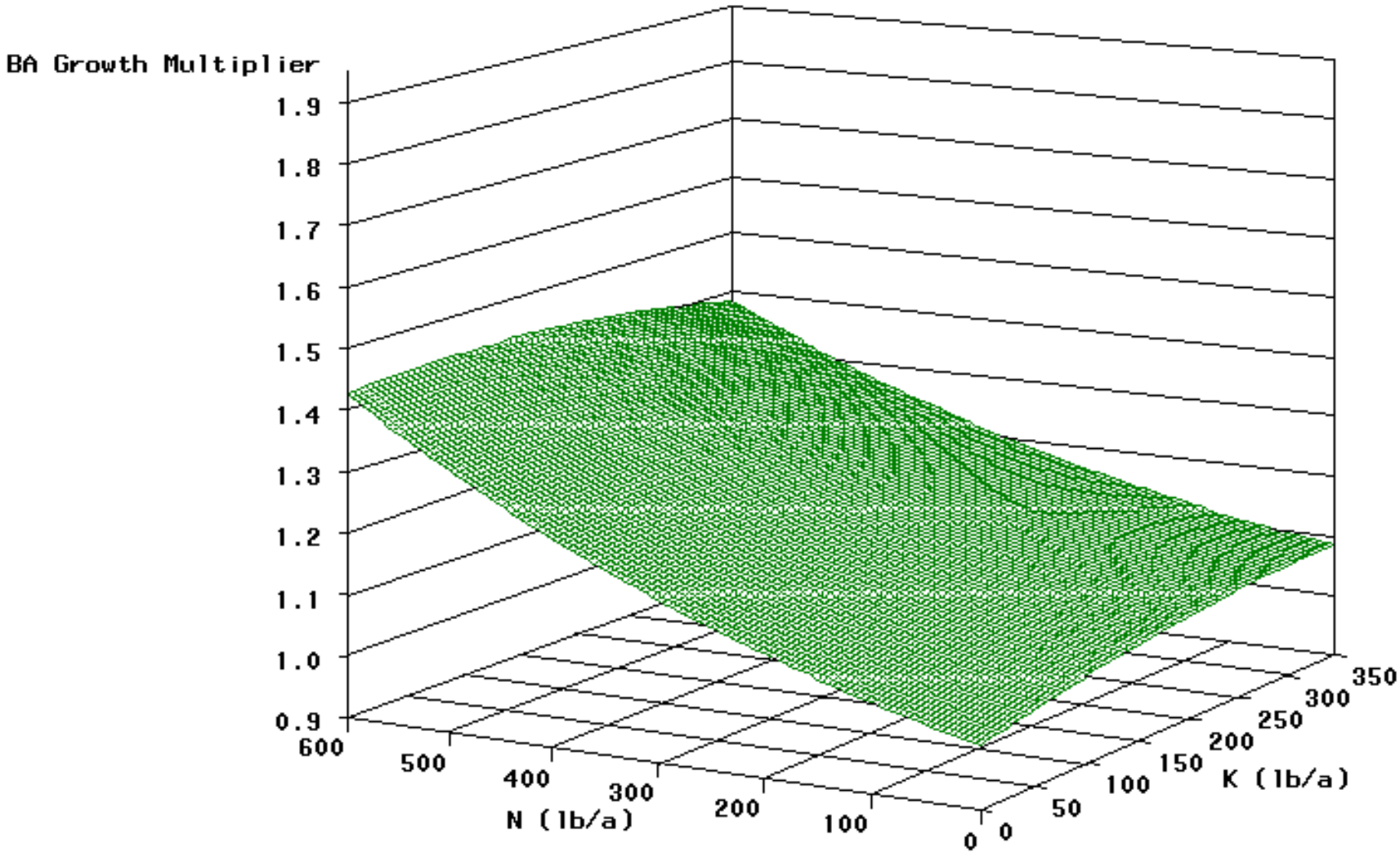
N and K Fertilizer Effects on 8–Year Gross Volume Growth
Species= DF



N and K Fertilizer Effects on 8-Year Gross BA Growth
Species= GF



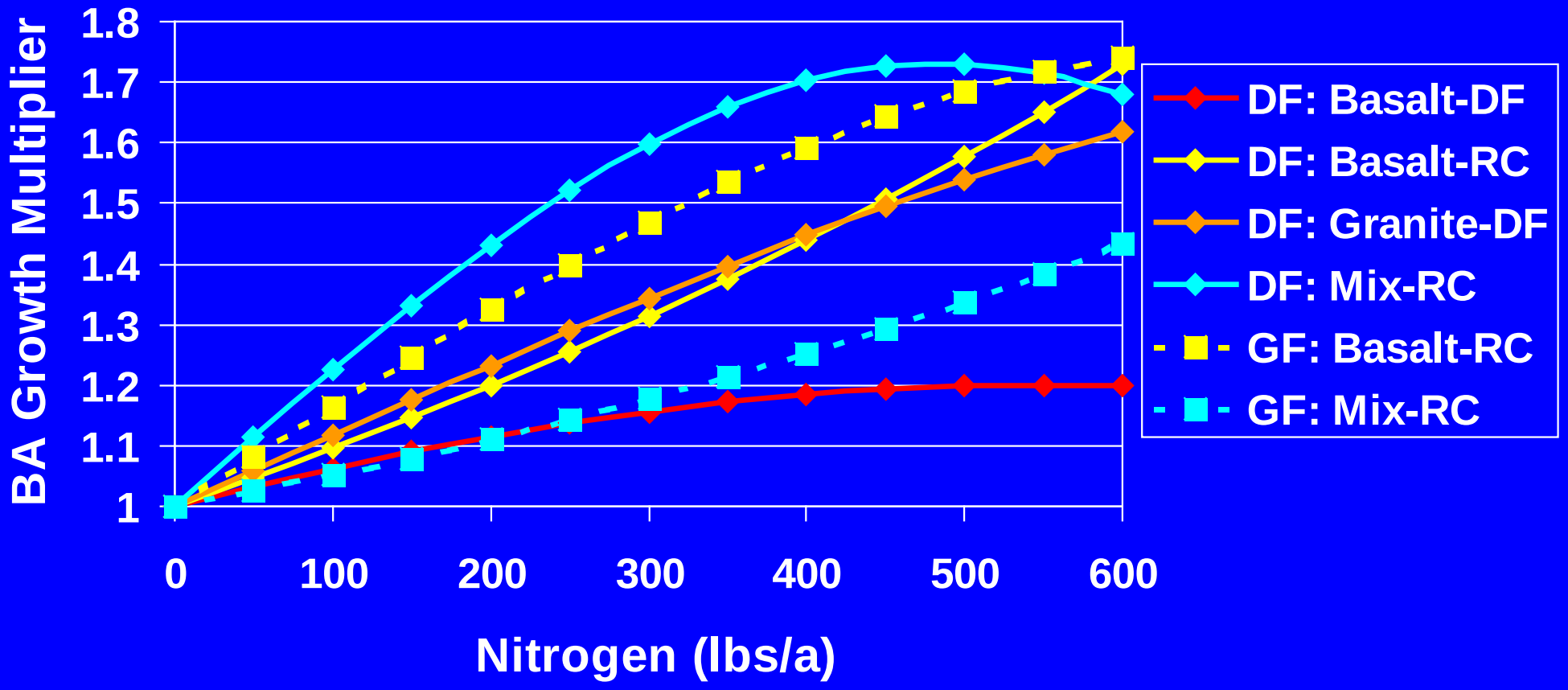
N and K Fertilizer Effects on 8-Year Gross BA Growth
Species= PP



Distribution of Species-specific growth data by rock type and vegetation series

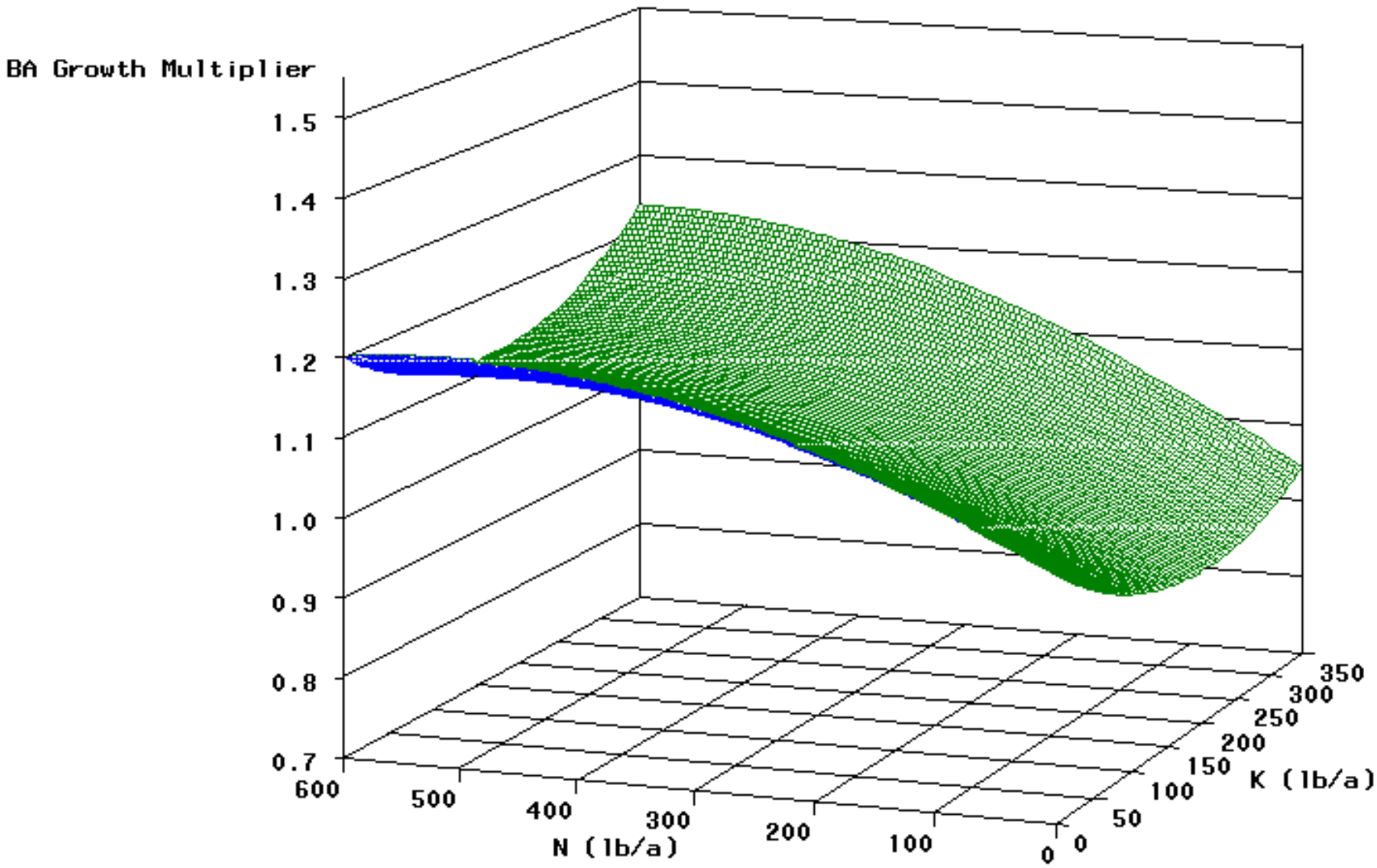
		Tree Species		
Series	Rock Type	DF	GF	PP
DF	Basalt	35	2	26
	Granite	49	0	40
	Metasediment	0	0	0
	Mixed	7	0	9
GF	Basalt	42	36	21
	Granite	34	15	19
	Metasediment	22	11	8
	Mixed	5	5	28
WRC/WH	Basalt	35	34	0
	Granite	27	26	0
	Metasediment	35	34	1
	Mixed	35	25	3

Nitrogen Fertilizer Effects on BA Growth by Rock Type and Vegetation Series



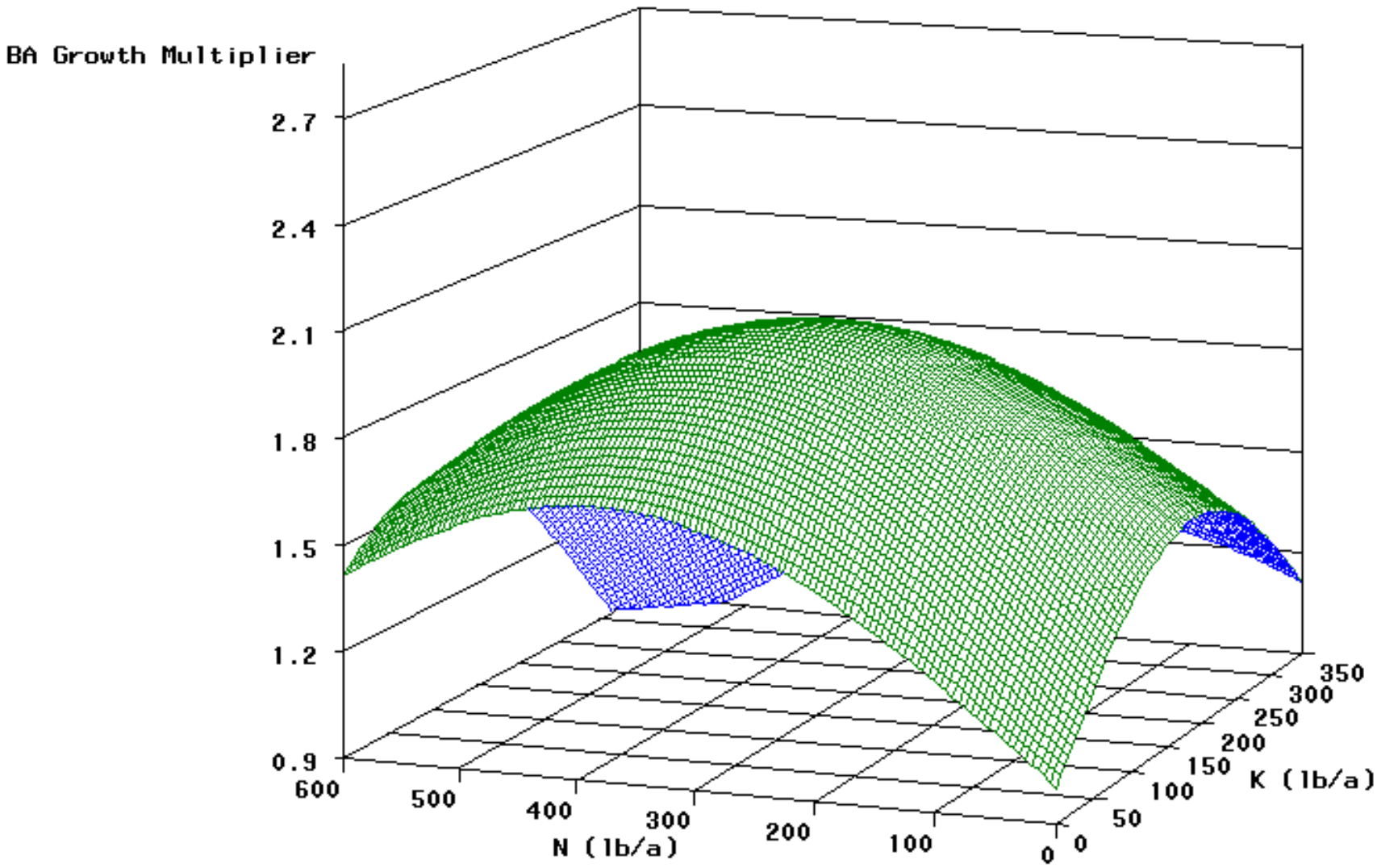
N and K Fertilizer Effects on 8-Year Gross BA Growth

Species= DF Rock Type= Basalt Vegetation Series= GF



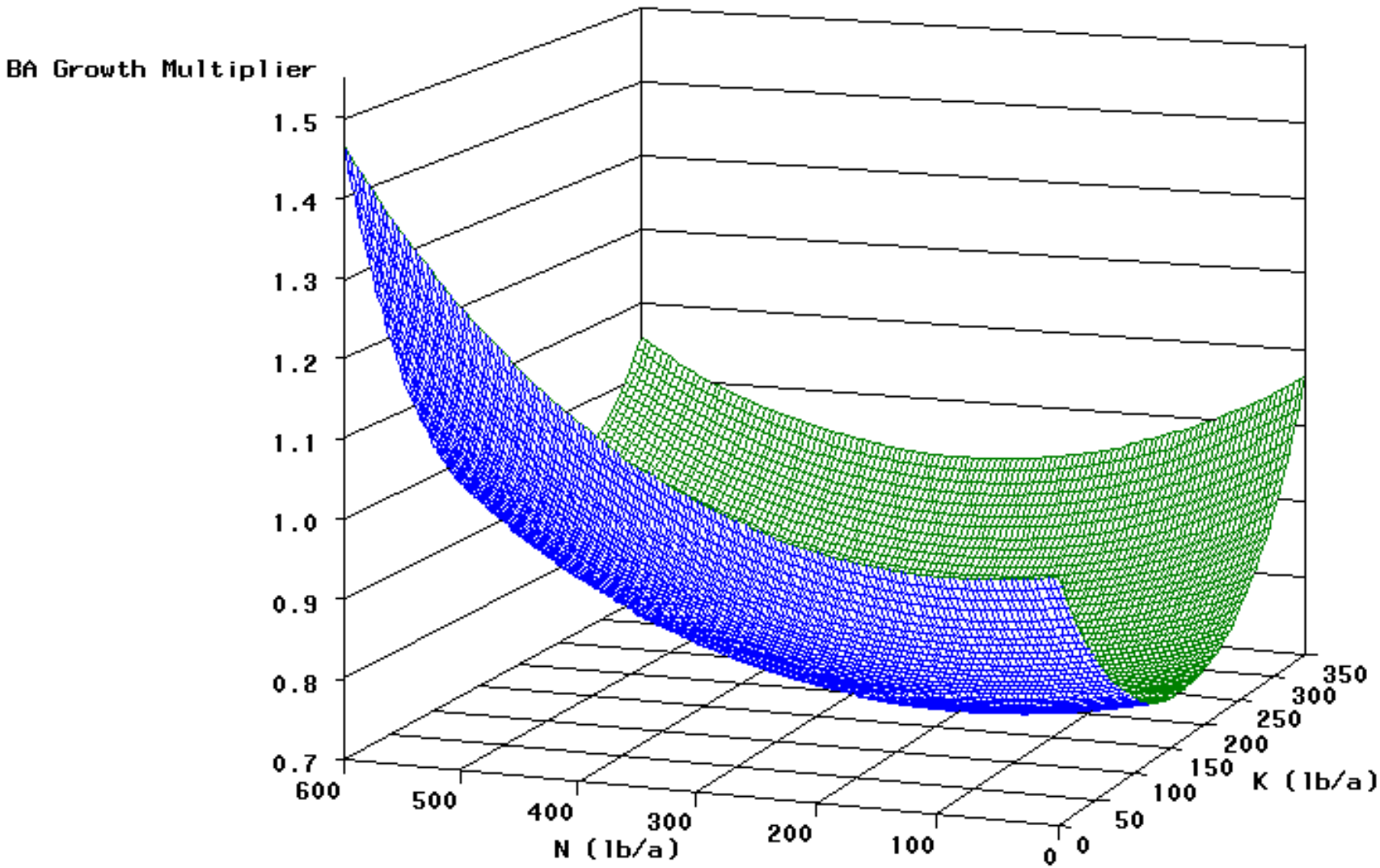
N and K Fertilizer Effects on 8—Year Gross BA Growth

Species=GF Rock Type=Basalt Vegetation Series=GF



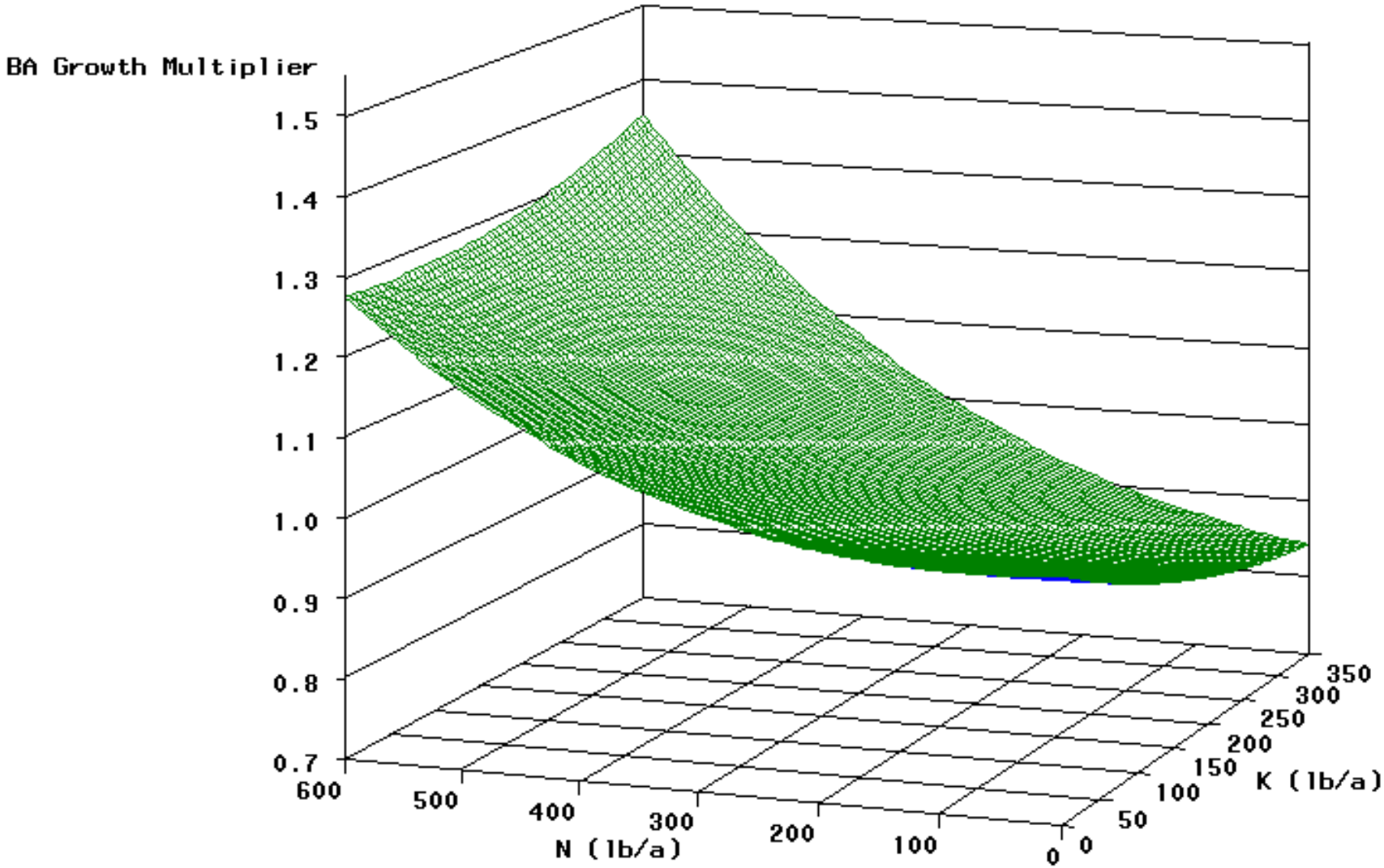
N and K Fertilizer Effects on 8-Year Gross BA Growth

Species= DF Rock Type= Granite Vegetation Series= WRC/WH



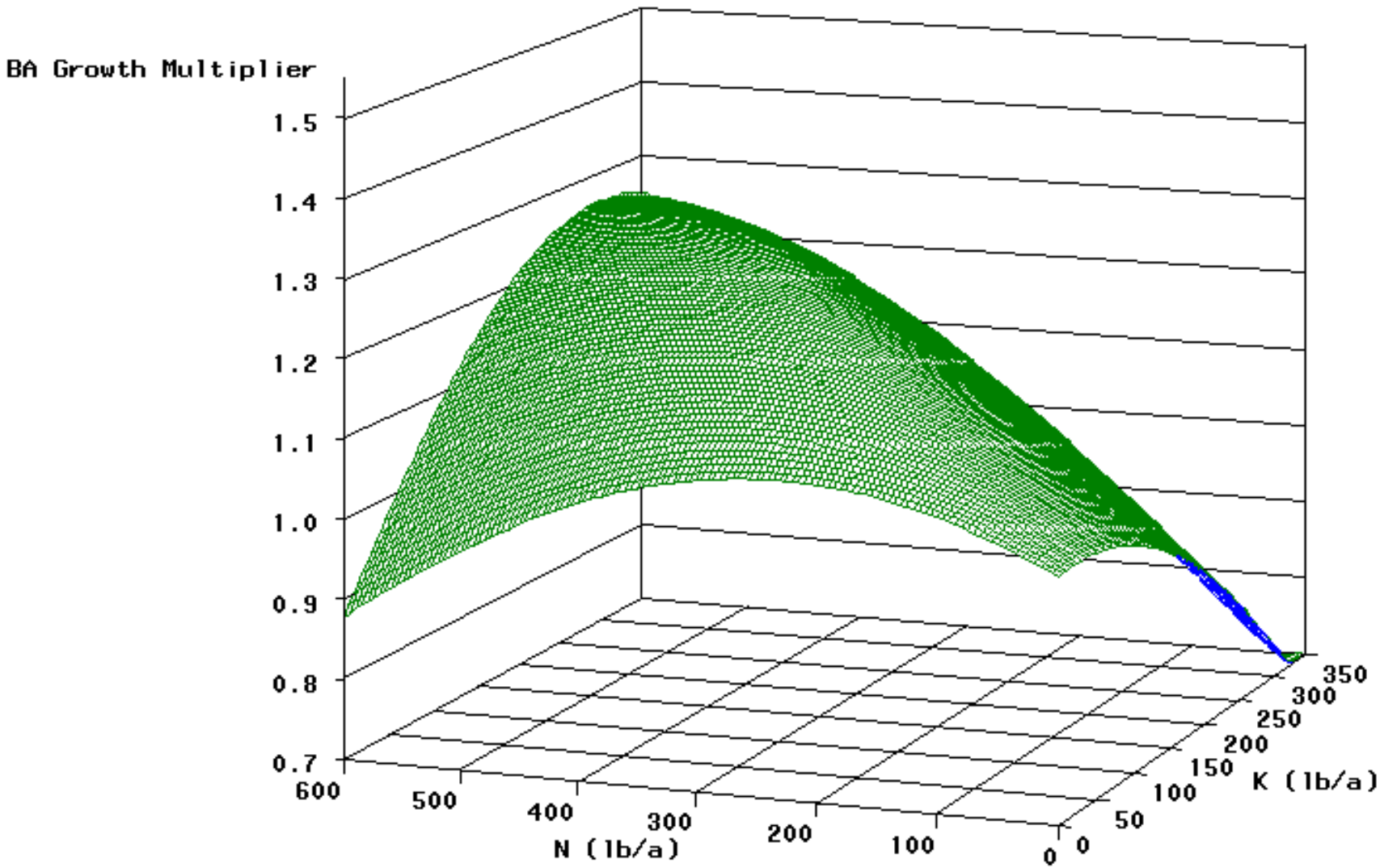
N and K Fertilizer Effects on 8-Year Gross BA Growth

Species=GF Rock Type=Granite Vegetation Series=WRC/WH



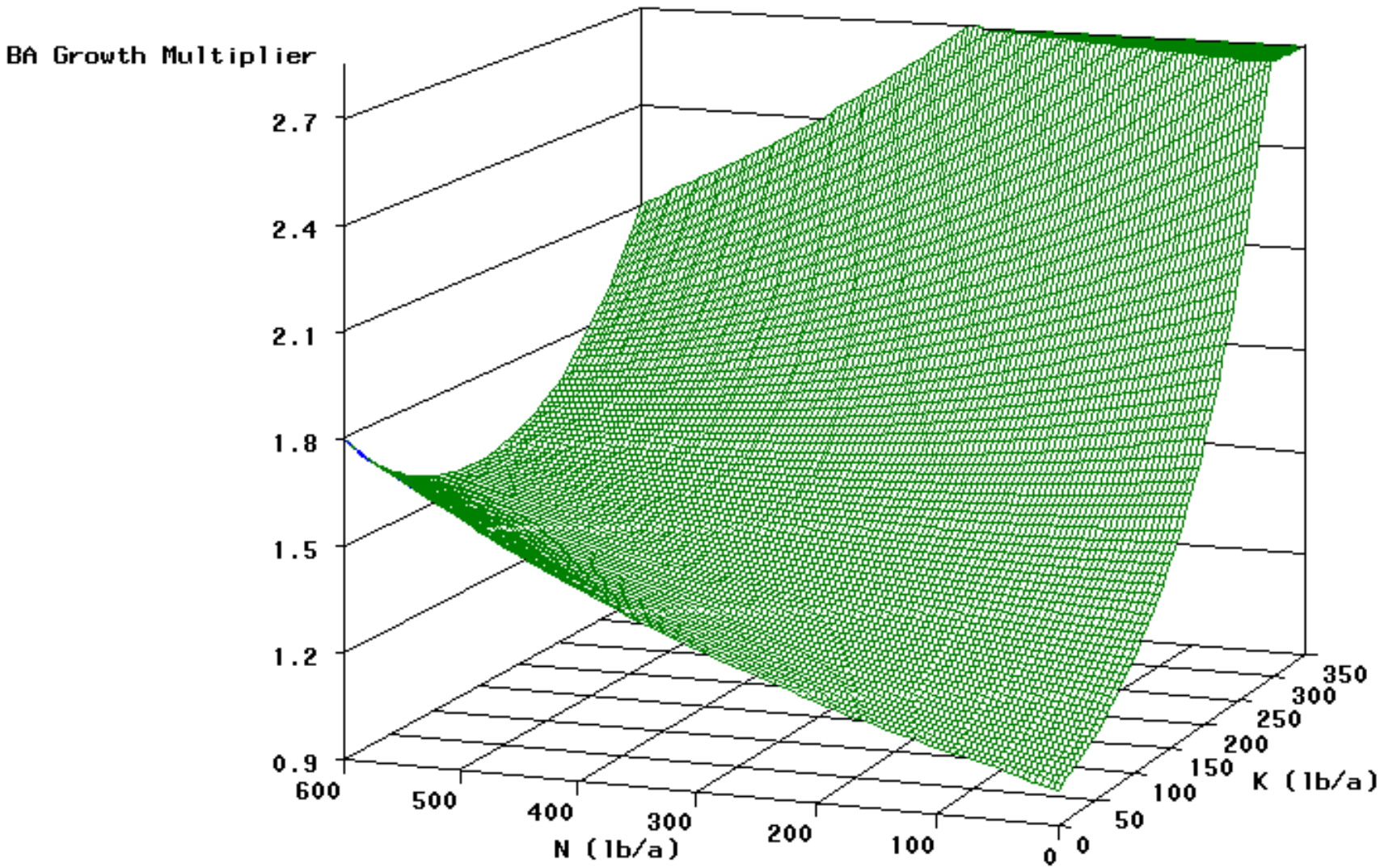
N and K Fertilizer Effects on 8-Year Gross BA Growth

Species= DF Rock Type= Metasediment Vegetation Series= WRC/WH



N and K Fertilizer Effects on 8-Year Gross BA Growth

Species = GF Rock Type = Metasediment Vegetation Series = WRC/WH



Sulfur and Micronutrient Analysis

Sulfur Effects (65 lbs S/a) and Micronutrient Effects

(B @5 lbs/a, Cu @10 lbs/a, Mo @ 1 lb/a, Zn @10 lbs/a) estimated with ANACOVA using only those sites where S was applied (as K_2SO_4).

DF (13 sites, 76 plots), GF (10 sites, 48 plots),

PP (7 sites, 35 plots)

Model:

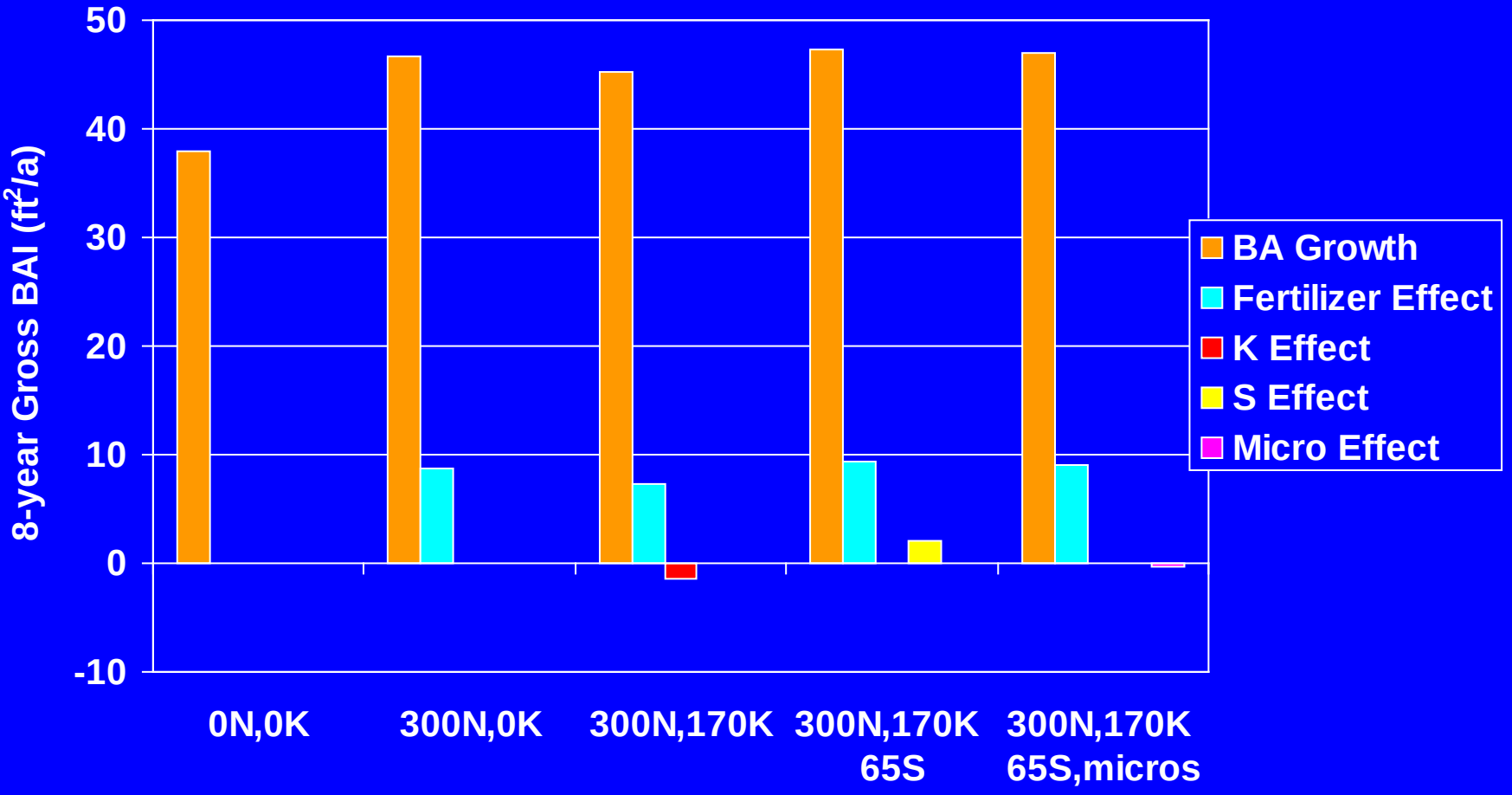
$$\ln(RGR) = \mu + Site + \beta 0 * BA_0 * Species + \beta 1 * Treatment * Species$$

Graphed response is RGR=100*growth/starting condition

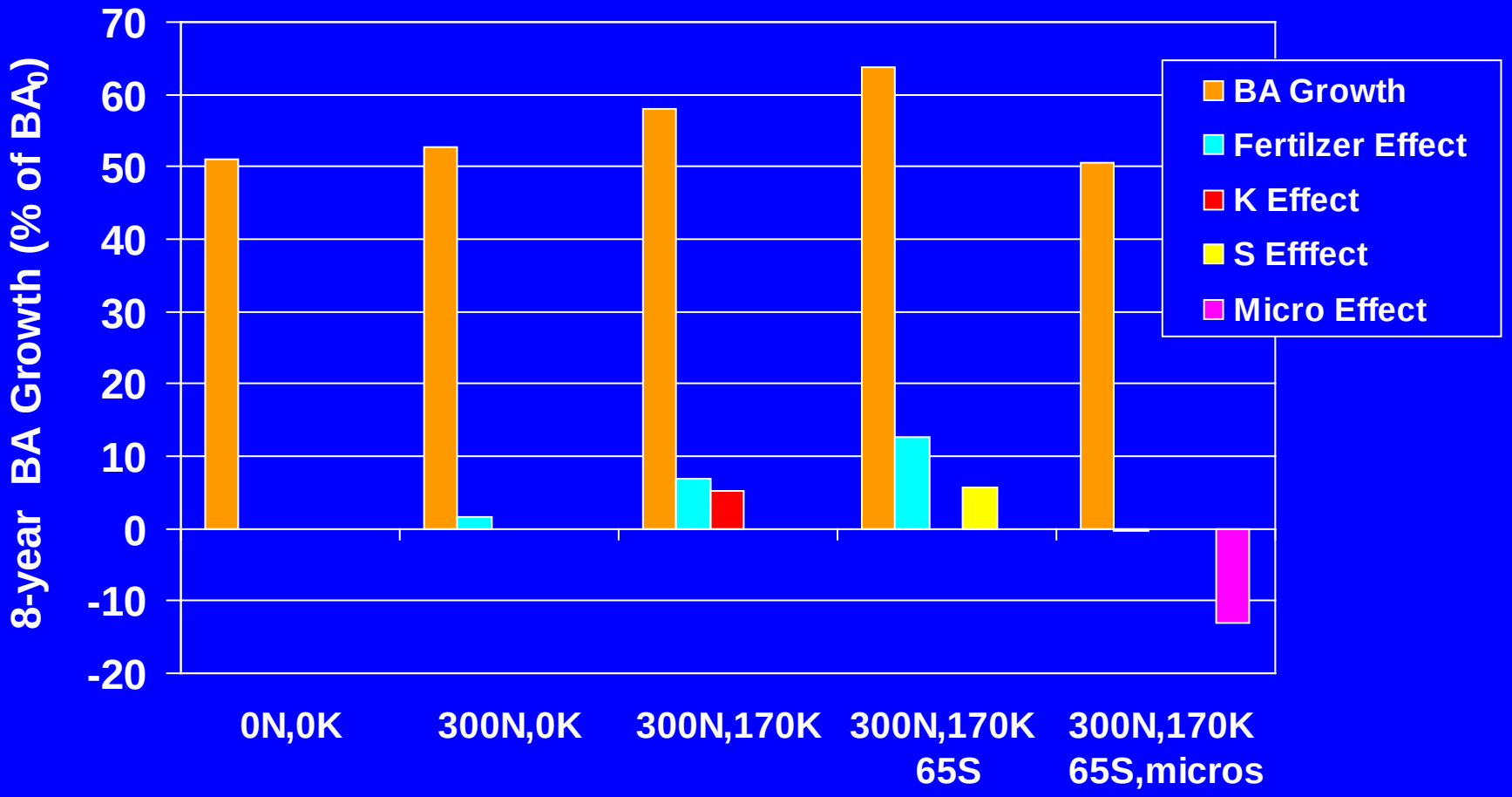
Foliar Chemistry Vector Analysis Results: S and micros (B, Mo, Cu, Zn)

Species	Results	Prognosis:
DF	S deficiency	Growth response to S
	No micro deficiencies	No growth response to micros
GF	S deficiency	Growth response to S
	No micro deficiencies	No growth response to micros
PP	S toxicity?	No growth response to S, perhaps some growth decline
	Micro deficiencies	Growth response to micros Unable to determine which (B, Mo, Cu, Zn) is responsible

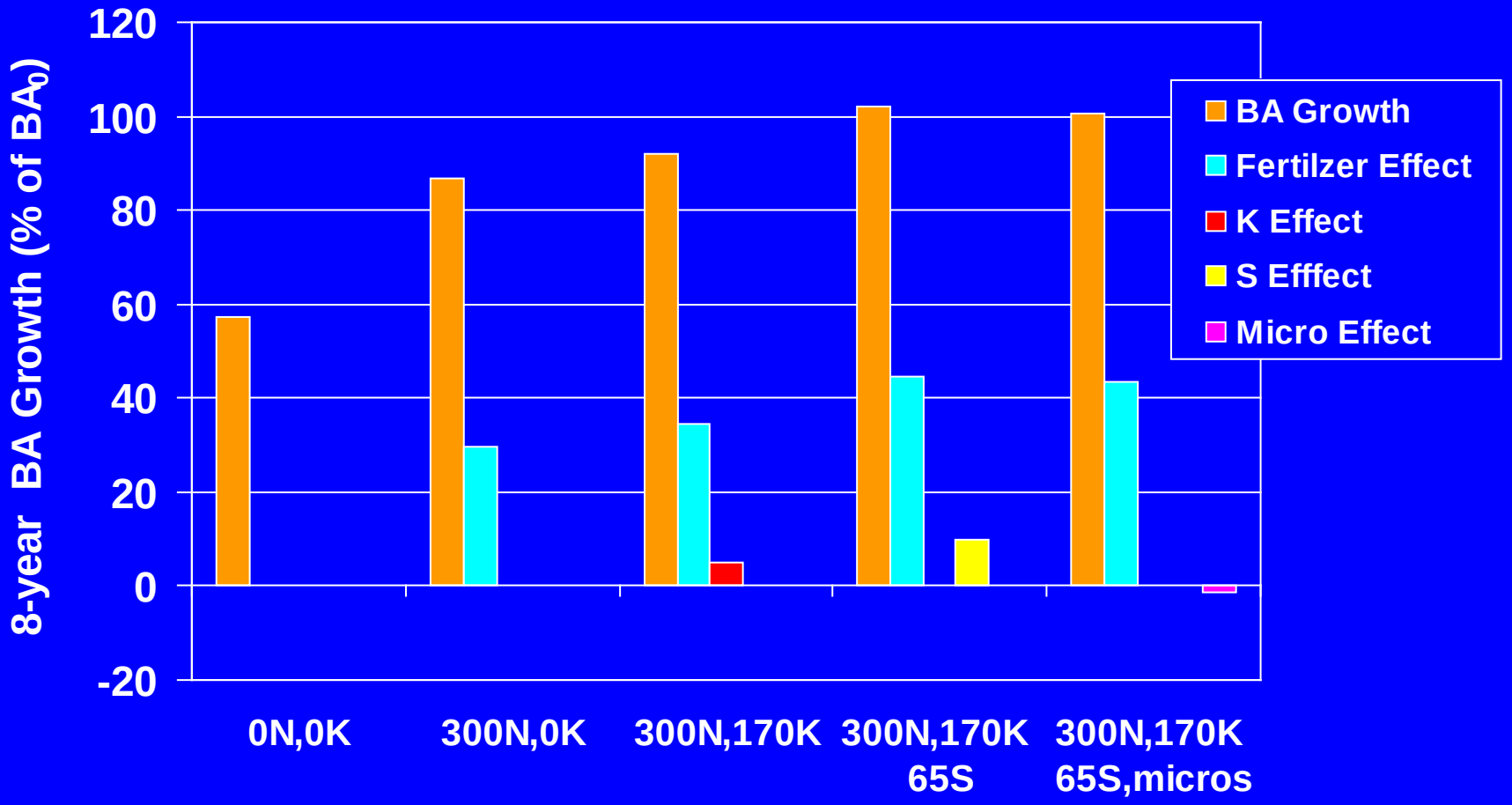
Sulfur and Micronutrients: effects on 8-year BA Growth



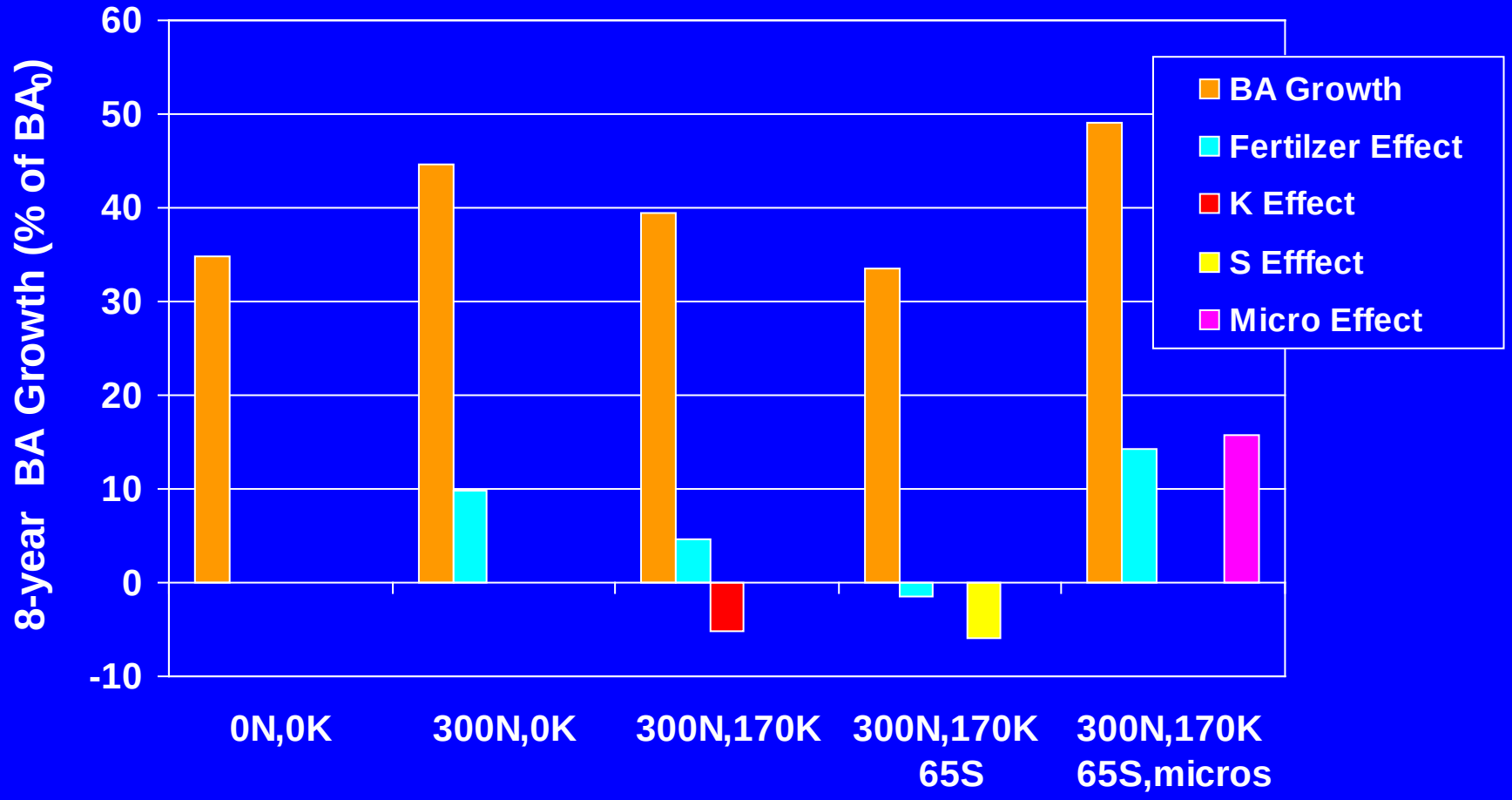
Sulfur and Micronutrients Effects: 8-year BA Response — Douglas-fir



Sulfur and Micronutrients Effects: 8-year BA Response — Grand Fir



Sulfur and Micronutrients Effects: 8-year BA Response — Ponderosa Pine



Summary of Results: Growth Reponse

- Growth response was higher in GF than DF or PP.
- Response was proportionate to N rate at lower rates, but increases declined at N rates above 300 lbs./a for DF. For GF and PP response was fairly linear.
- K fertilizer additions increased growth in GF, but had no apparent effect on PP growth. K affected DF growth, but the magnitude was small.
- N and K effects varied by rock type and vegetation series.
- SO_4 increased response in GF and, to a lesser extent, DF but not in PP.
- Micronutrients produced a growth response in PP but not DF or GF.

Summary of Results: Growth Reponse

Vector Analysis

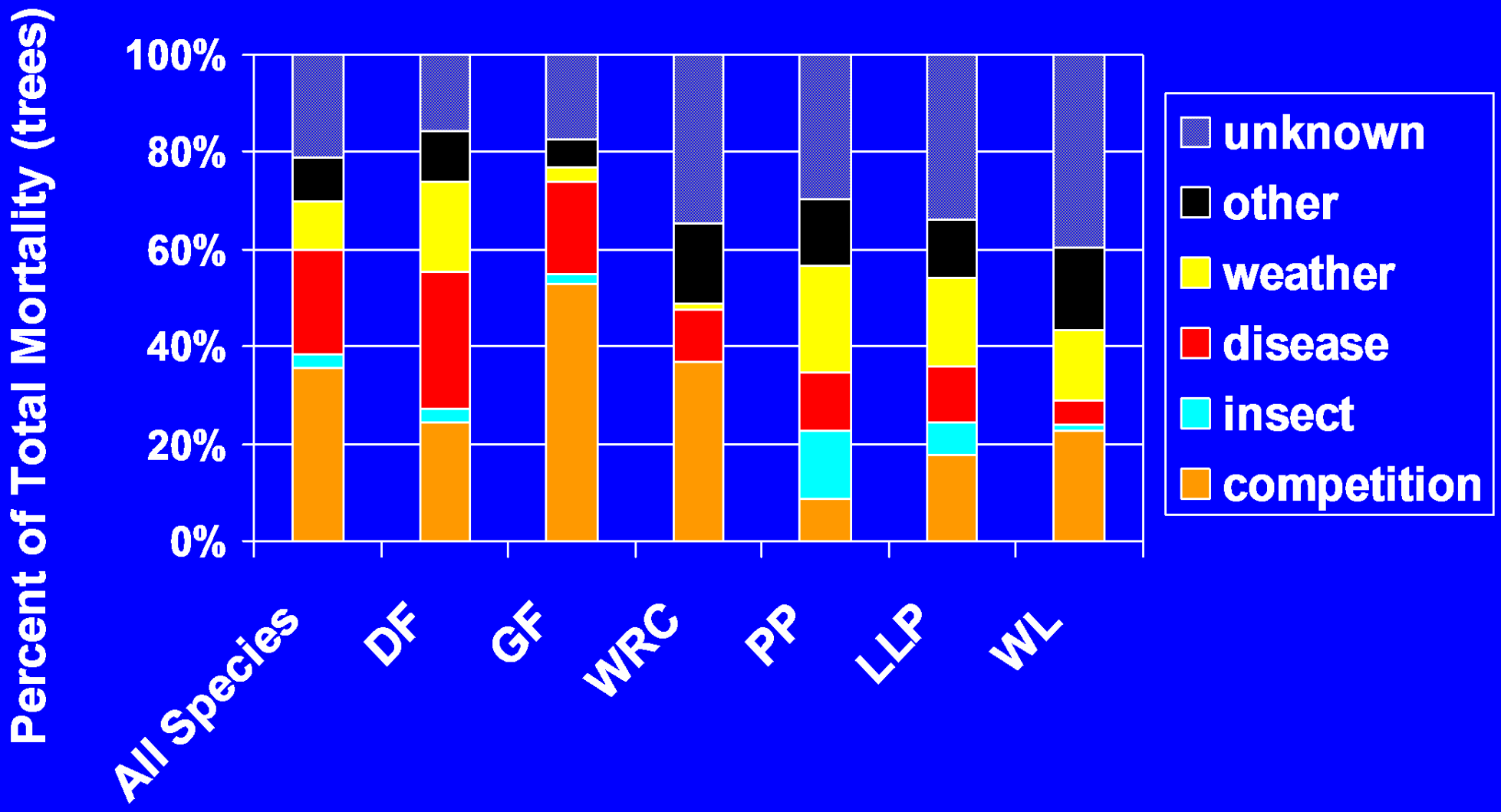
Agreement between foliage vector analysis predictions and actual growth responses was good for K, S and micros. However, vector analysis failed to correctly predict response to high N applications.

What's Dying?

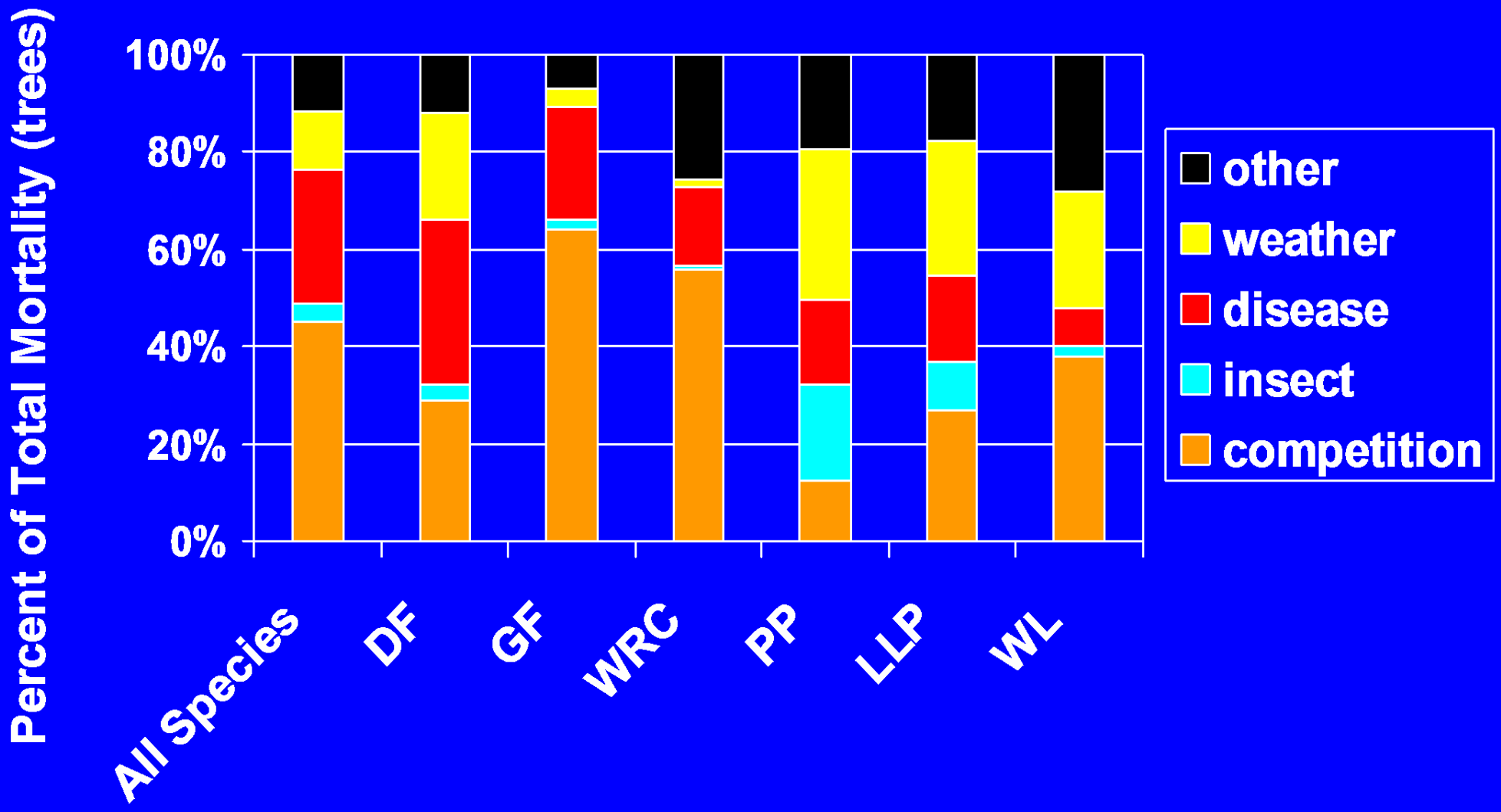
	Total Trees	Dead Trees	% Mortality
All species	66800	3593	5.4
Douglas-fir	23176	1088	4.7
Grand Fir	17696	1453	8.2
Western Redcedar	10771	359	3.3
Ponderosa Pine	7935	207	2.6
Lodgepole Pine	3061	185	6.0
Western Larch	1911	83	4.3

	Mean DBH	Inner-Quartile Range
All trees	4.8 inches	0.9 to 7.36 inches
Dead trees	3.9 inches	0.7 to 5.8 inches

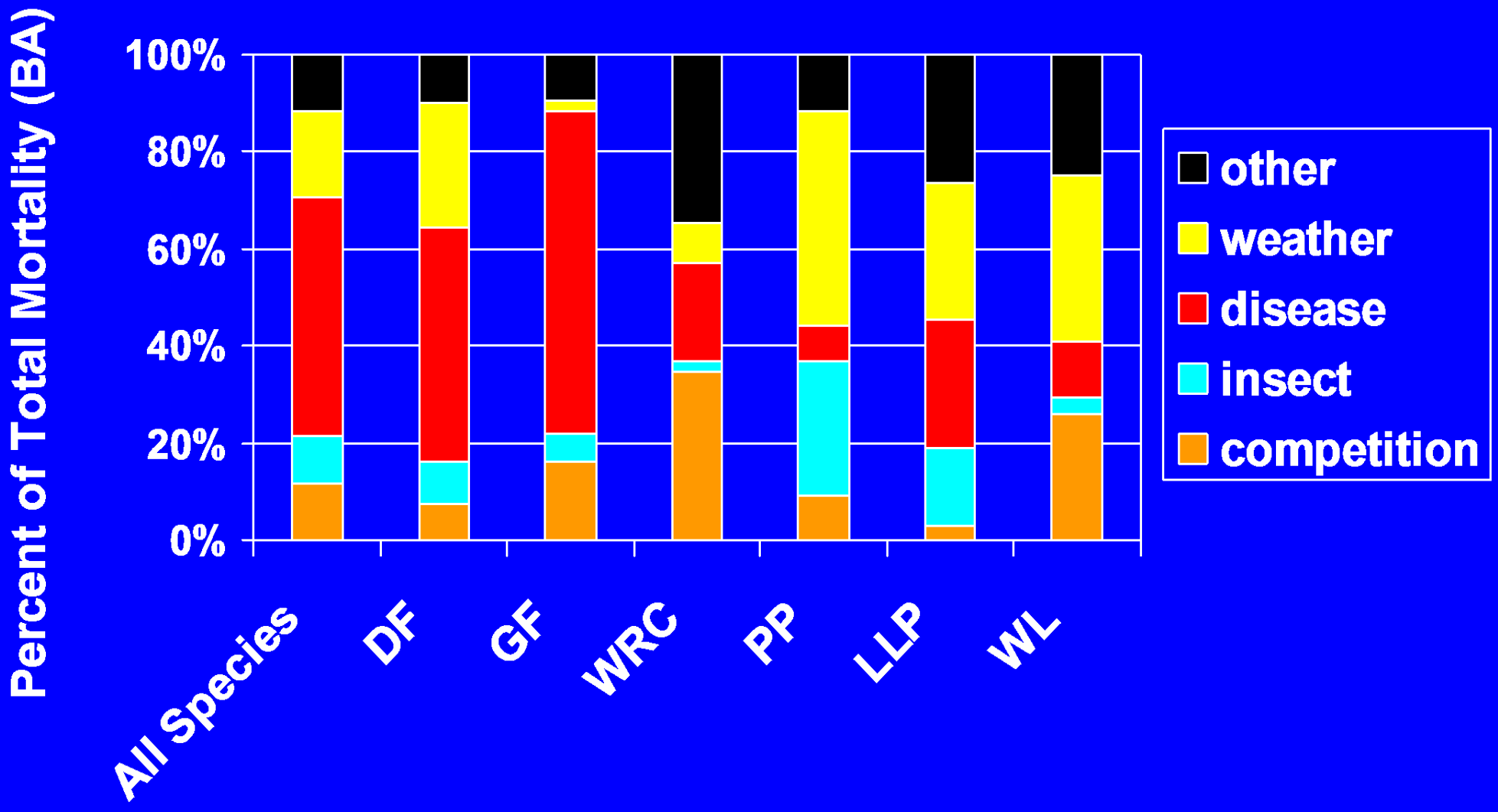
Causes of Mortality



Causes of Mortality



Causes of Mortality



Species-specifc Mortality Analysis: N and K

Only plots with ≥1.0 ft^2/a initial BA of a species were used (DF: 29 sites, 335 plots GF: 21 sites, 177 plots PP: 22 sites, 167 plots)

Dependent variable = ln(% mortality + 1)

where mortality is expressed in trees/a or BA/a

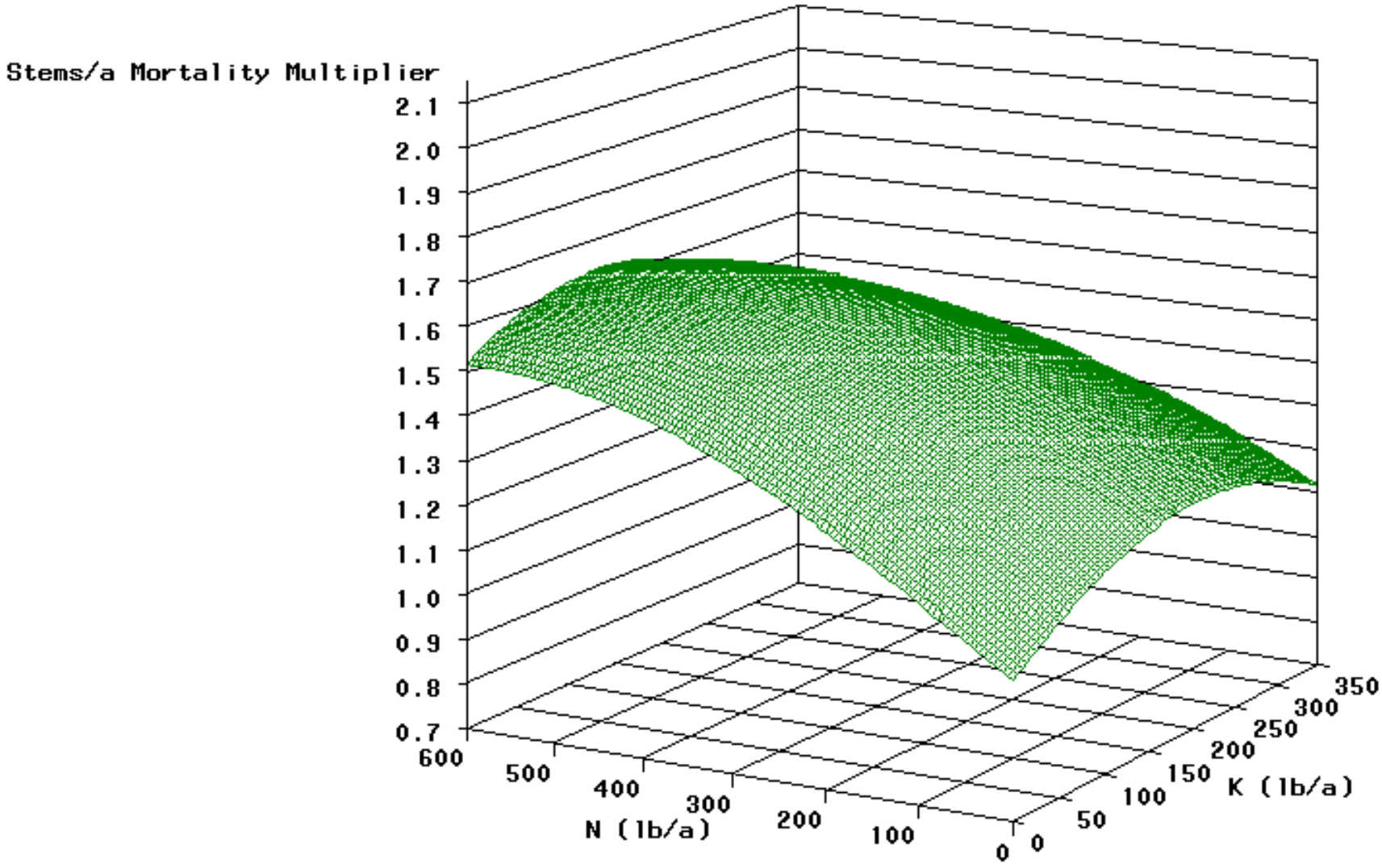
N and K fertilizer effects estimated using a species-specific multiplicative quadratic response surface model:

$$\ln PMort = \mu + Site + \beta 01 * BA_0 + \beta 02 * GBAI_8 + \beta 1 * N + \beta 2 * N^2 + \beta 3 * K + \beta 4 * K^2 + \beta 5 * NK$$

Graphed response = mortality as a proportion of control plot mortality (a mortality multiplier)

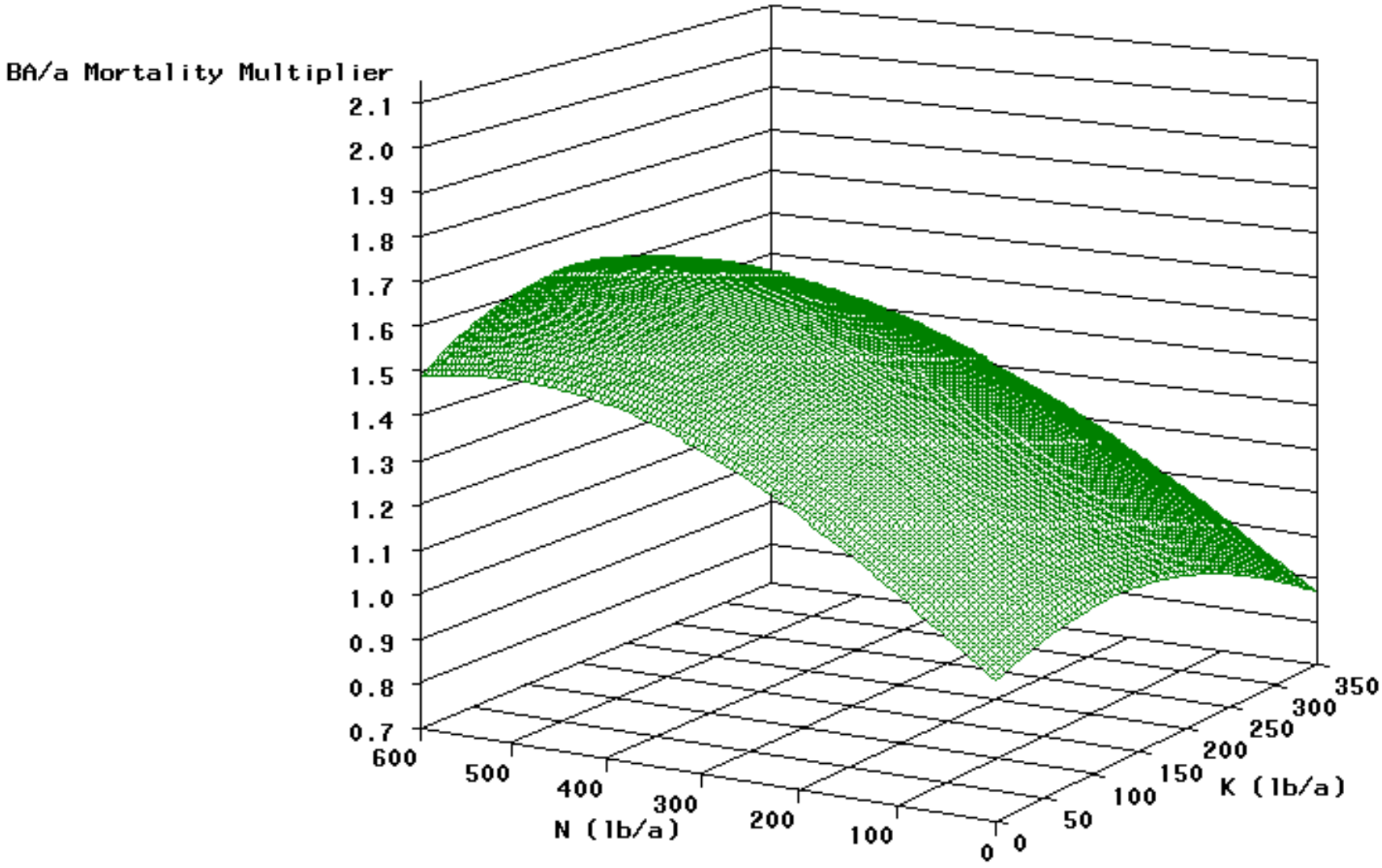
N and K Fertilizer Effects on 8—Year Trees/a Mortality

Species = DF



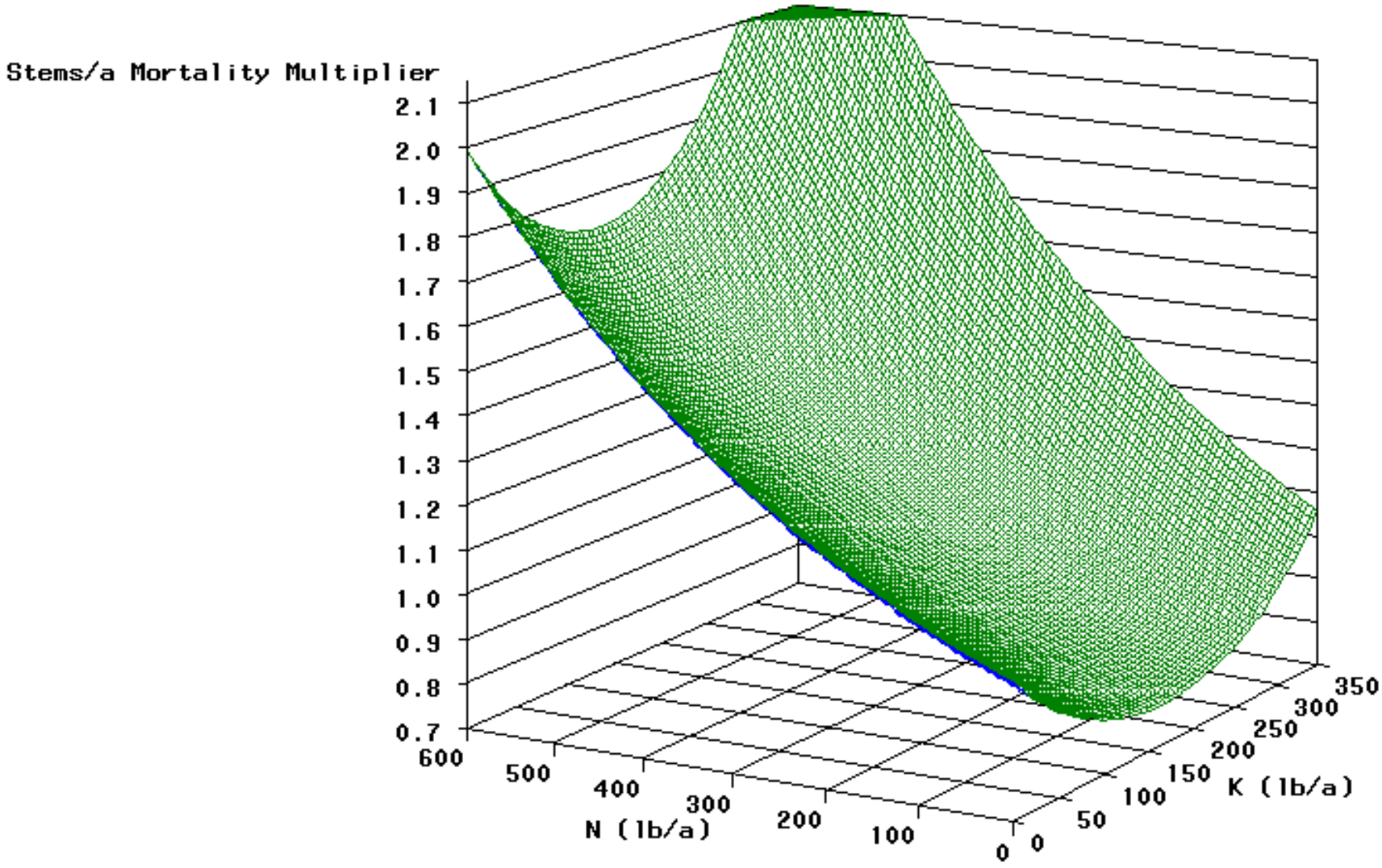
N and K Fertilizer Effects on 8–Year BA/a Mortality

Species = DF



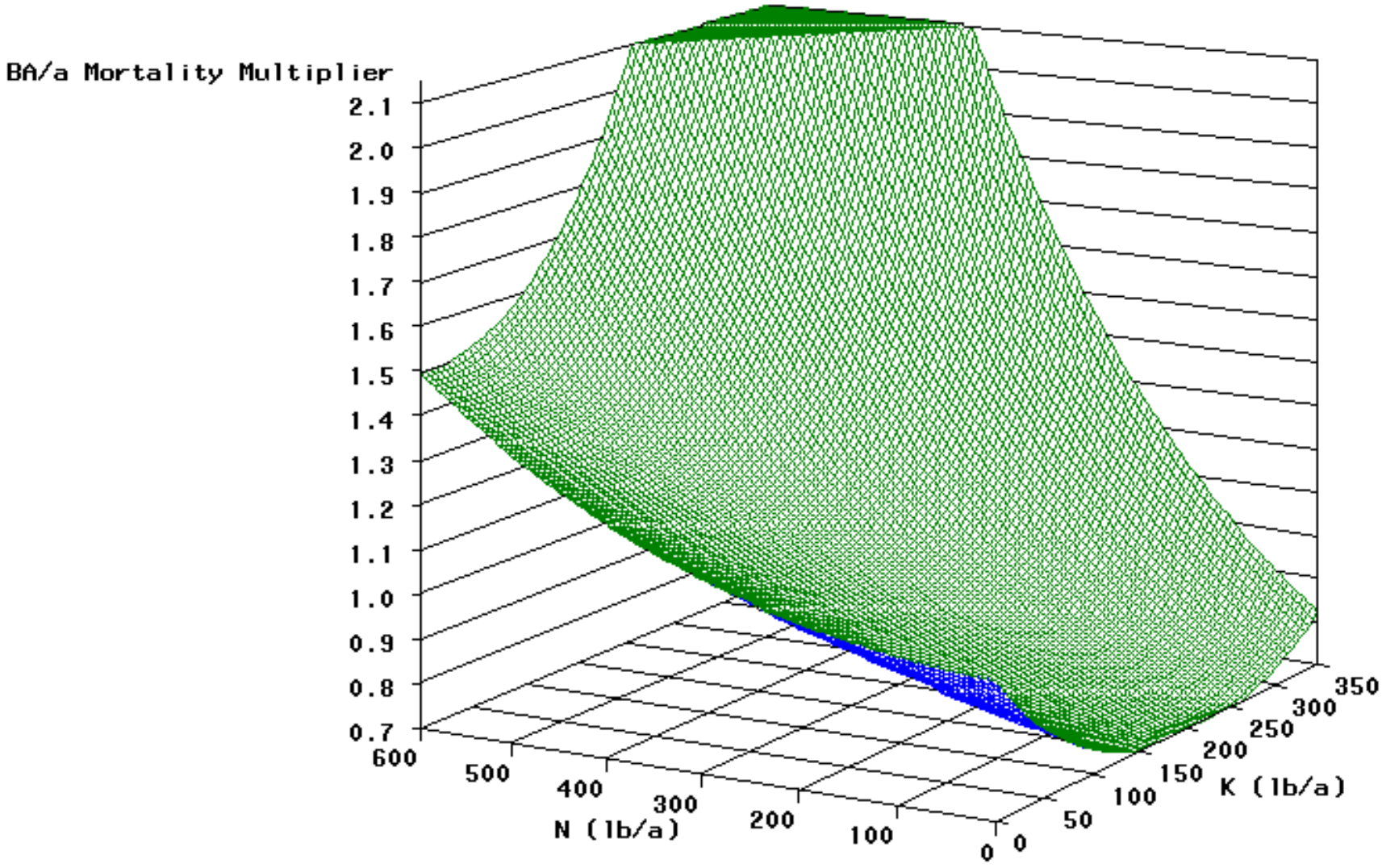
N and K Fertilizer Effects on 8–Year Trees/a Mortality

Species = GF



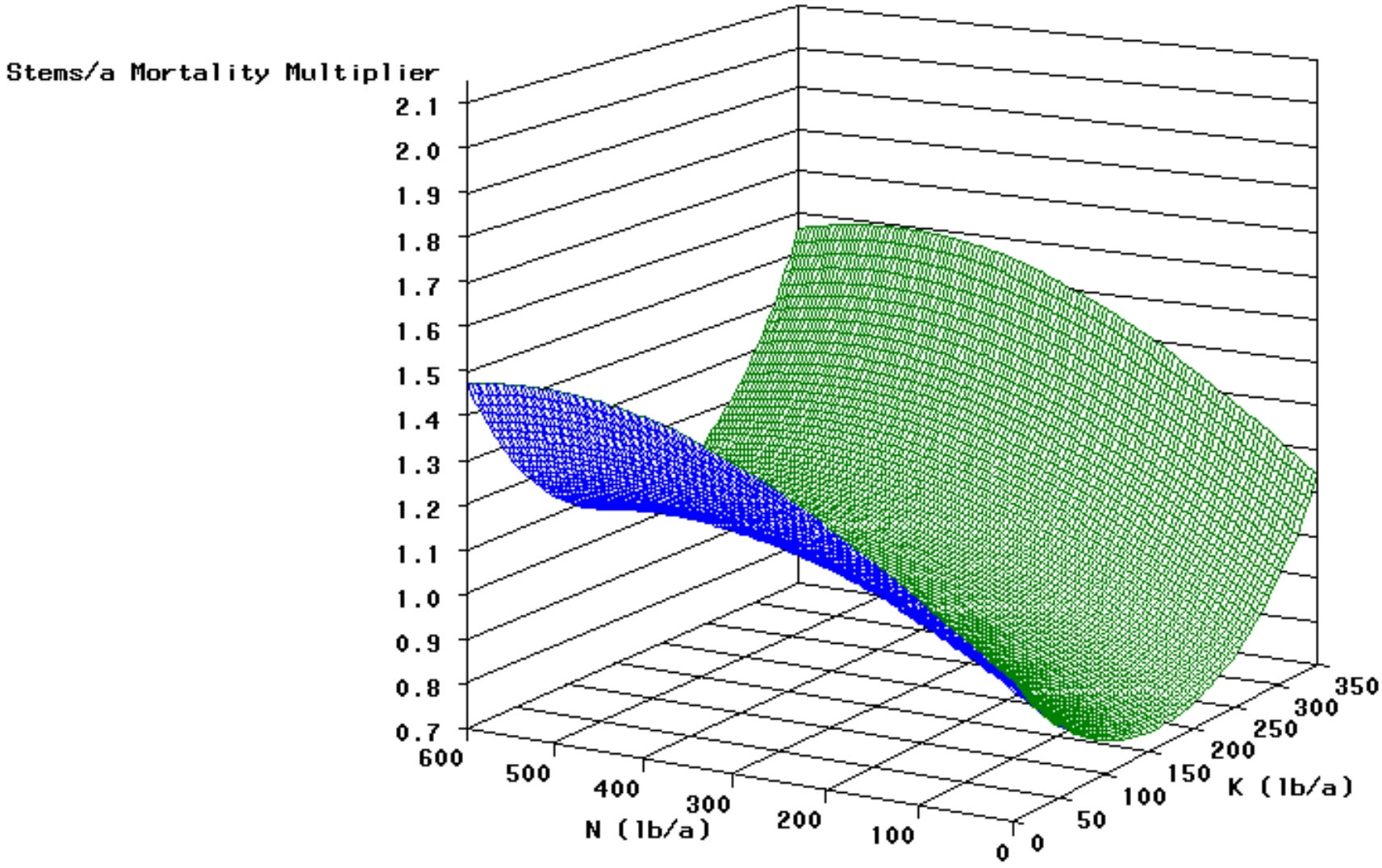
N and K Fertilizer Effects on 8–Year BA/a Mortality

Species = GF



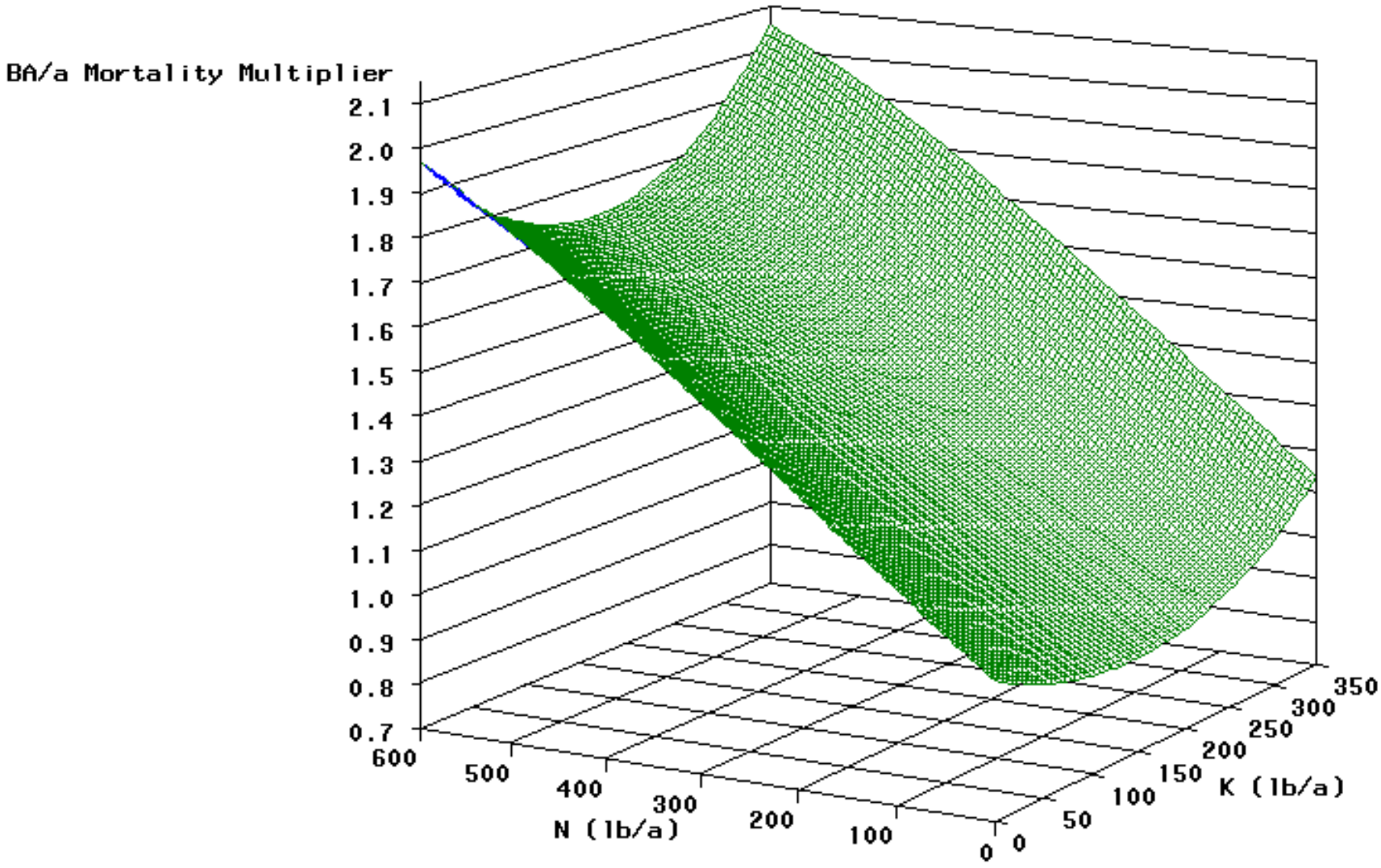
N and K Fertilizer Effects on 8—Year Trees/a Mortality

Species = PP



N and K Fertilizer Effects on 8–Year BA/a Mortality

Species = PP



Species-specifc Mortality Analysis: Sulfur and Micronutrients

Sulfur @65 lbs/a, Boron @5 lbs/a, Copper @10 lbs/a, Molybdenum @ 1 lb/a, Zinc @10 lbs/a

Analysis used only those sites where S was applied

DF (13 sites, 76 plots), GF (10 sites, 48 plots), PP (7 sites, 35 plots)

Dependent variable = ln(% BA mortality + 1)

= ln(100 * initial BA_s of dead trees/total initial BA_s + 1)

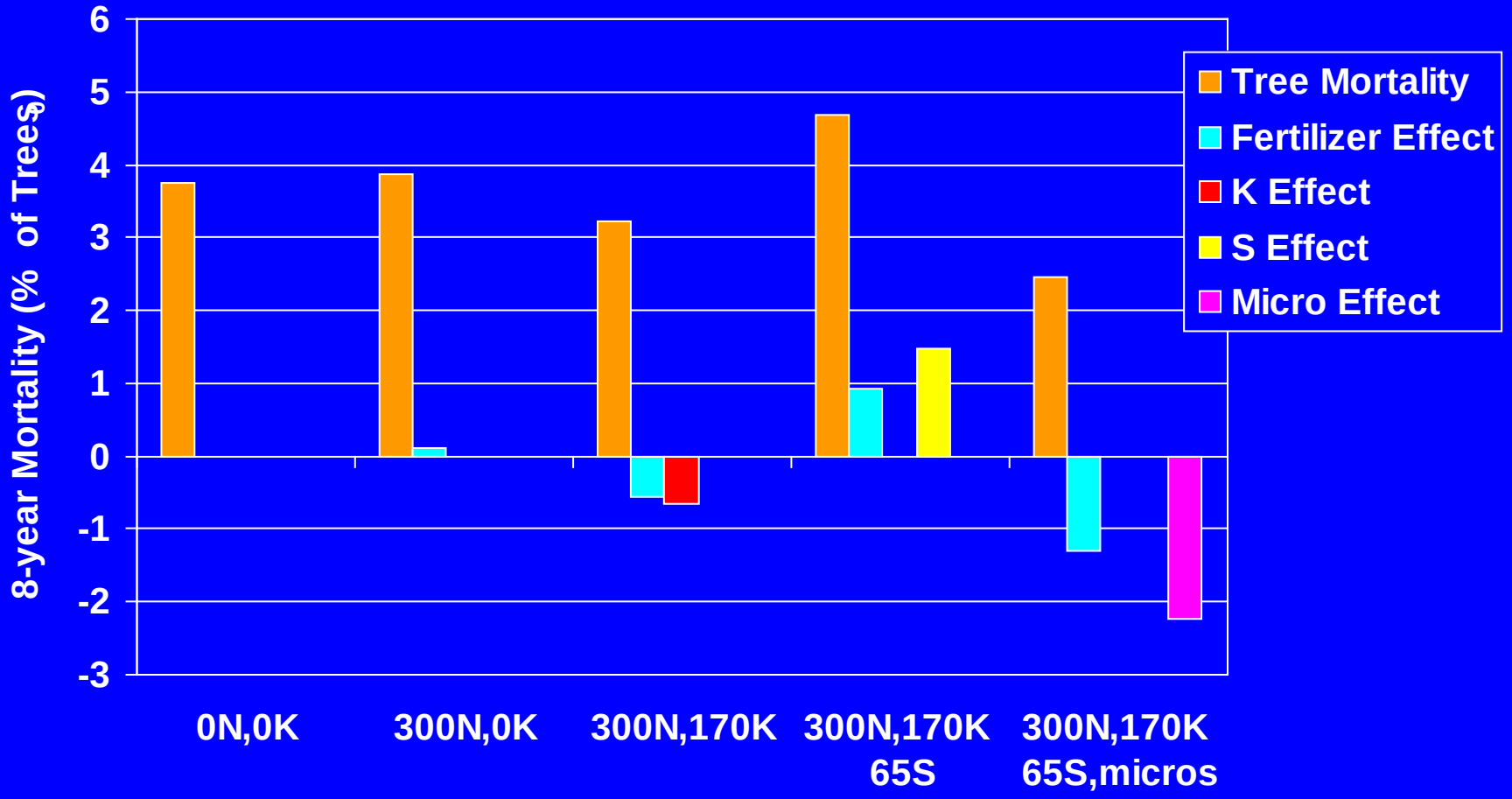
S and micros fertilizer effects estimated using a species-specific ANOVA model:

$$LPMBA = \mu + Site + Treatment$$

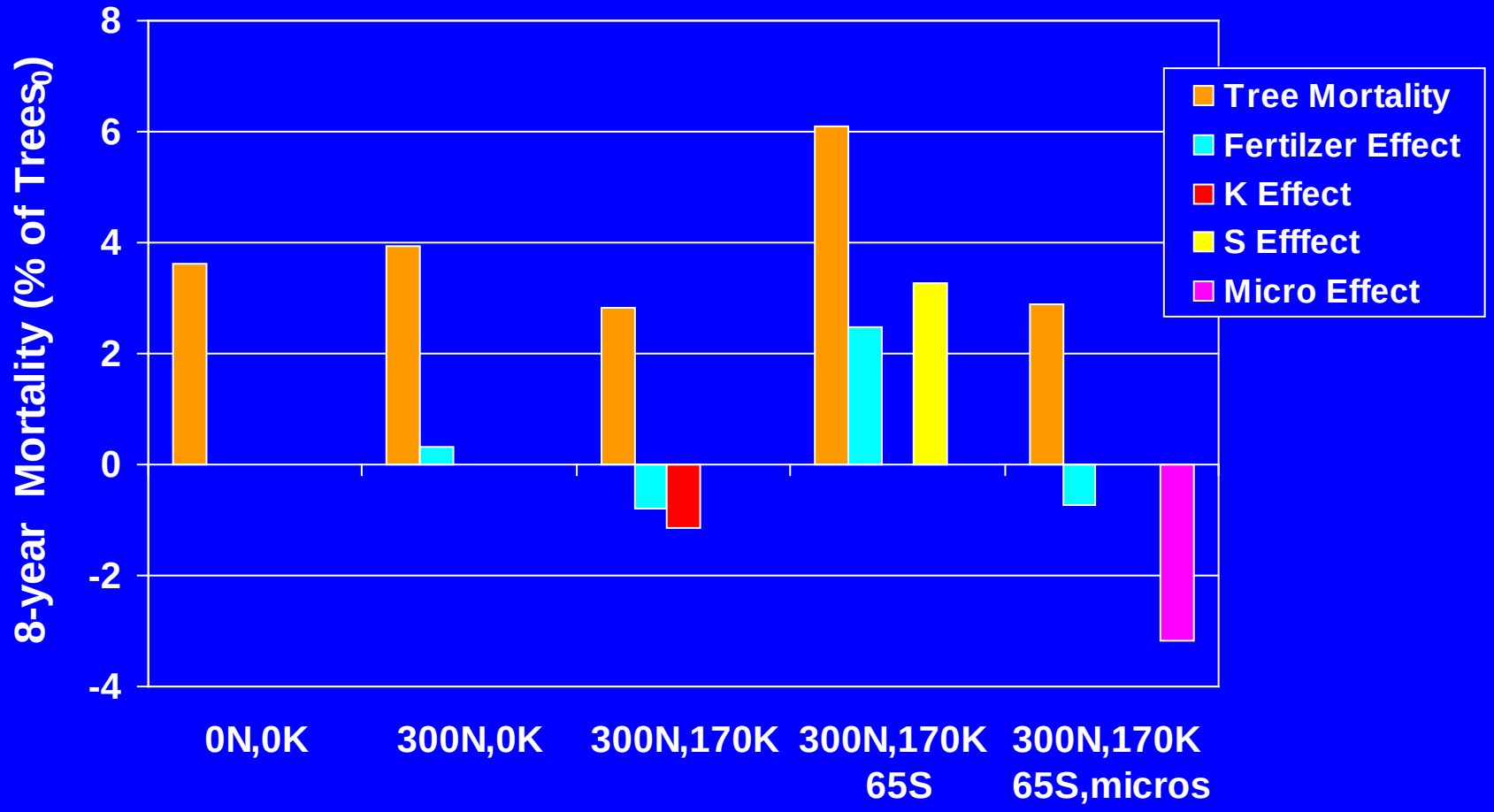
Graphed response = mortality as a % of initial BA

$$= e^{(LPMBA + \sigma^2/2)} - 1$$

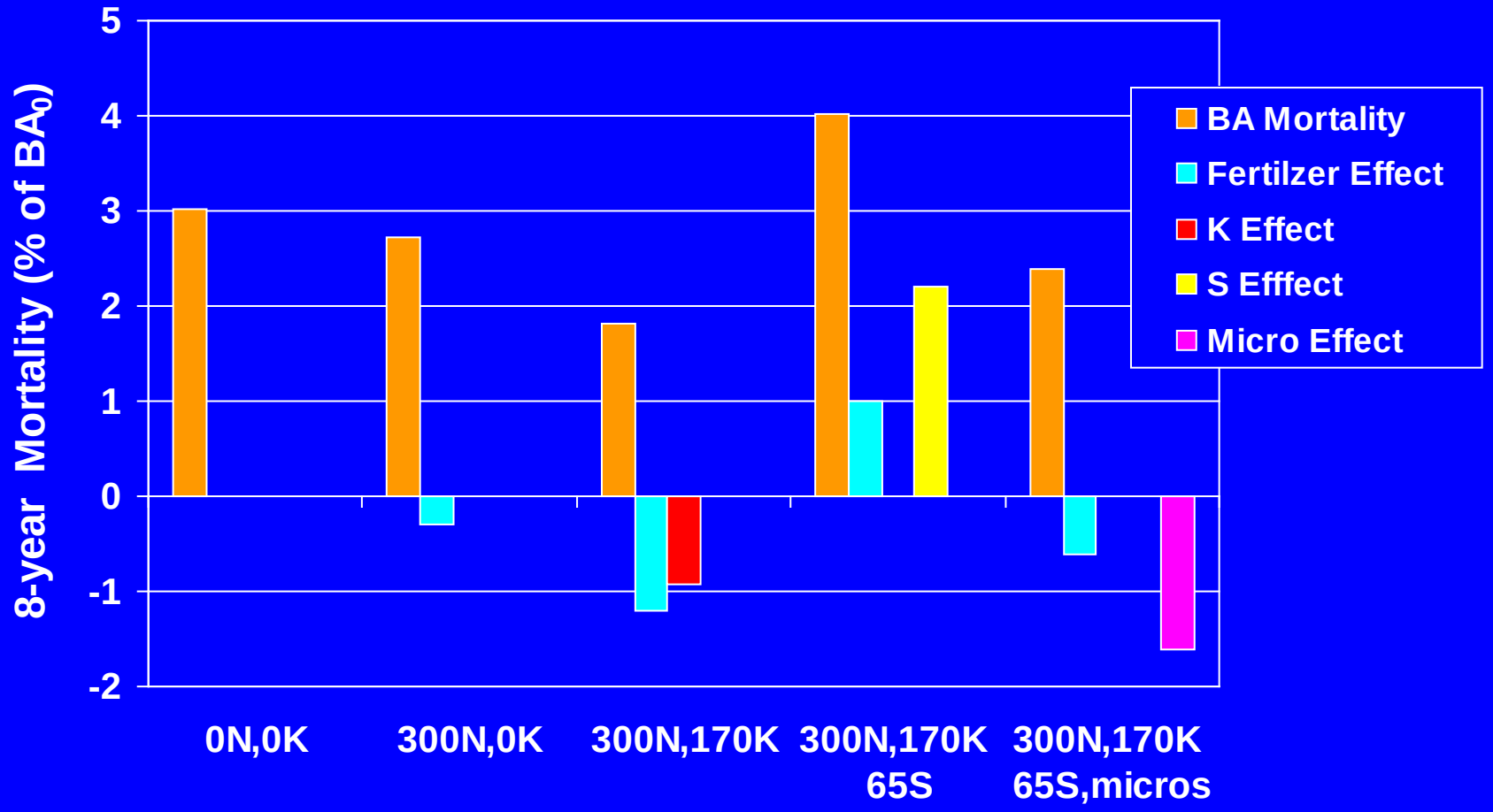
Sulfur and micronutrients: effects on 8-year Tree Mortality



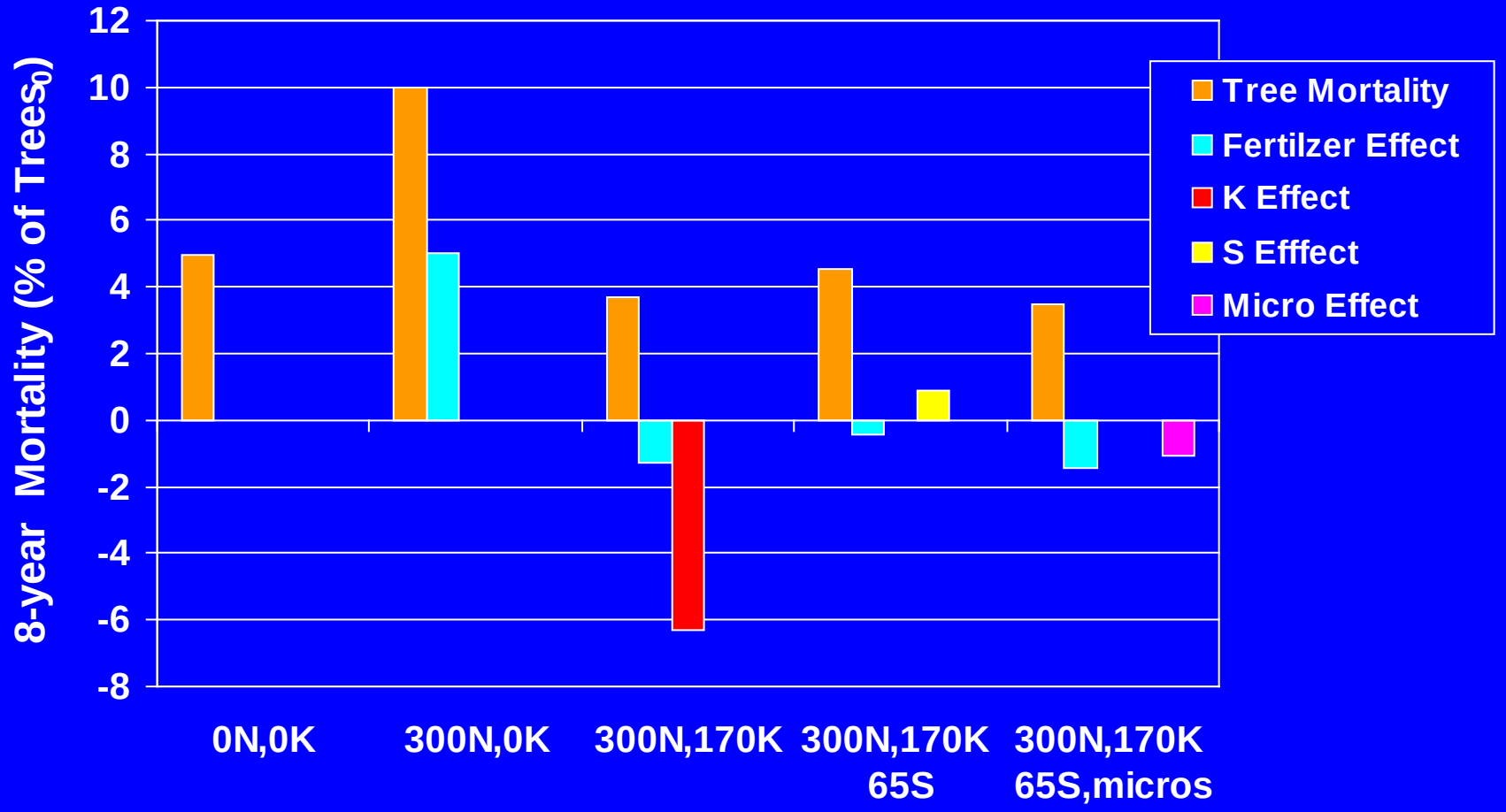
Sulfur and Micronutrients Effects: 8-year Tree Mortality — Douglas-Fir



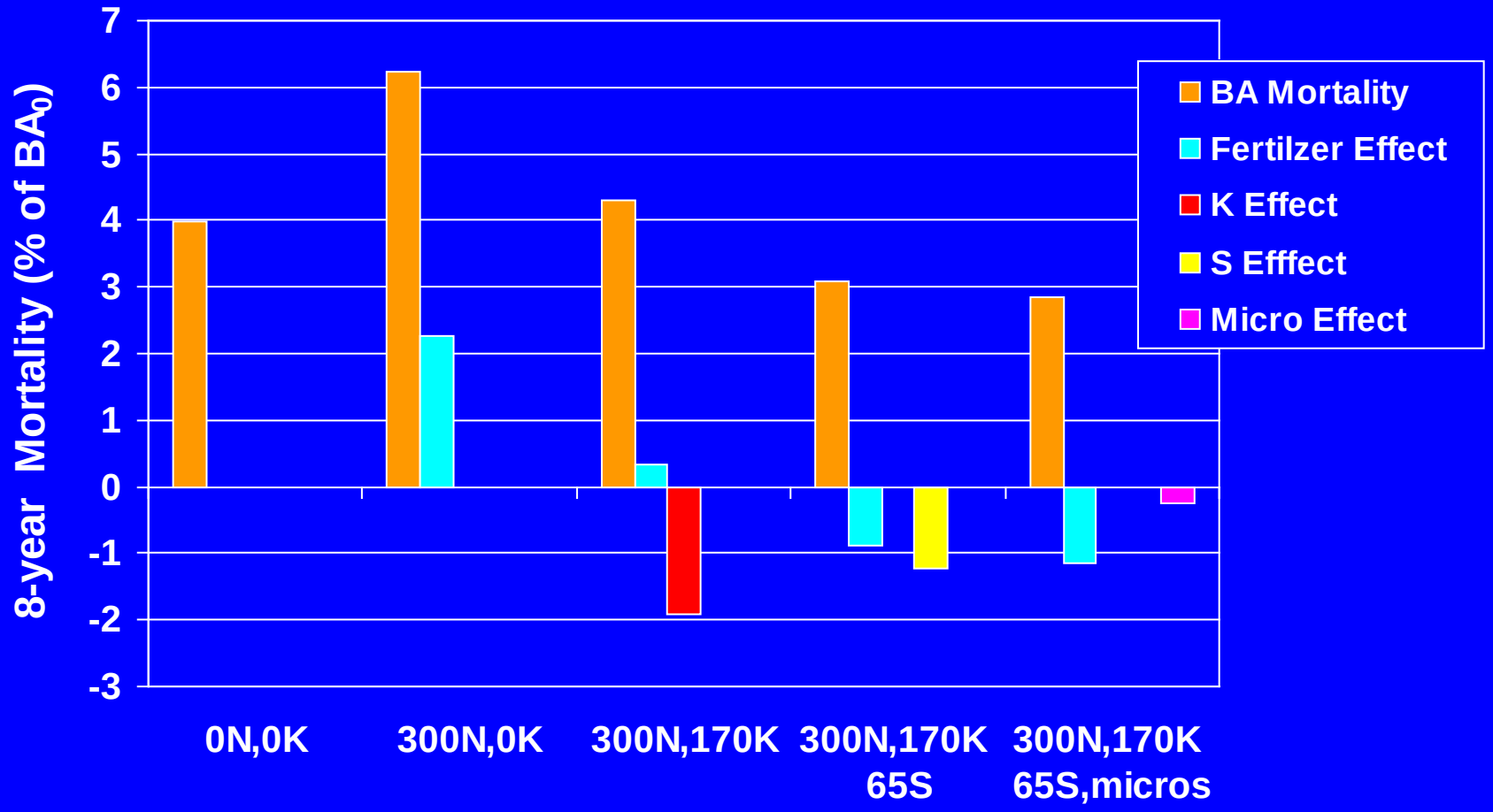
Sulfur and Micronutrients Effects: 8-year BA Mortality — Douglas-Fir



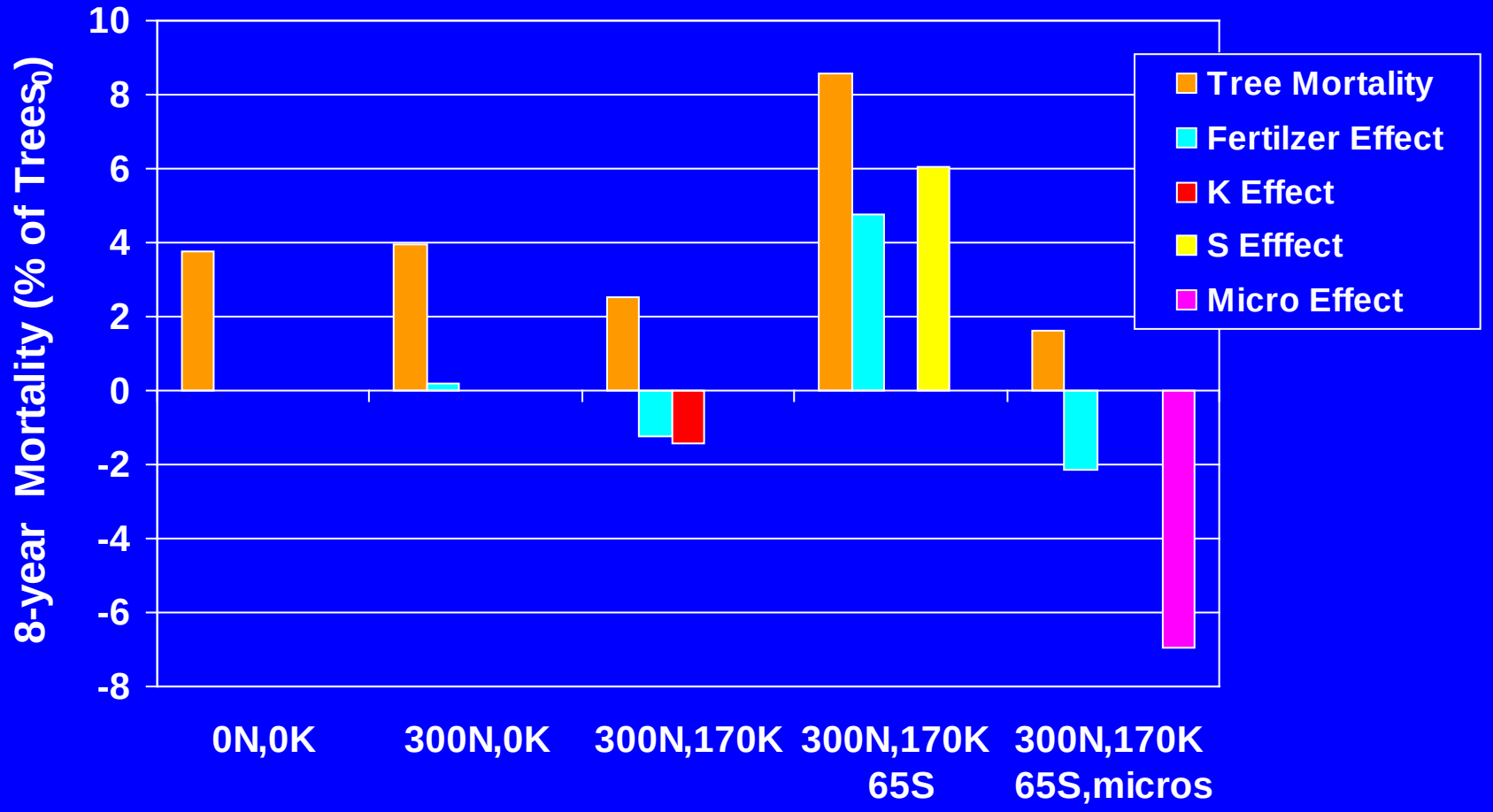
Sulfur and Micronutrients Effects: 8-year Tree Mortality — Grand Fir



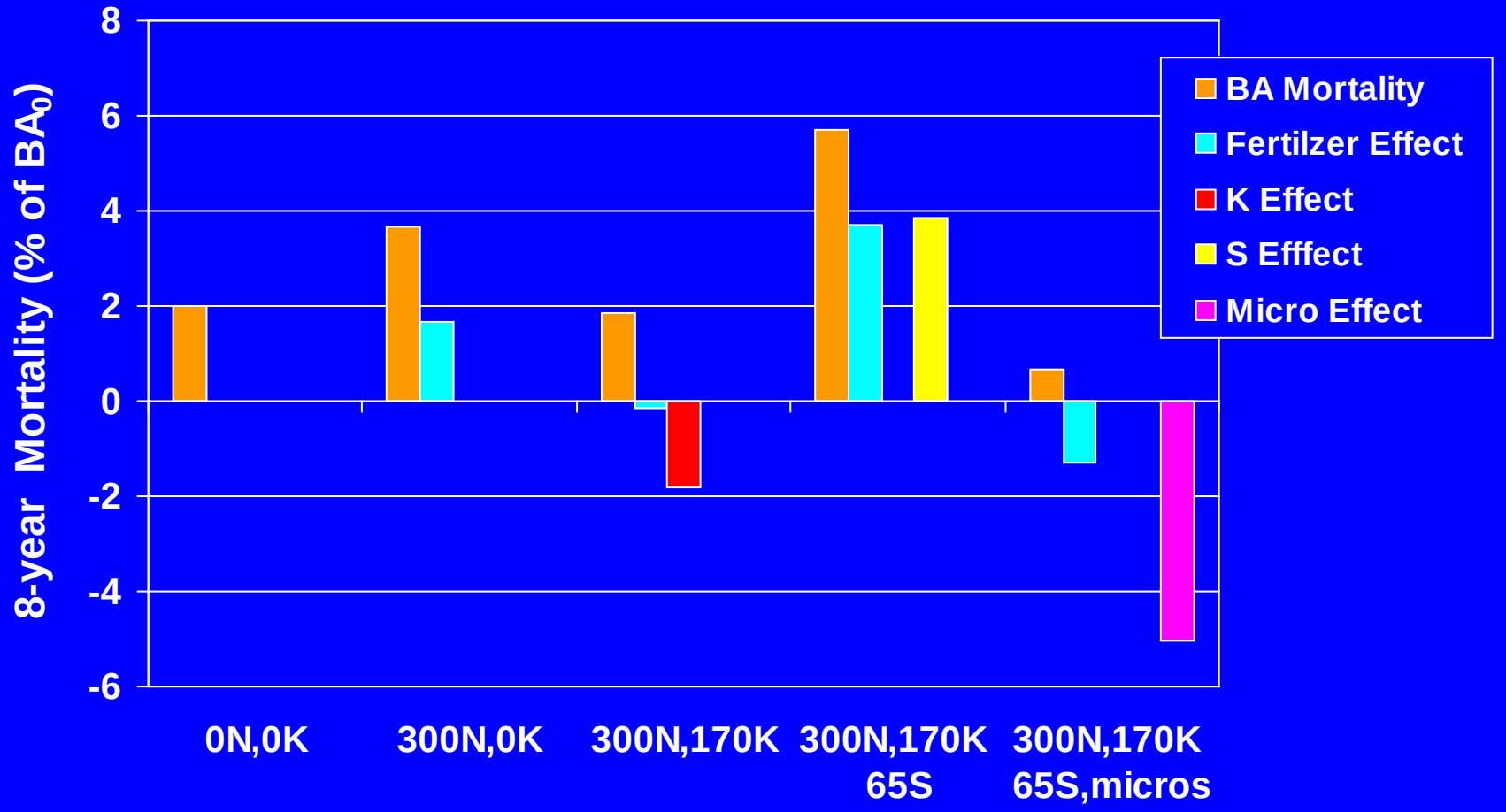
Sulfur and Micronutrients Effects: 8-year BA Mortality — Grand Fir



Sulfur and Micronutrients Effects: 8-year Tree Mortality — Ponderosa Pine



Sulfur and Micronutrients Effects: 8-year BA Mortality — Ponderosa Pine



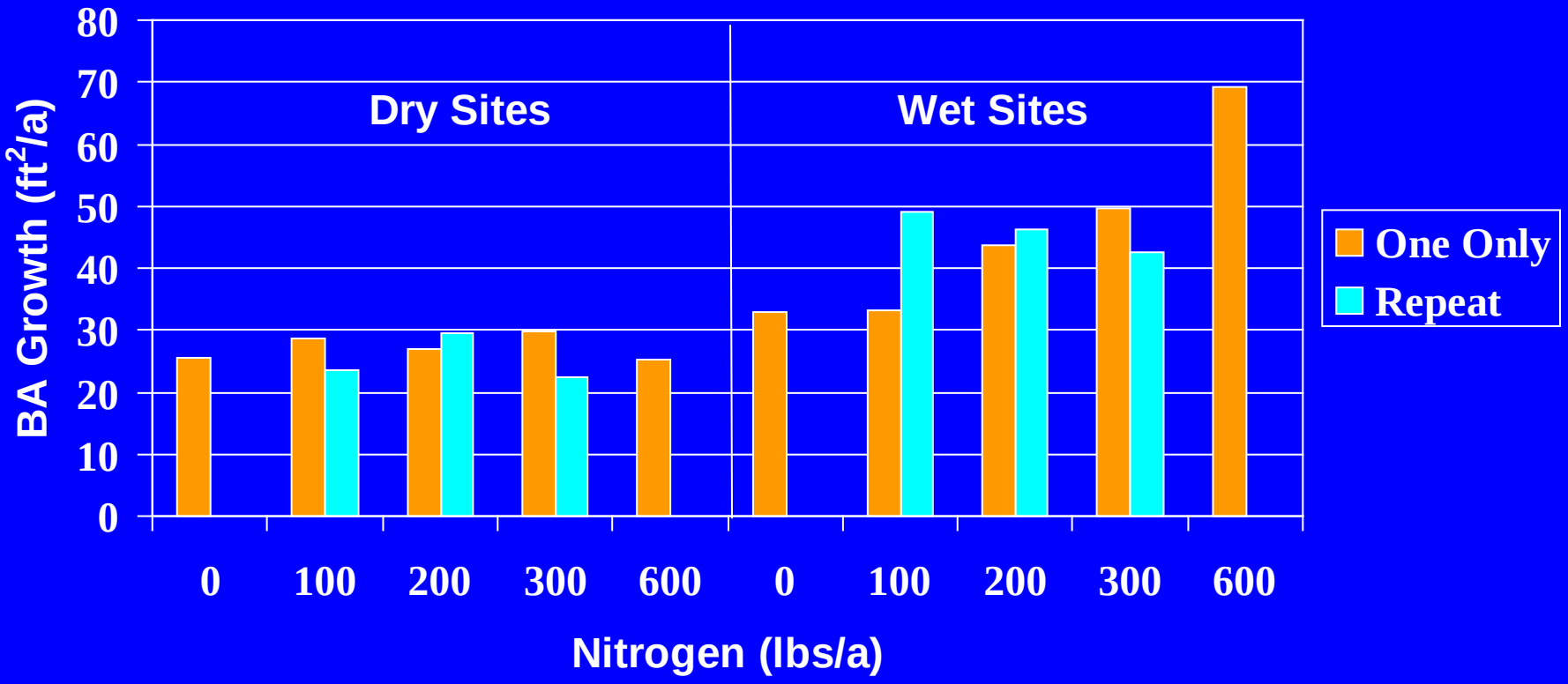
Summary of Results: Mortality

- Response was proportionate to N rate at lower rates, but increases declined at N rates above 300 lbs./a for DF. For GF response was fairly linear. PP behavior was intermediate.
- K fertilizer additions appeared to decrease mortality in GF and PP; results for DF are unclear. In GF this effect appears to predominantly involve smaller trees, while in PP this involves larger trees.
- SO_4 increased mortality in DF and PP, but not in GF.
- Micronutrients lowered mortality in PP and DF, but not in GF.

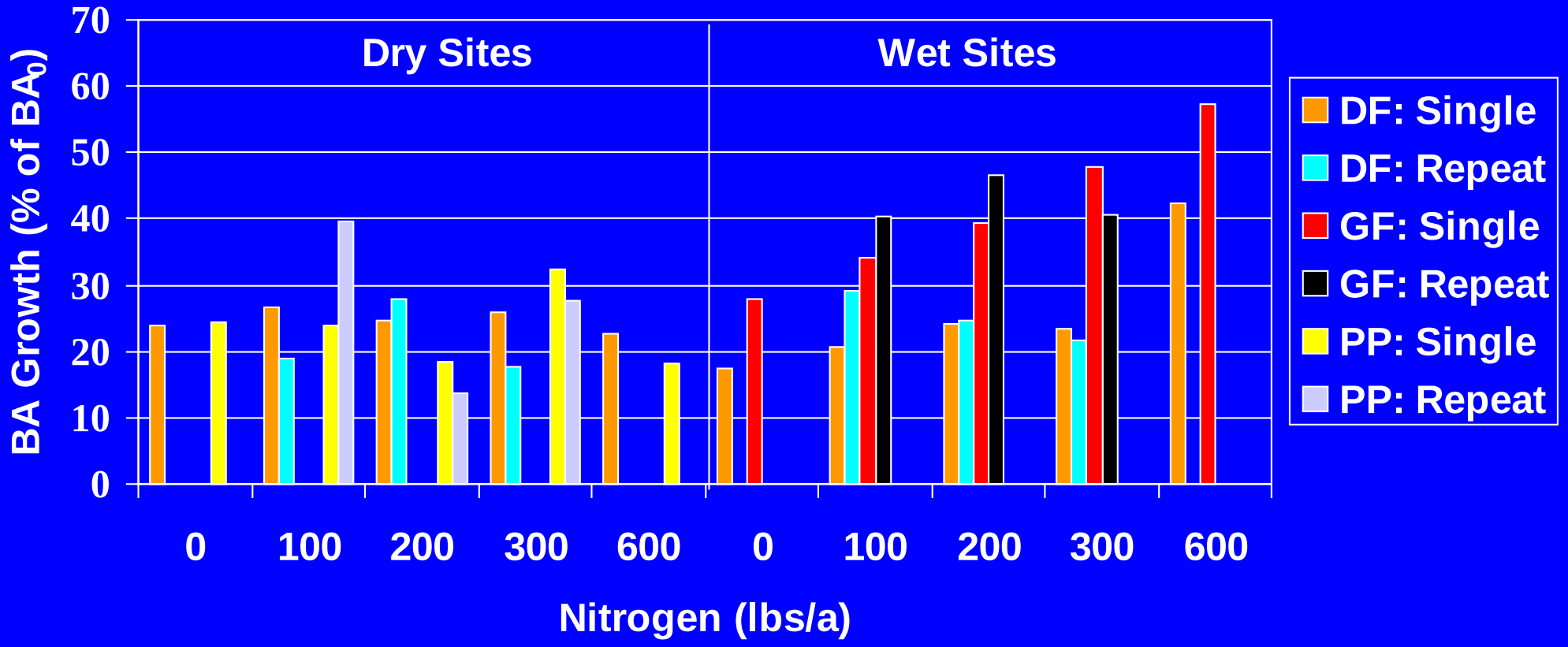
Effects of Repeated N Applications

- 4 sites (2 DF/Basalt, 2 WRC-WH/Basalt)
- Repeat of 100, 200, or 300 lbs N/a application at 4 years on one set of plots and at 8 years on another set
- Analysis limited to those plots without any K application

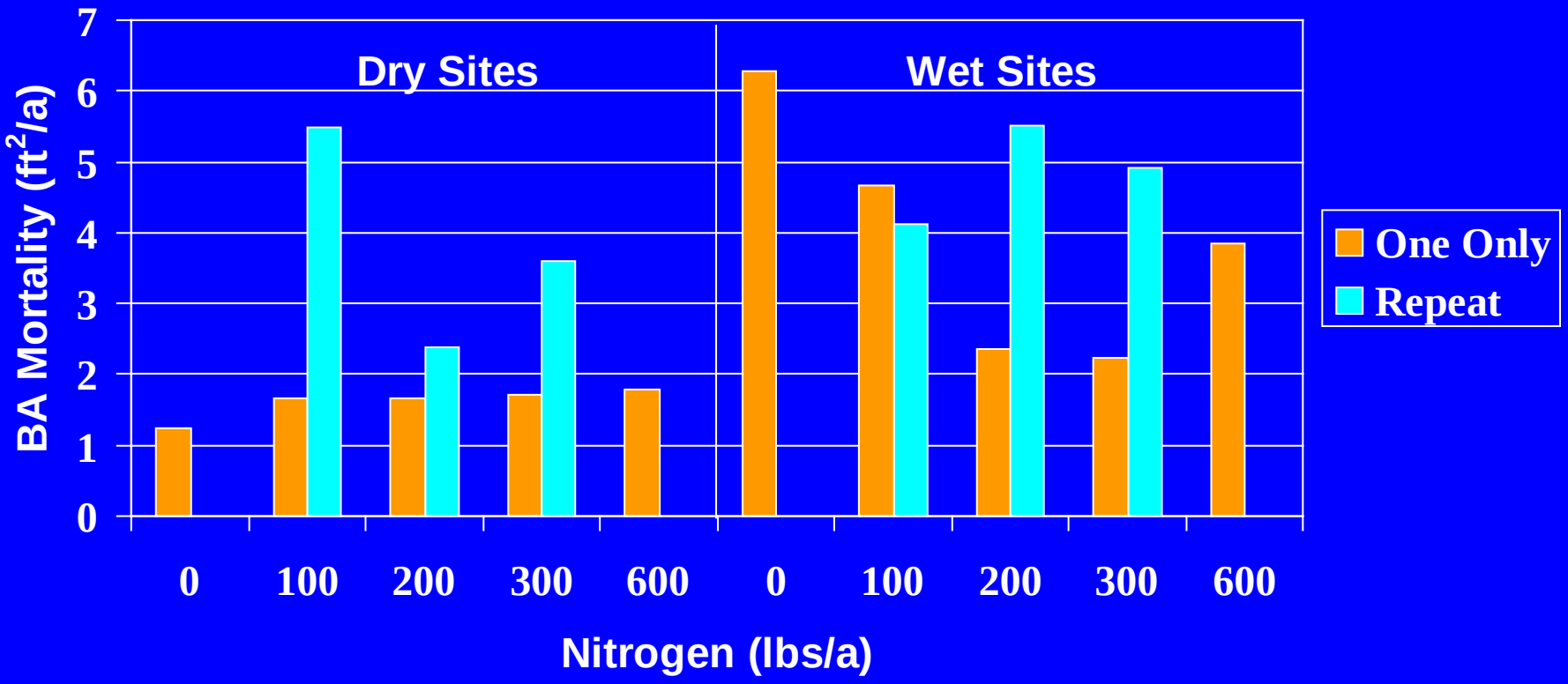
Repeated N Application Effects: 8-year BA Growth



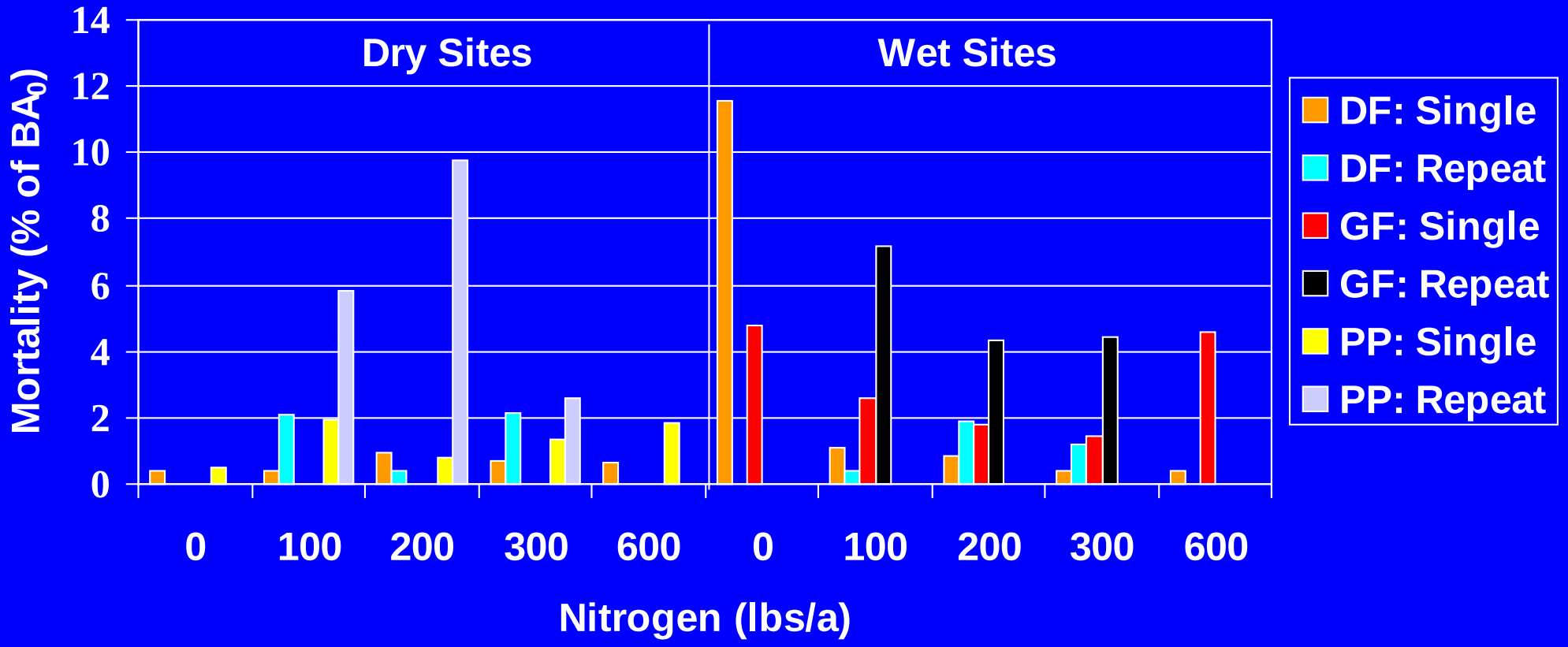
Repeated N Application Effects: 8-year BA Growth by Species



Repeated N Application Effects: 8-year BA Mortality



Repeated N Application Effects: 8-year BA Mortality by Species

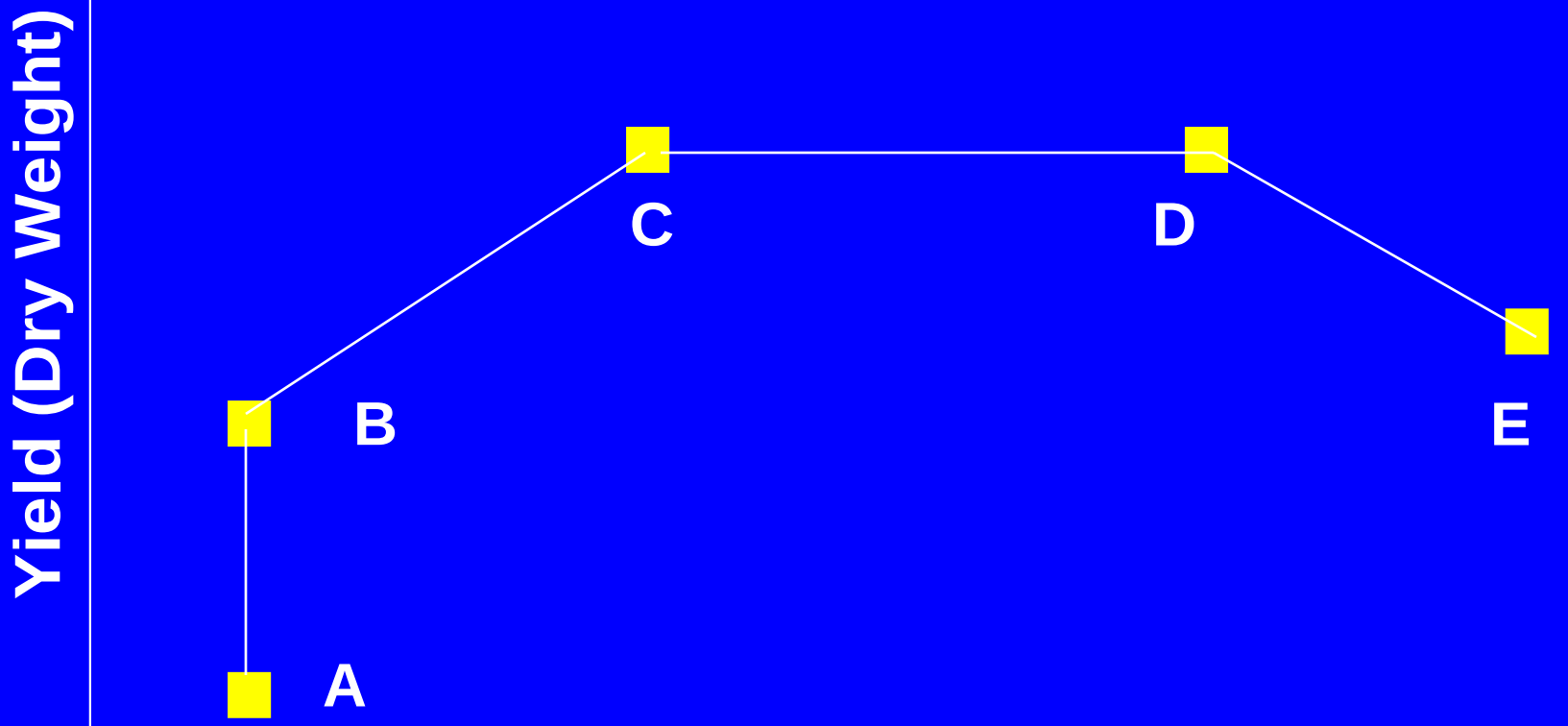


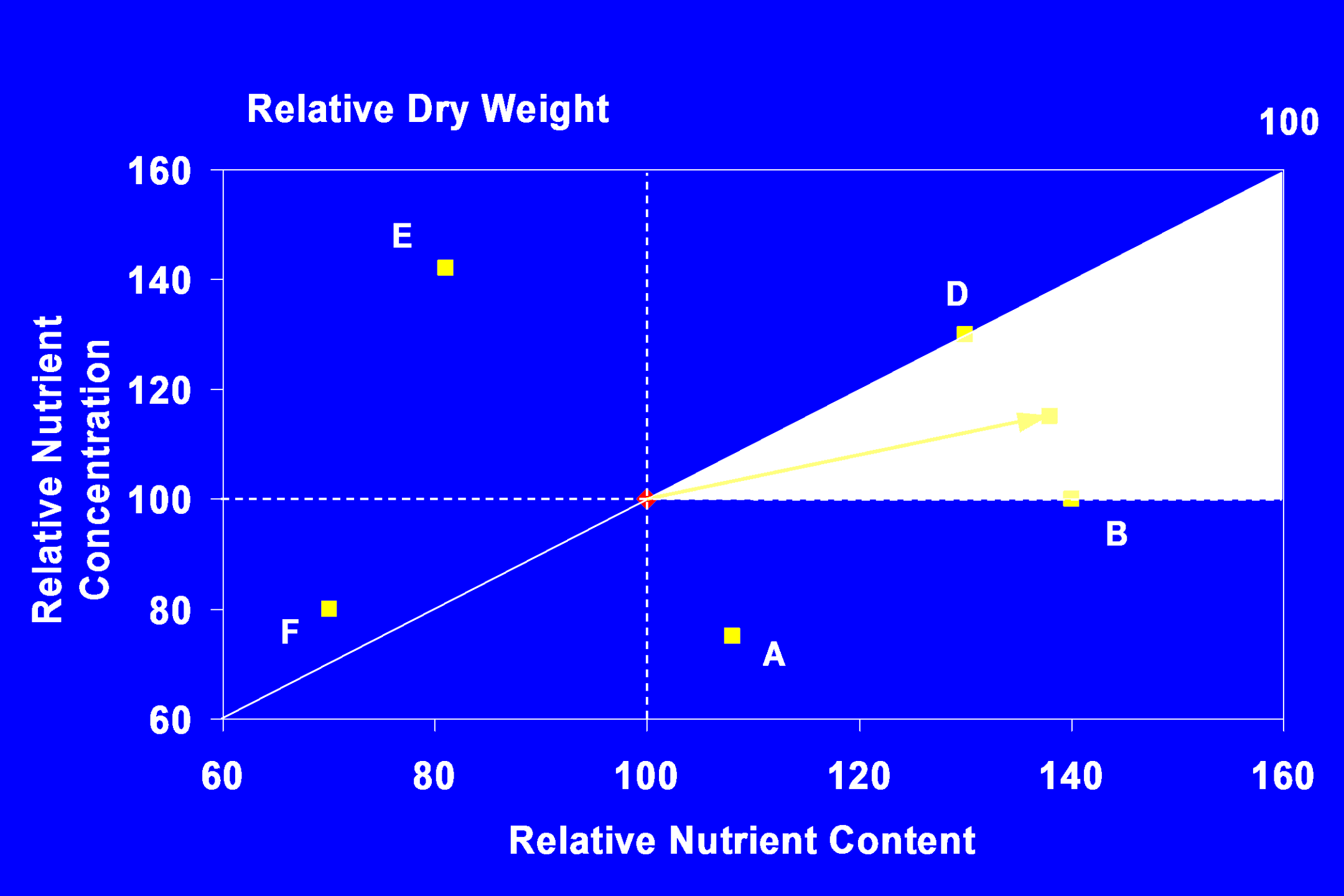
Summary: Repeated N Application Effects

- On the dry sites, most N treatments failed to produce any growth response in either DF or PP.
- On wet sites, both GF and DF increased in growth with increasing N application.
- Reapplication of N at 4 years did increase growth response, but only on wet sites and at low N rates (100 to 200 lbs/a). Reapplication of higher N rates did not produce additional response.
- Reapplication increased mortality on both wet and dry sites. While mortality on dry sites increased with all reapplication rates, on wet sites only the higher N reapplication rates produced higher mortality in DF

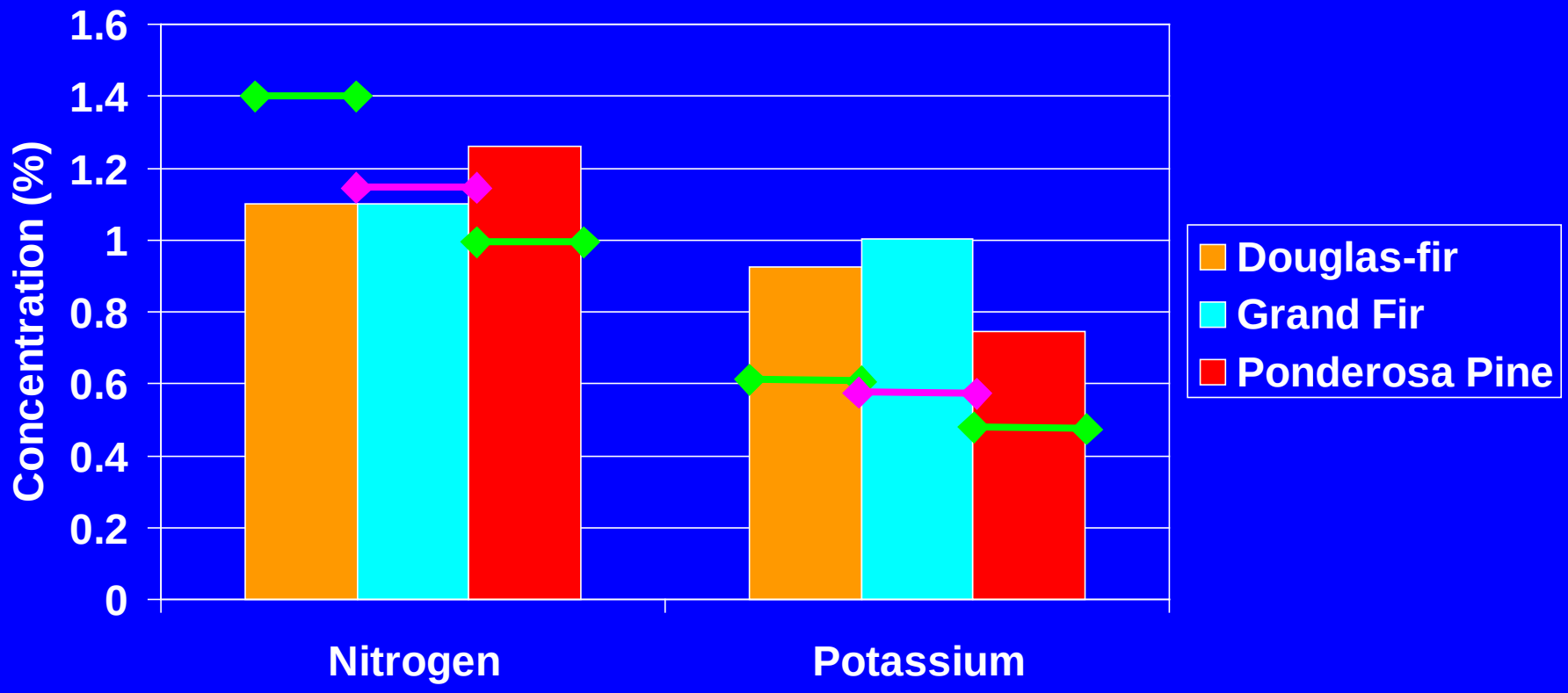
Yield Curve

From Macy (1936) as adapted by Morrow (1979).

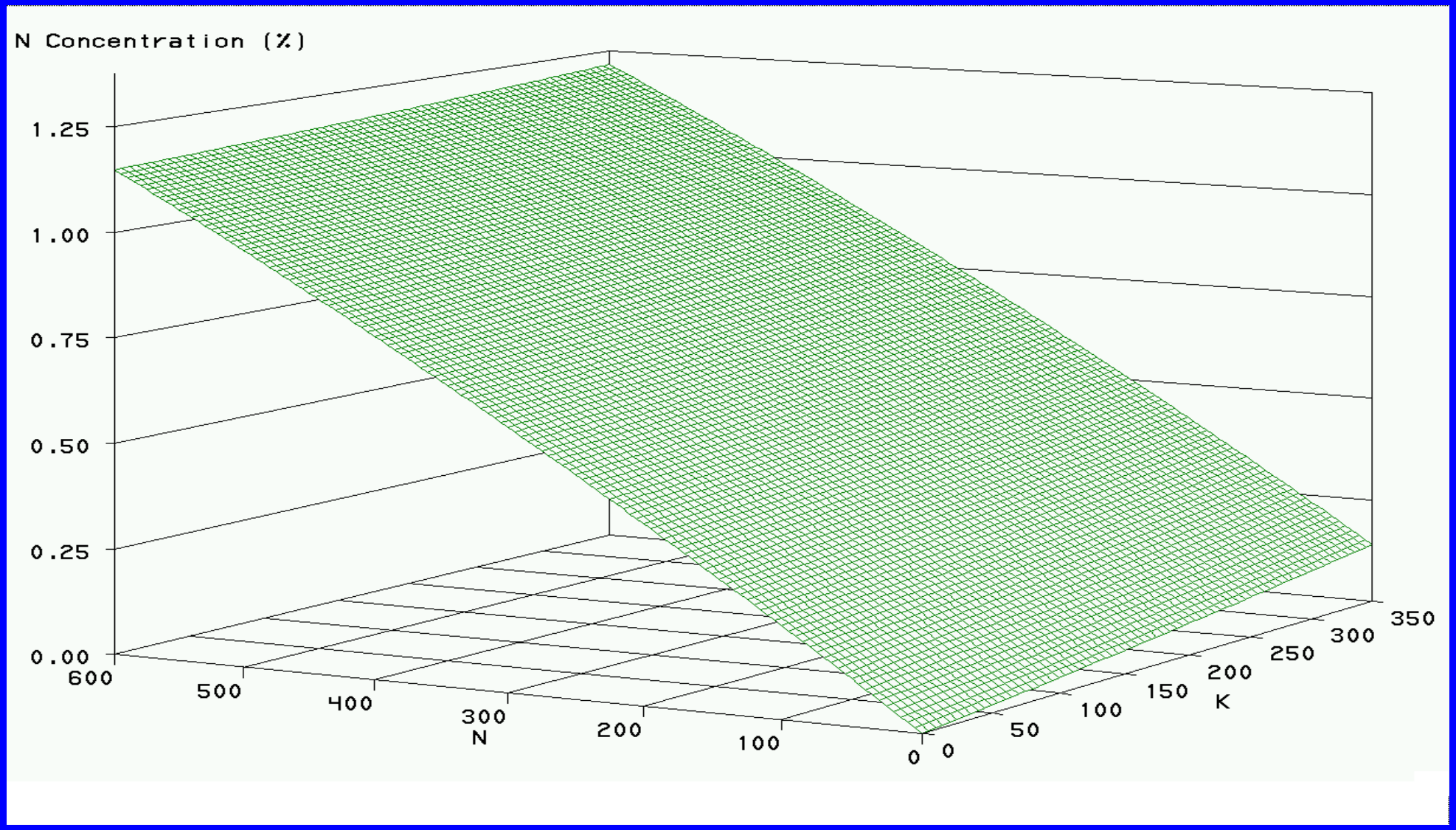



Relative Dry Weight
100
160
140
120
100
80
60
Relative Nutrient Concentration
E
D
B
F
A
60
80
100
120
140
160
Relative Nutrient Content

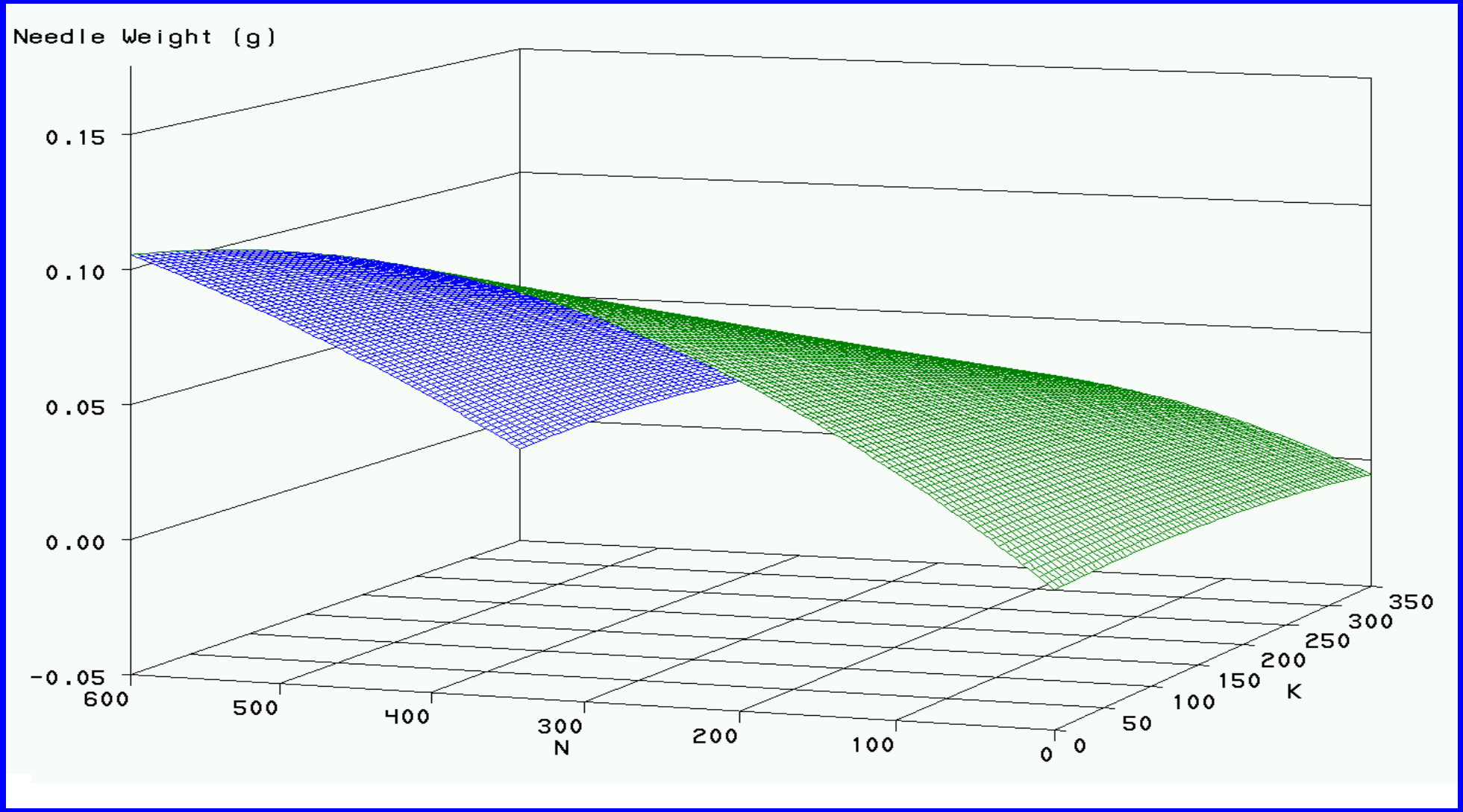
Control Plot Foliar Concentration by Species



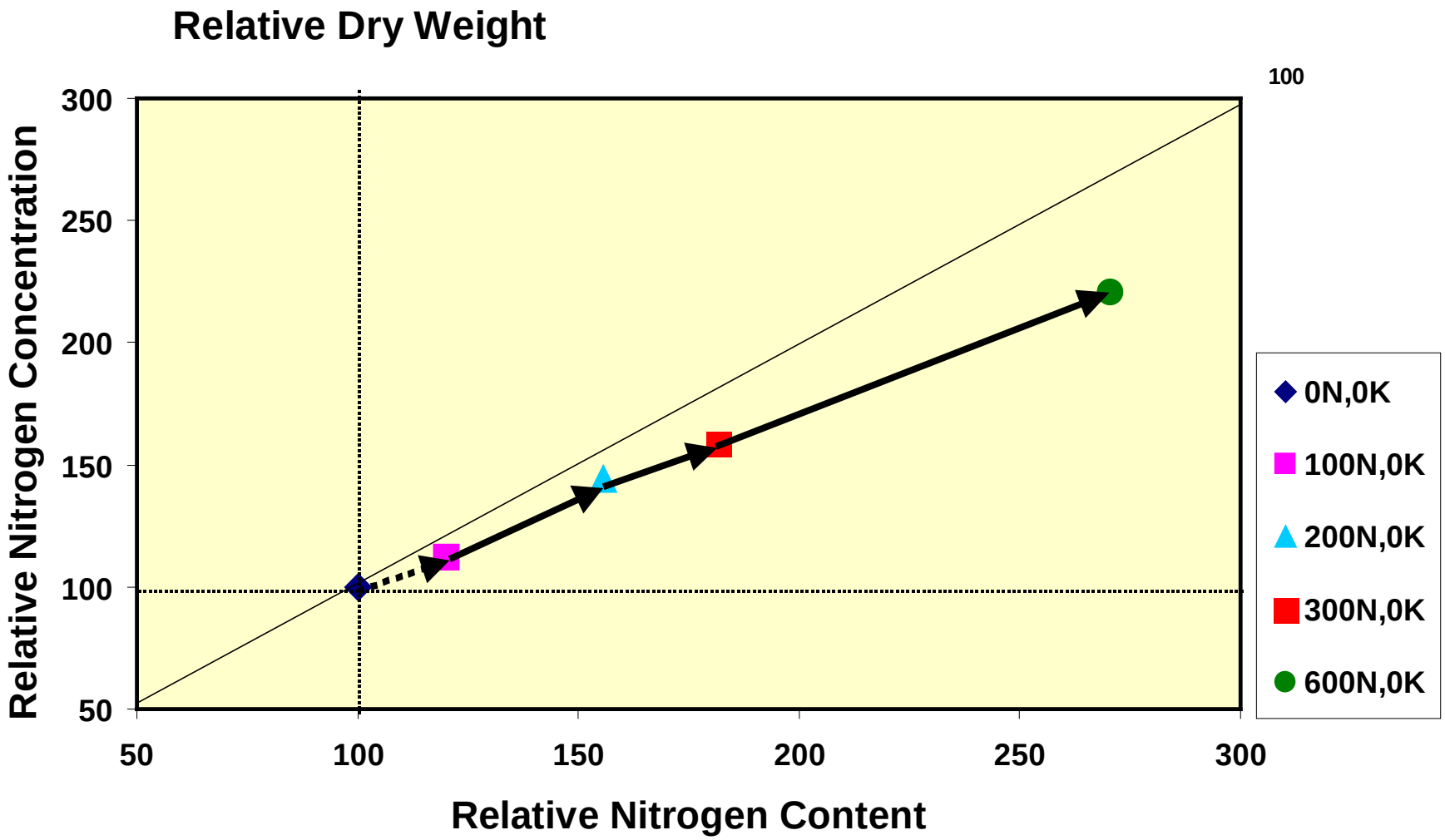
N and K Fertilizer Effects: Douglas-fir Nitrogen Concentration



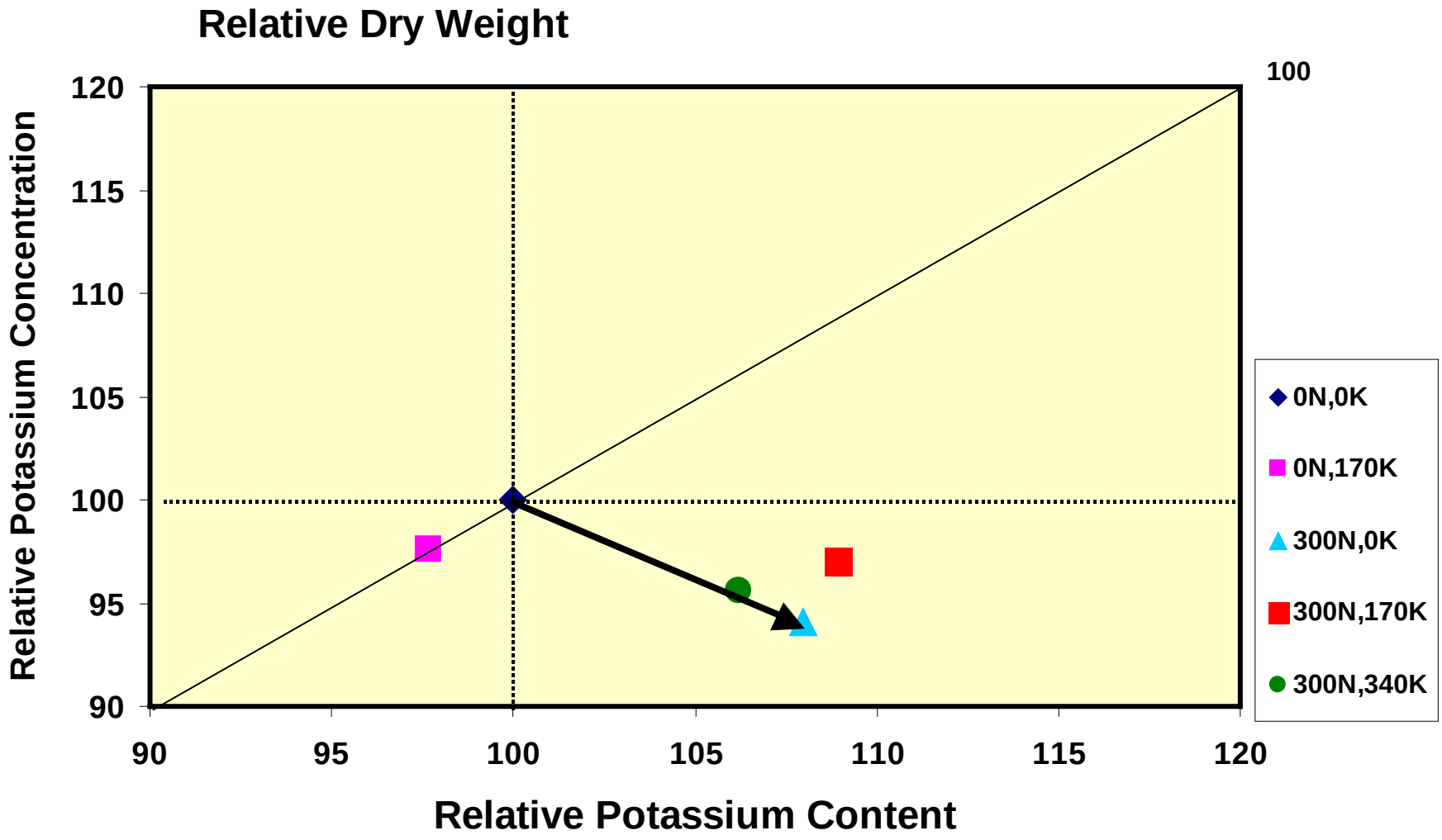
N and K Fertilizer Effects: Douglas-fir Needle Weight



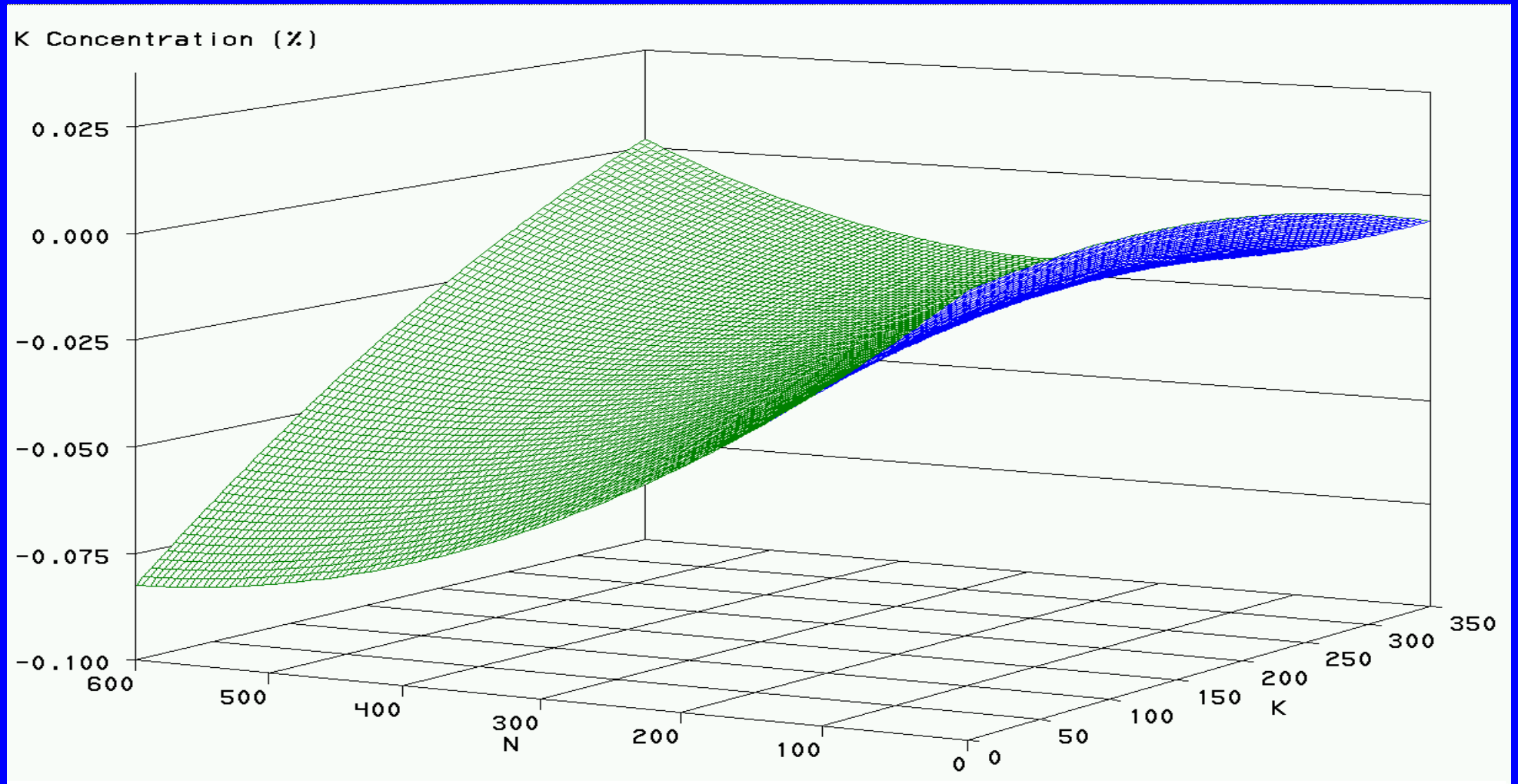
Douglas-fir: All Rock Types



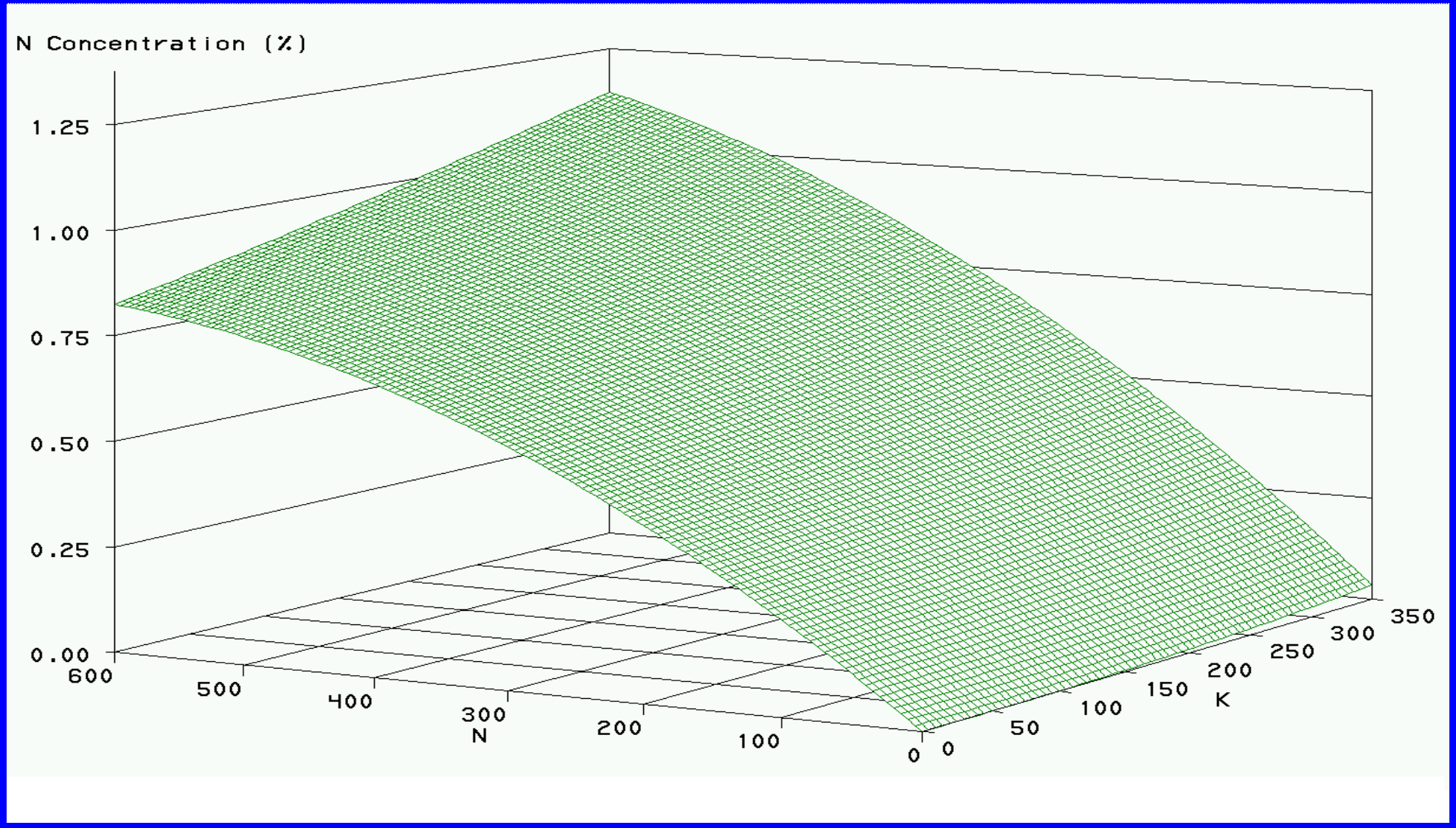
Douglas-fir: All Rock Types



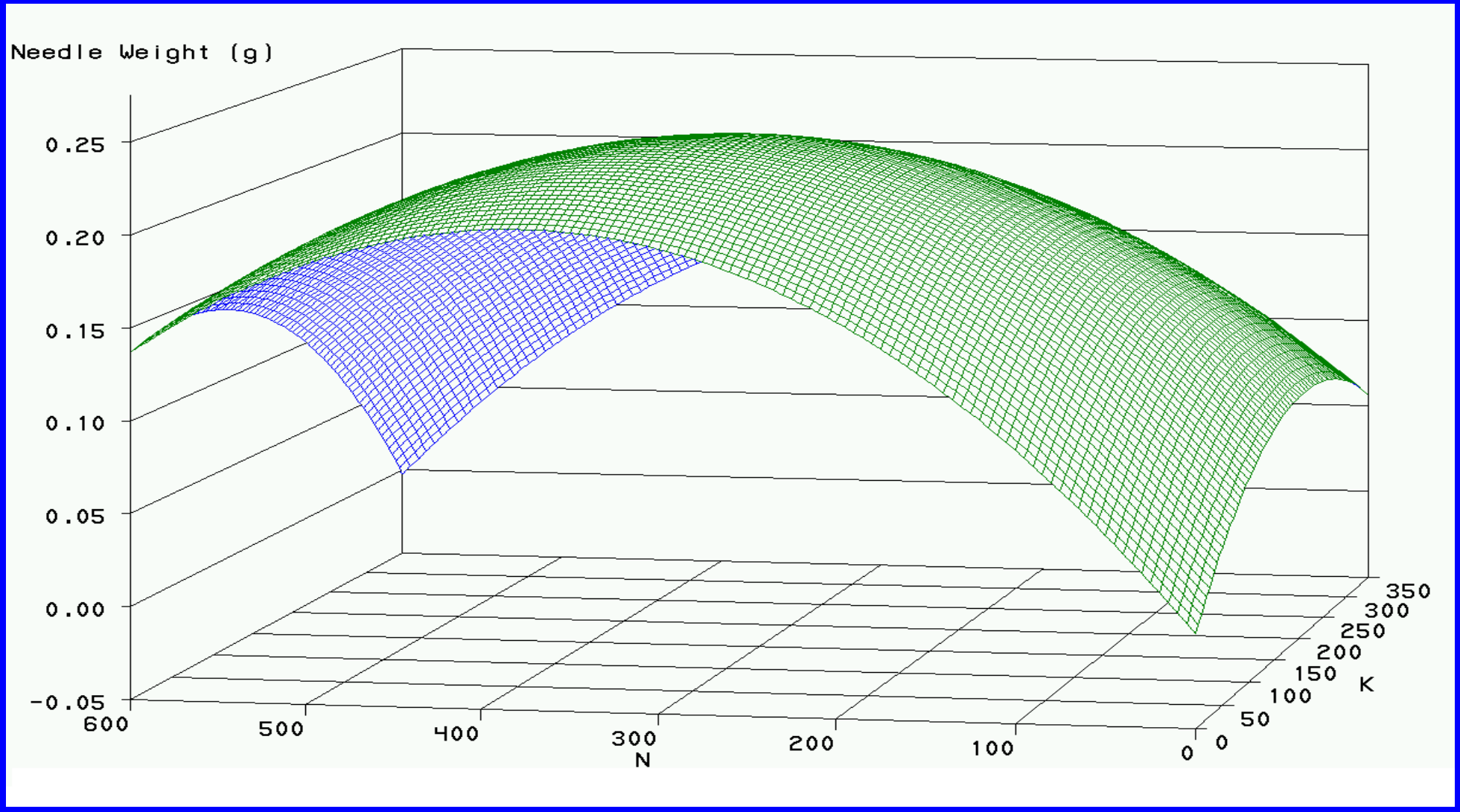
N and K Fertilizer Effects: Douglas-fir Potassium Concentration



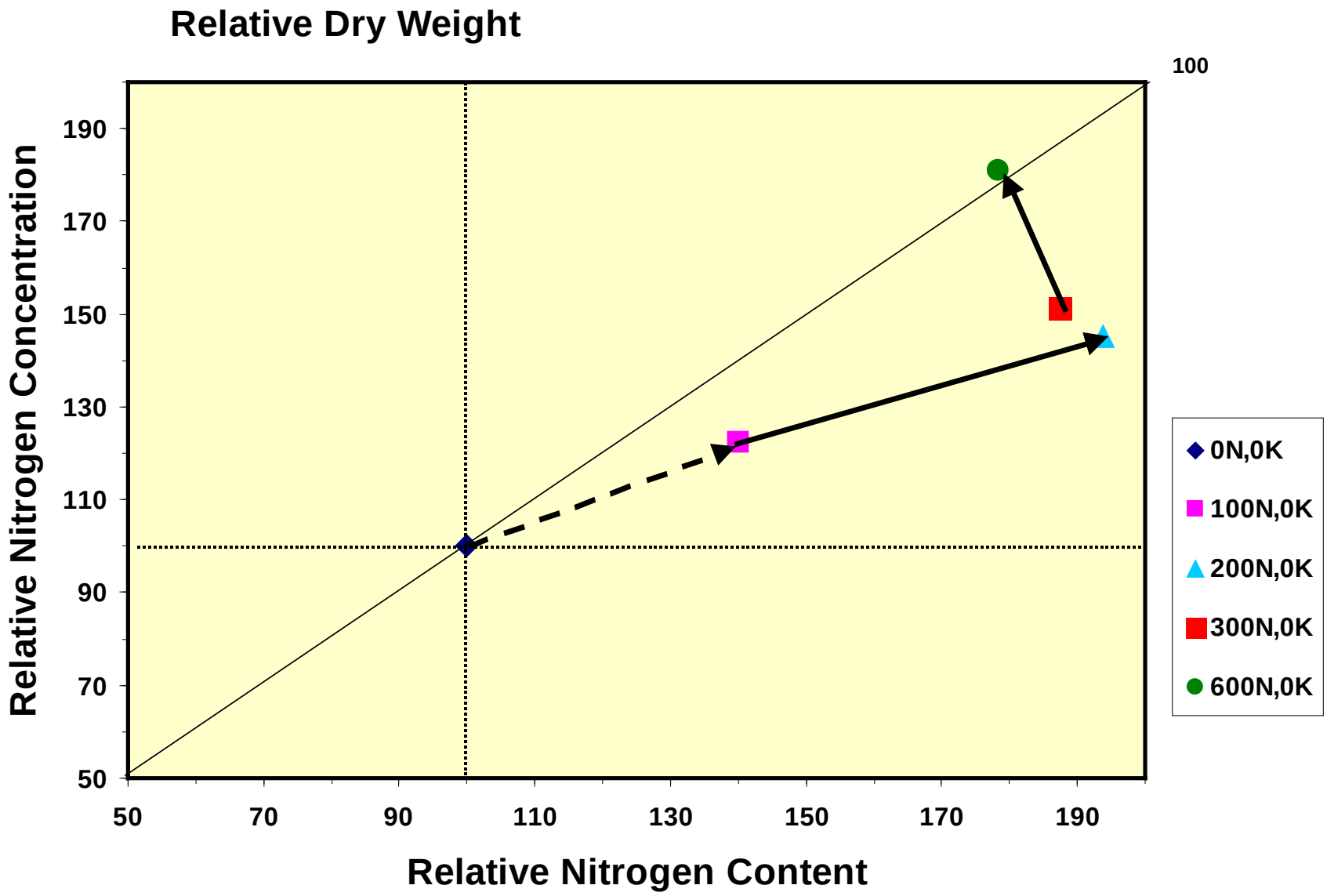
N and K Fertilizer Effects: Grand Fir Nitrogen Concentration



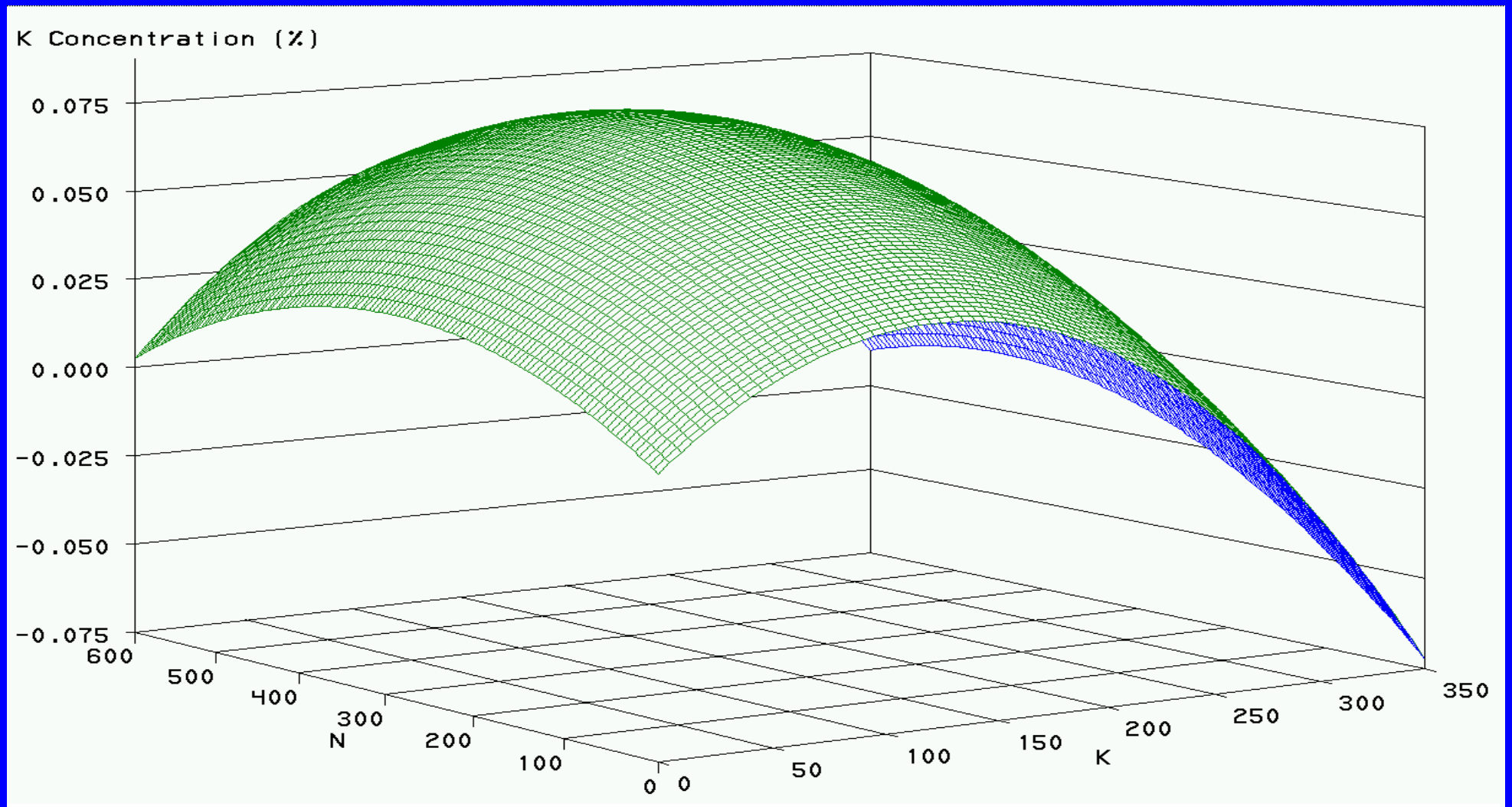
N and K Fertilizer Effects: Grand Fir Needle Weight



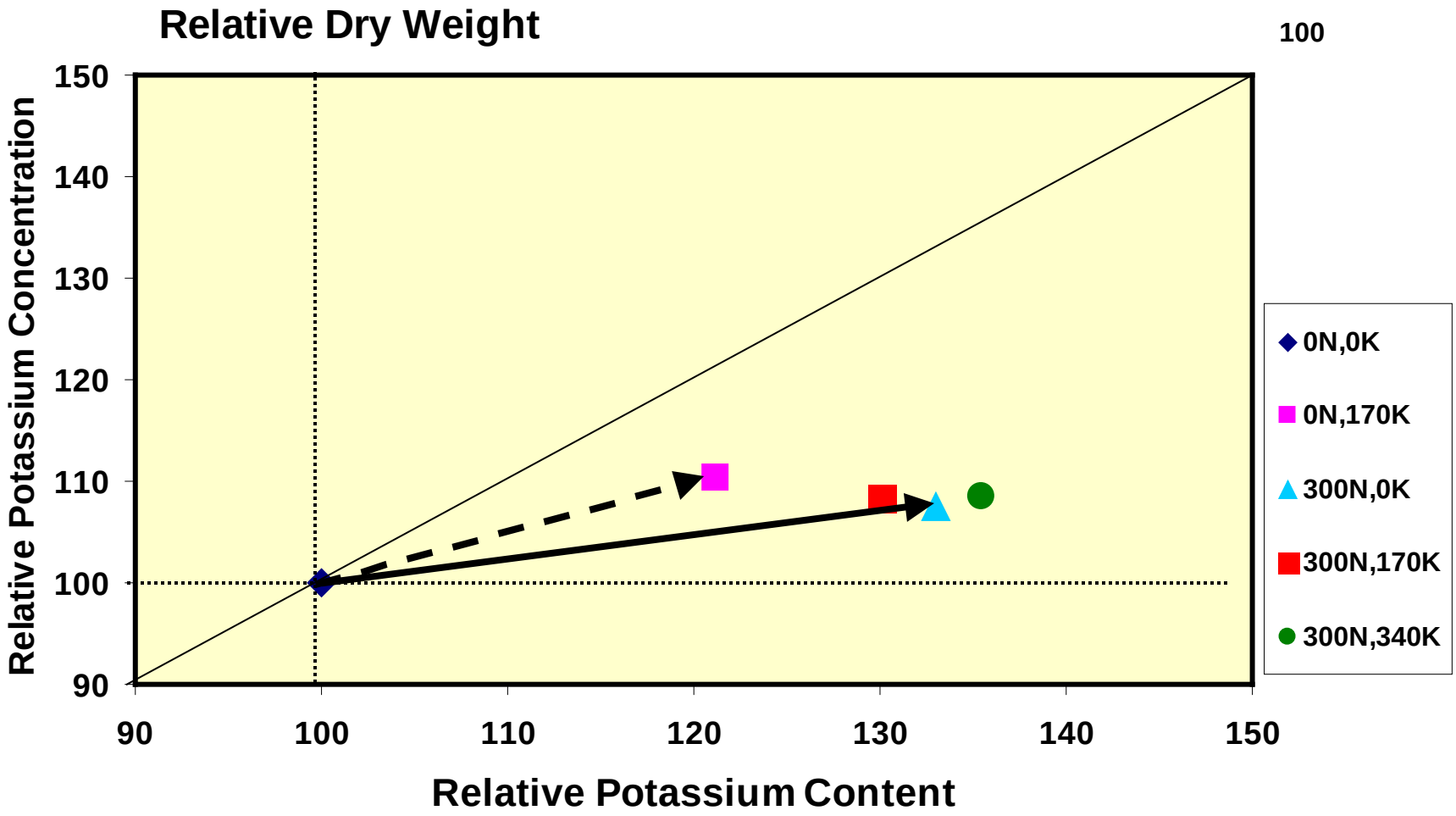
Grand fir: All Rock Types



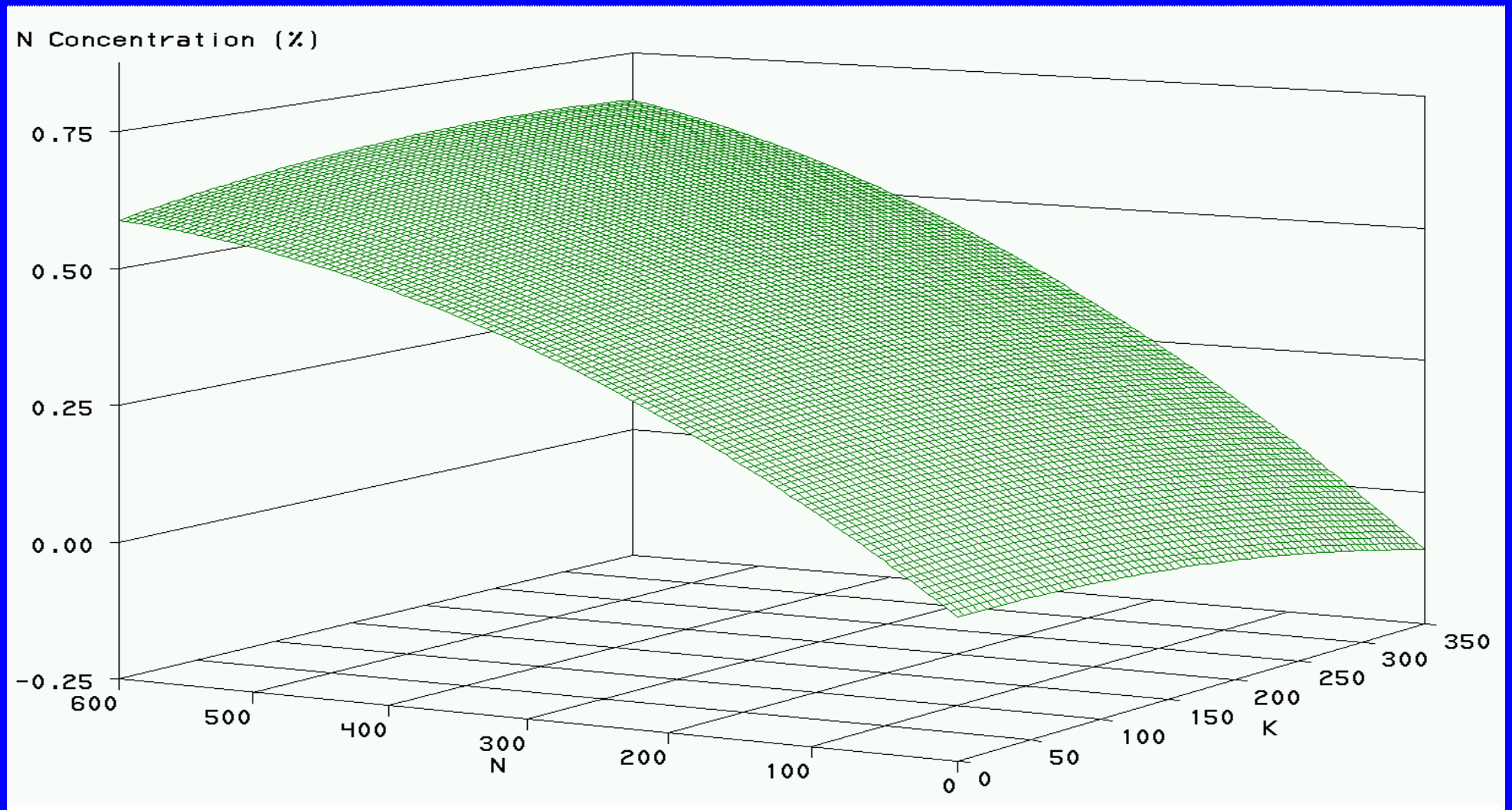
N and K Fertilizer Effects: Grand Fir Potassium Concentration



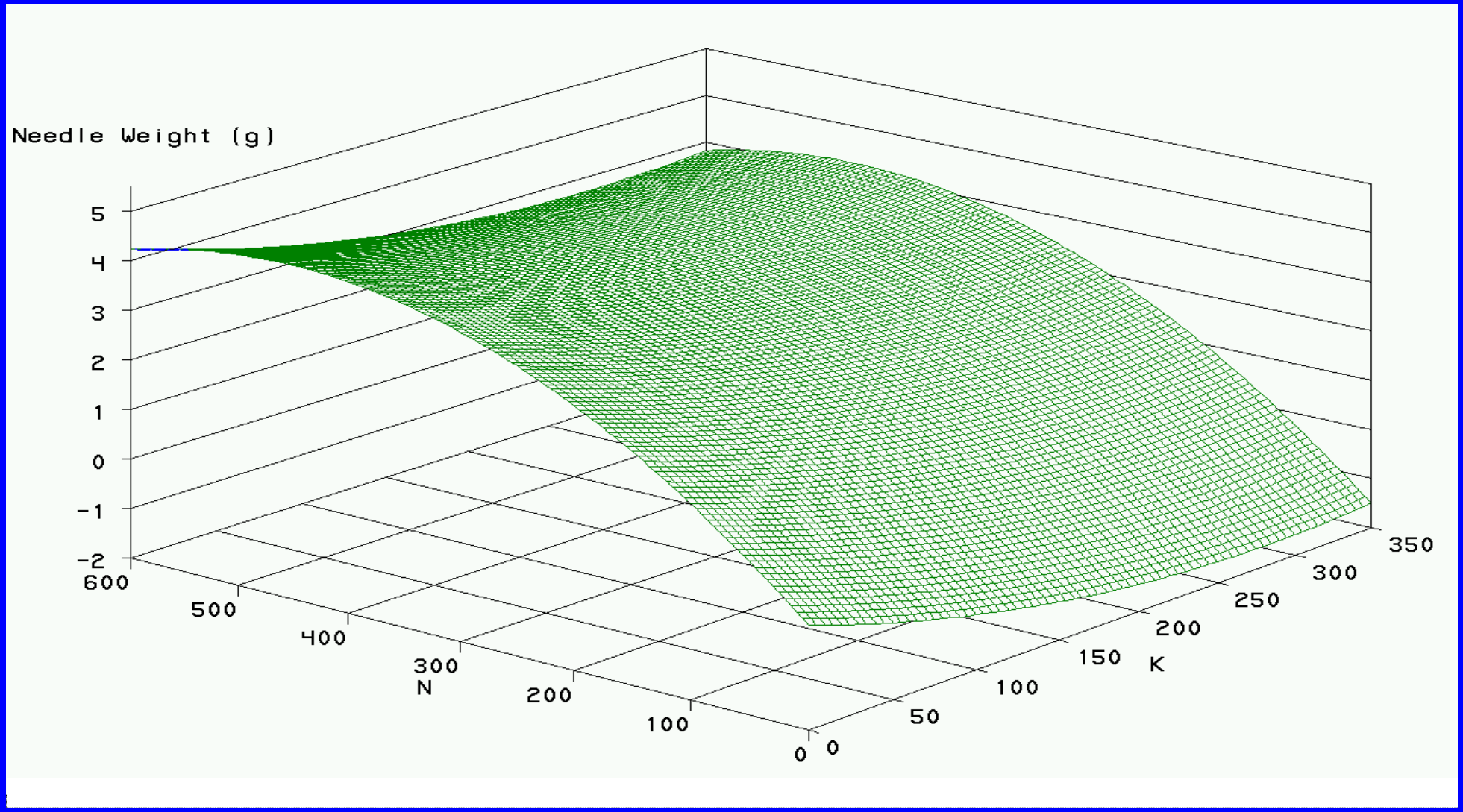
Grand fir: All Rock Types



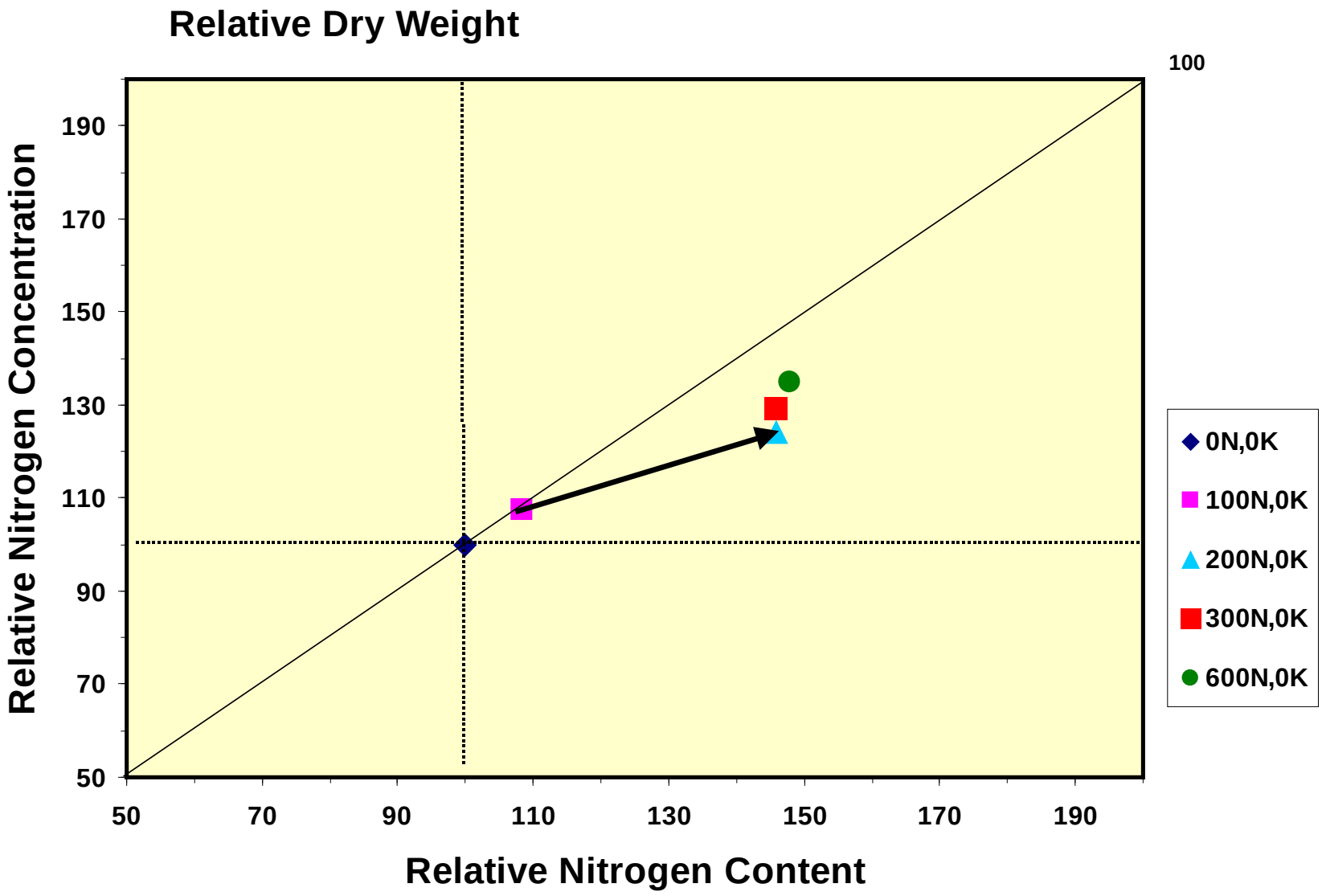
N and K Fertilizer Effects: Ponderosa Pine Nitrogen Concentration



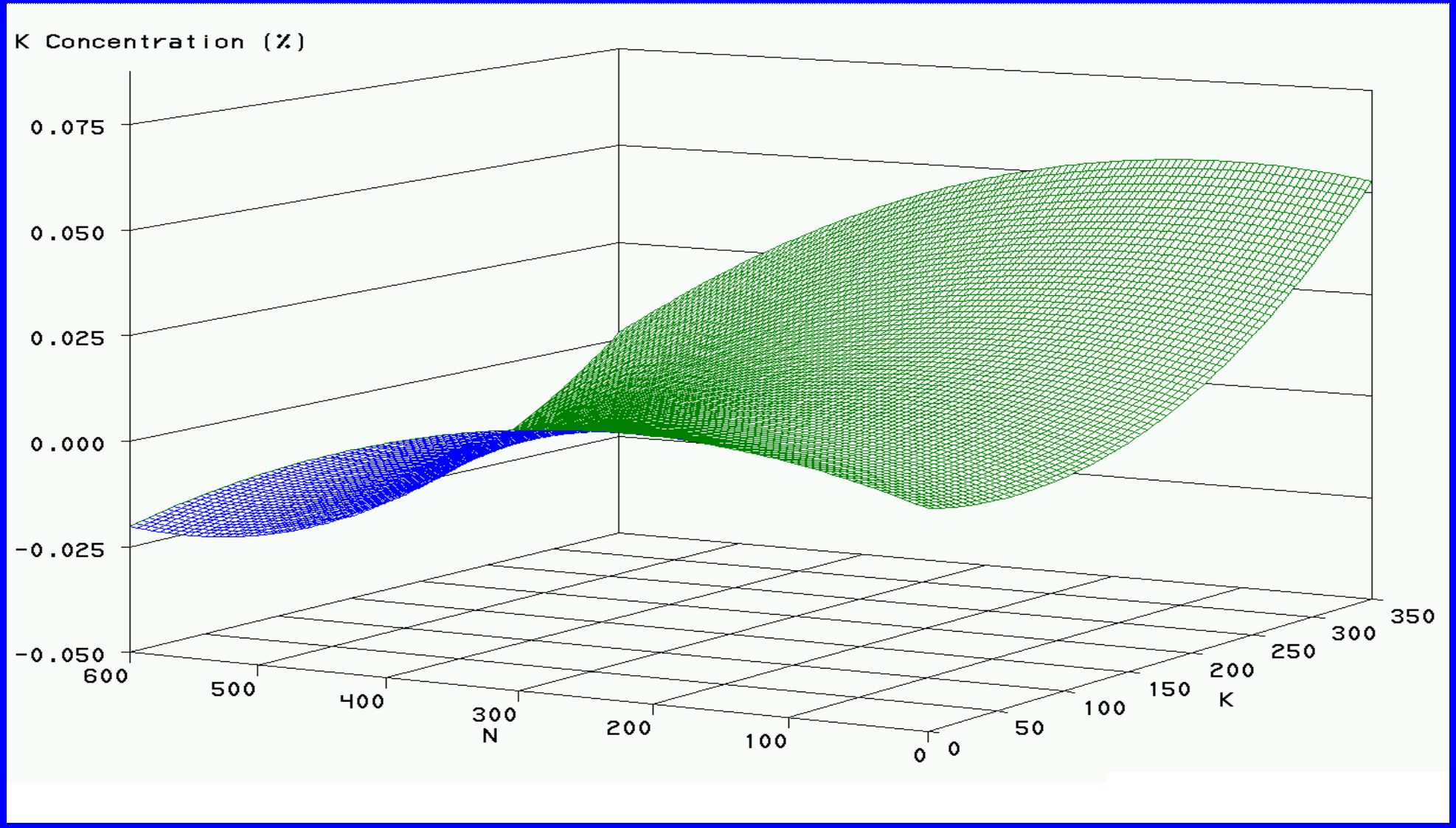
N and K Fertilizer Effects: Ponderosa Pine Needle Weight



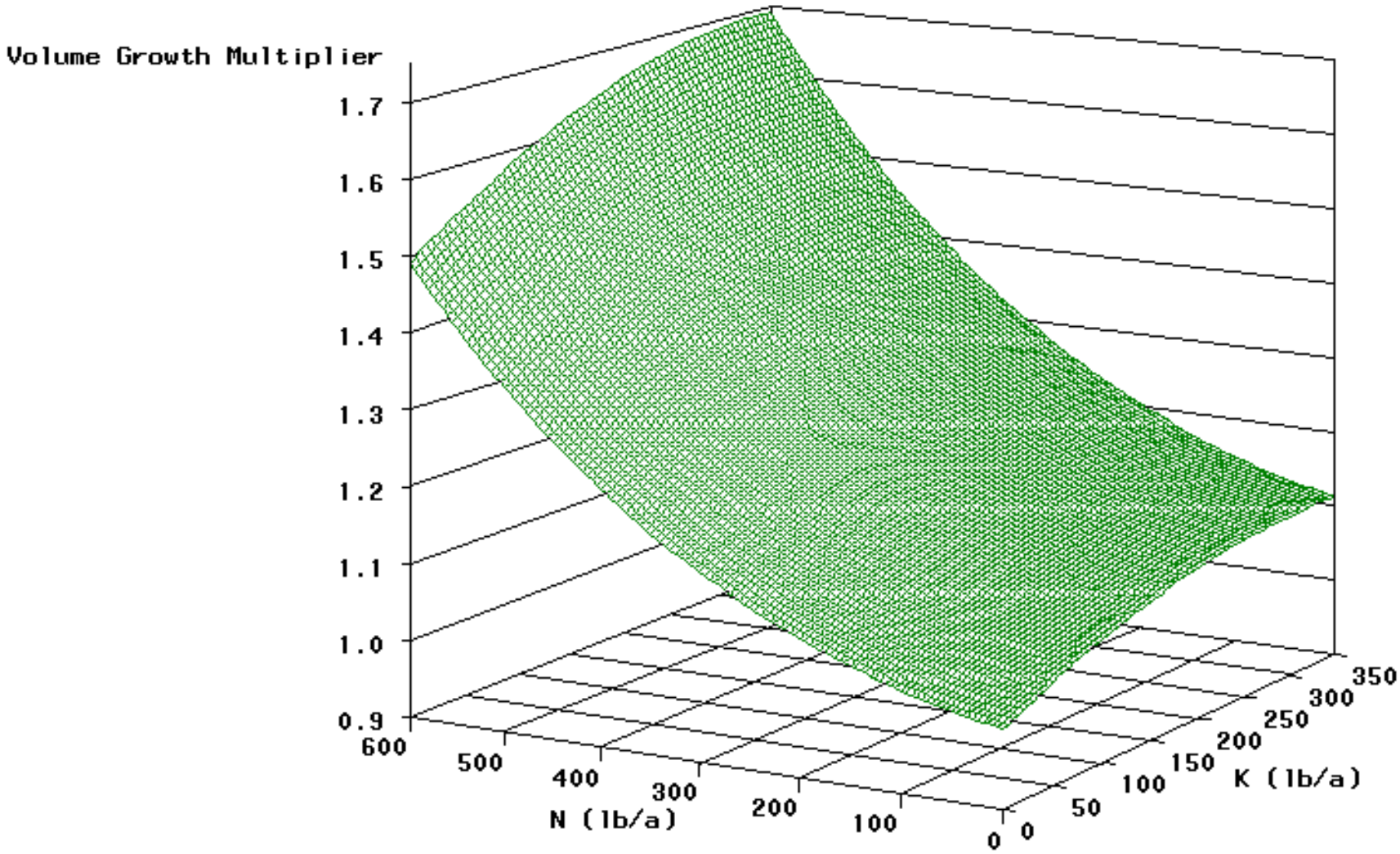
Ponderosa pine: All Rock Types



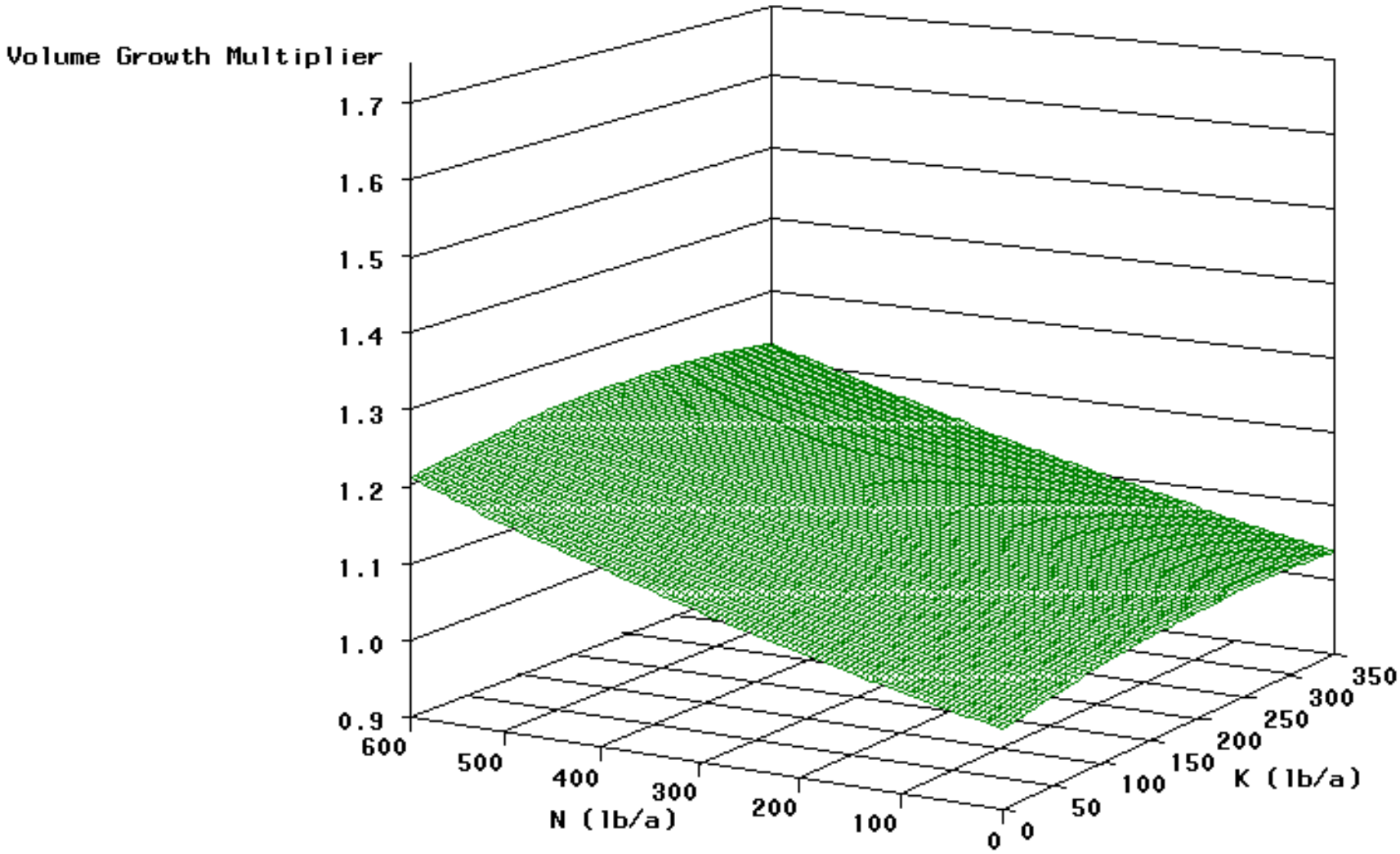
N and K Fertilizer Effects: Ponderosa Pine Potassium Concentration



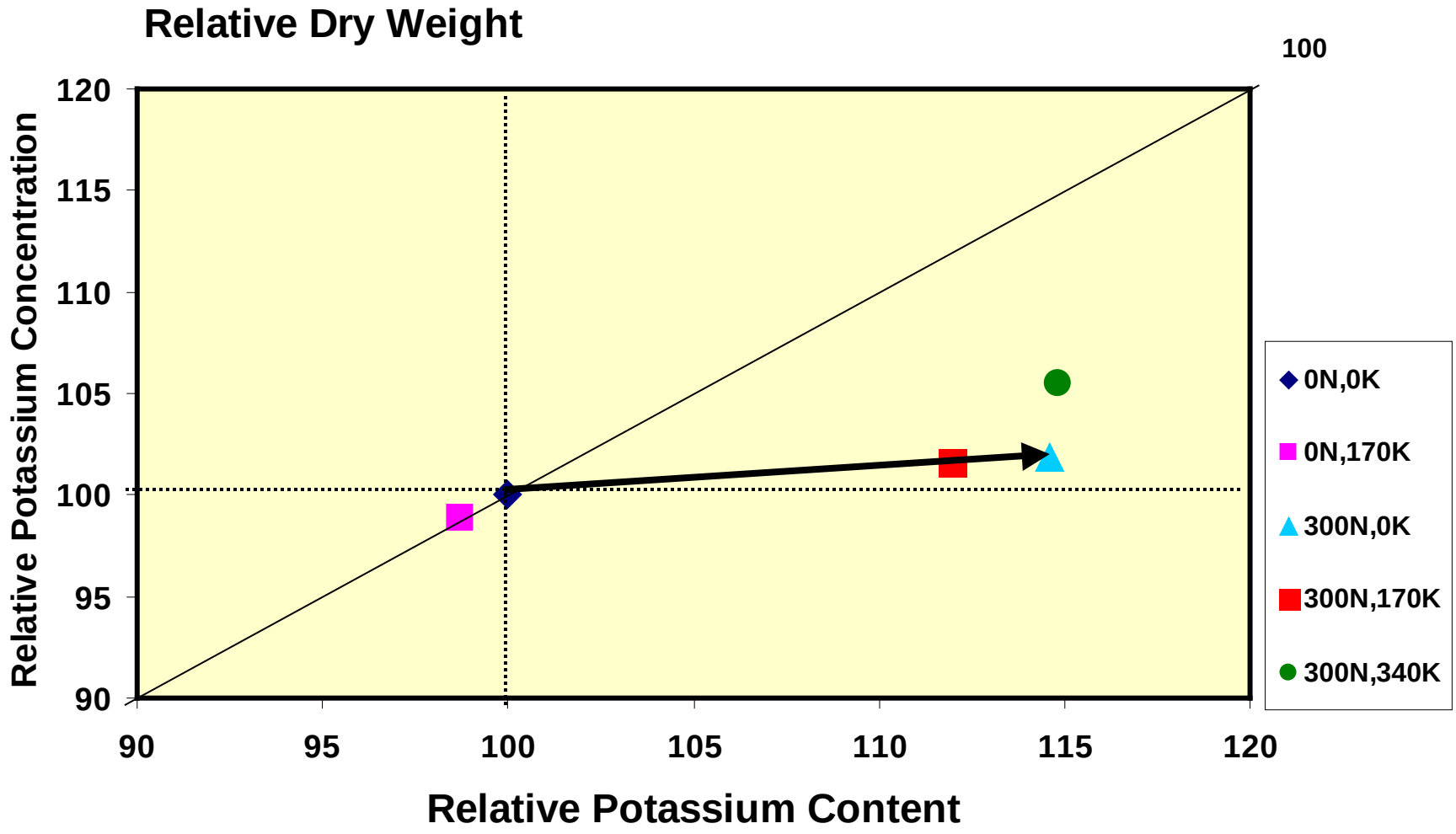
N and K Fertilizer Effects on 8–Year Gross Volume Growth
Species= GF



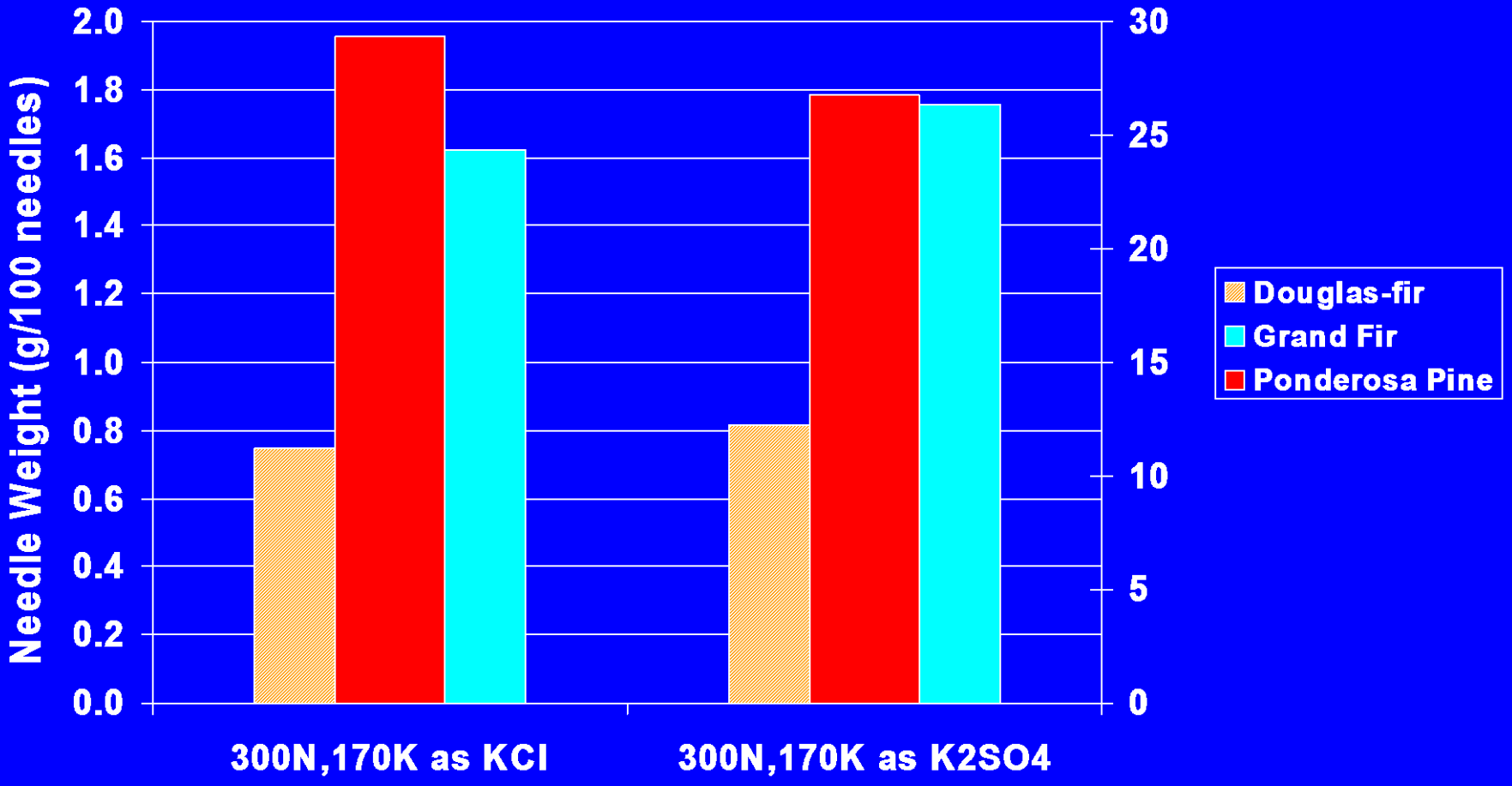
N and K Fertilizer Effects on 8–Year Gross Volume Growth
Species= PP



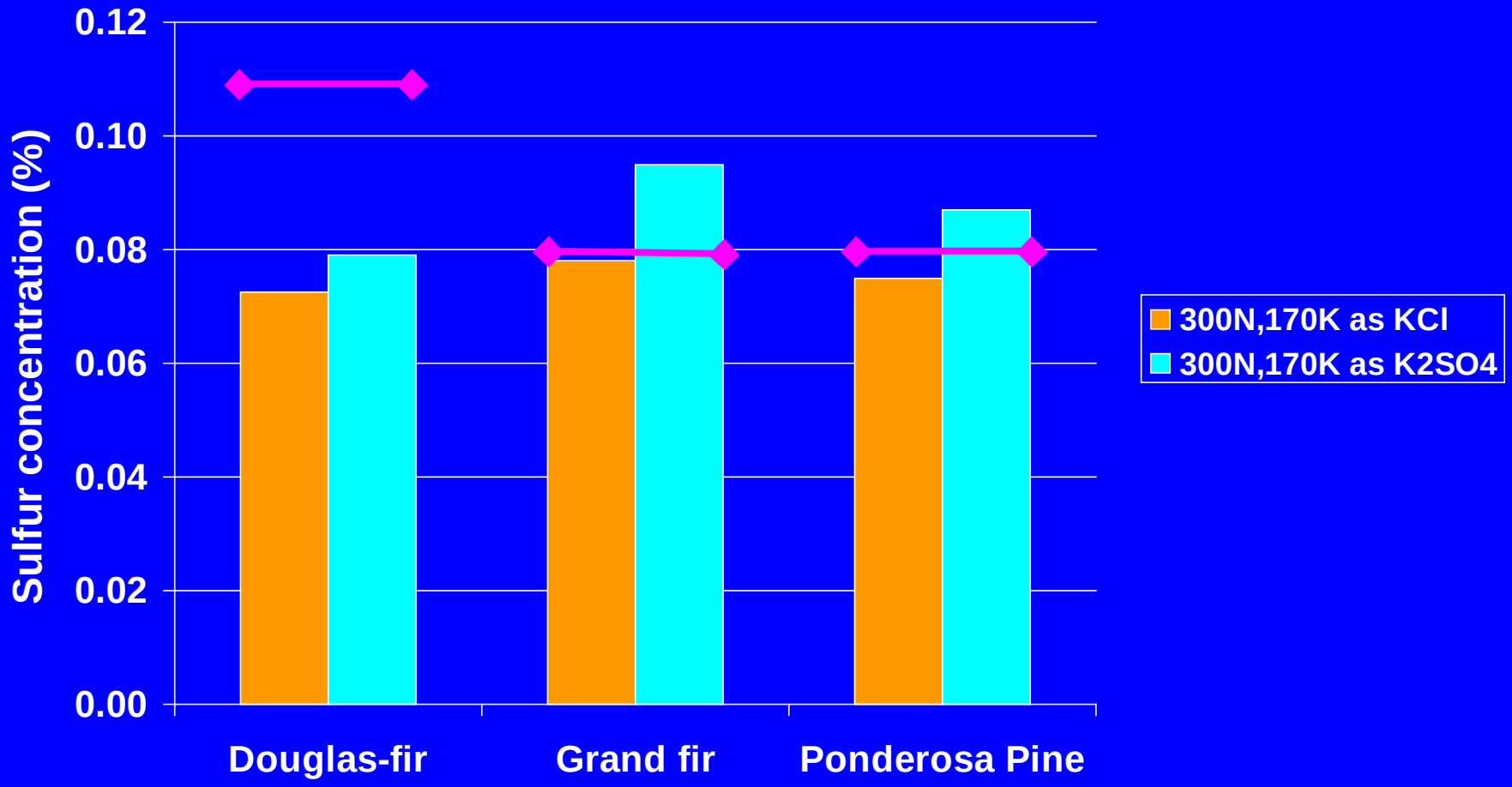
Ponderosa pine: All Rock Types



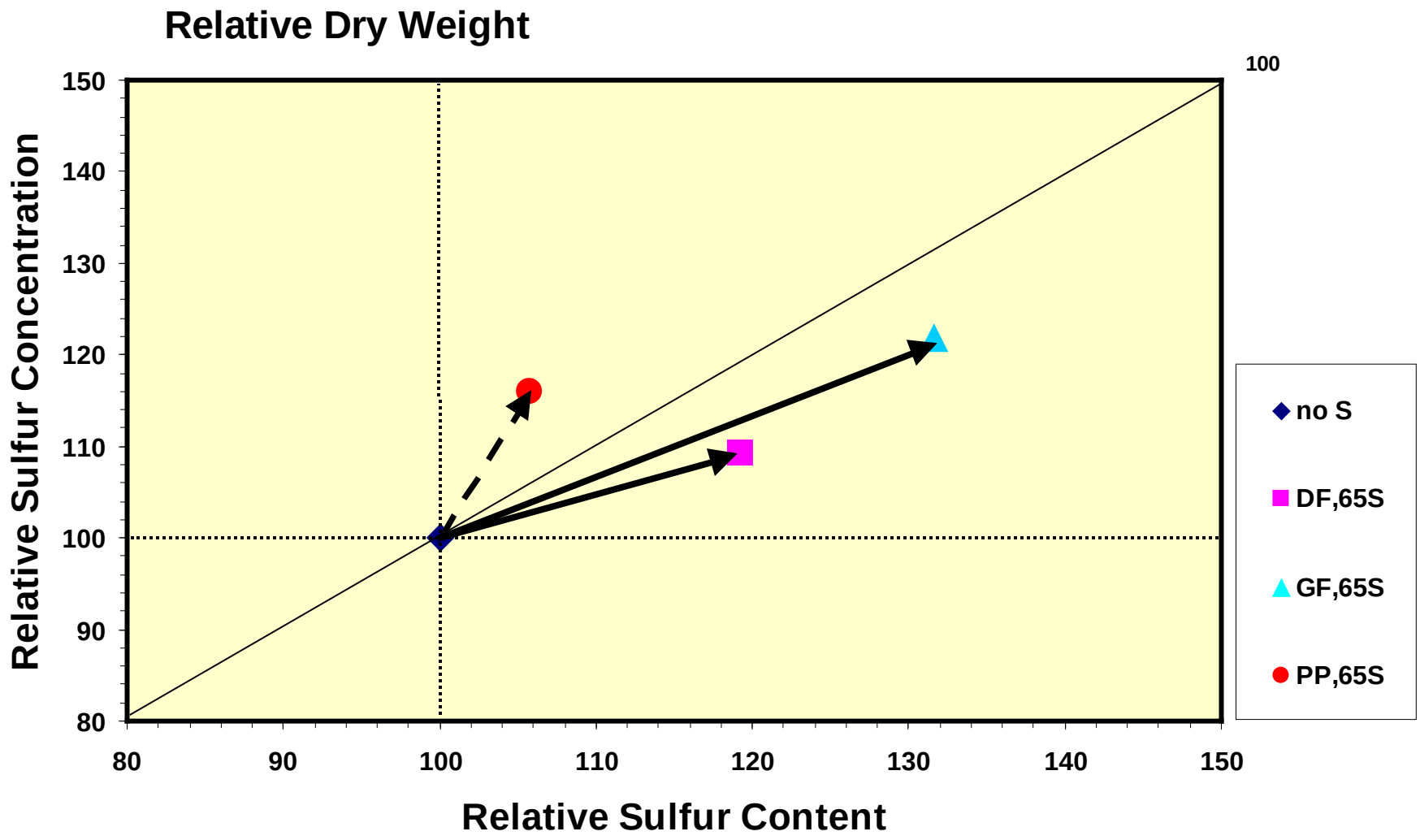
Sulfur Effects: Needle Weight



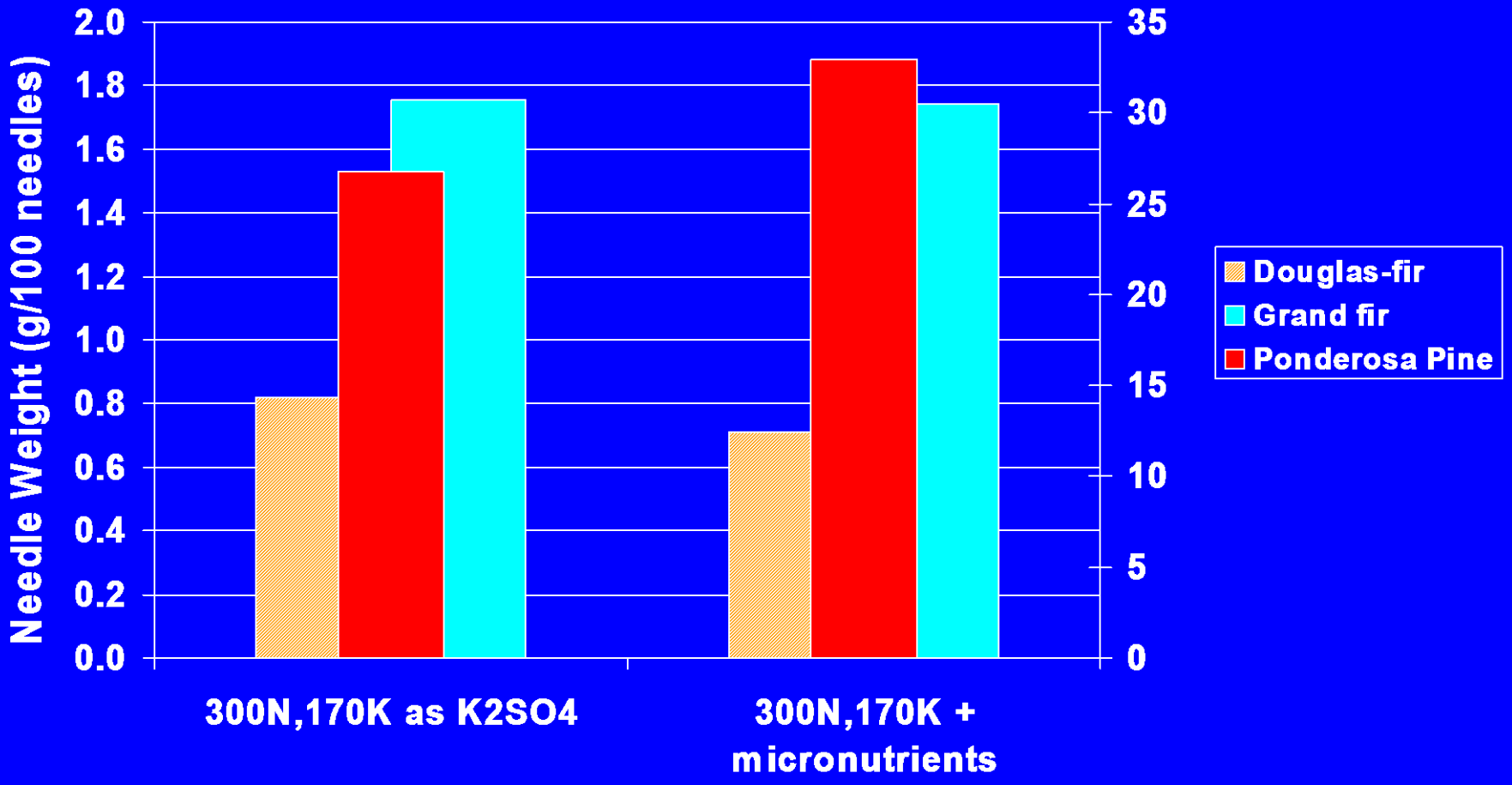
Sulfur Effects: Sulfur Concentration



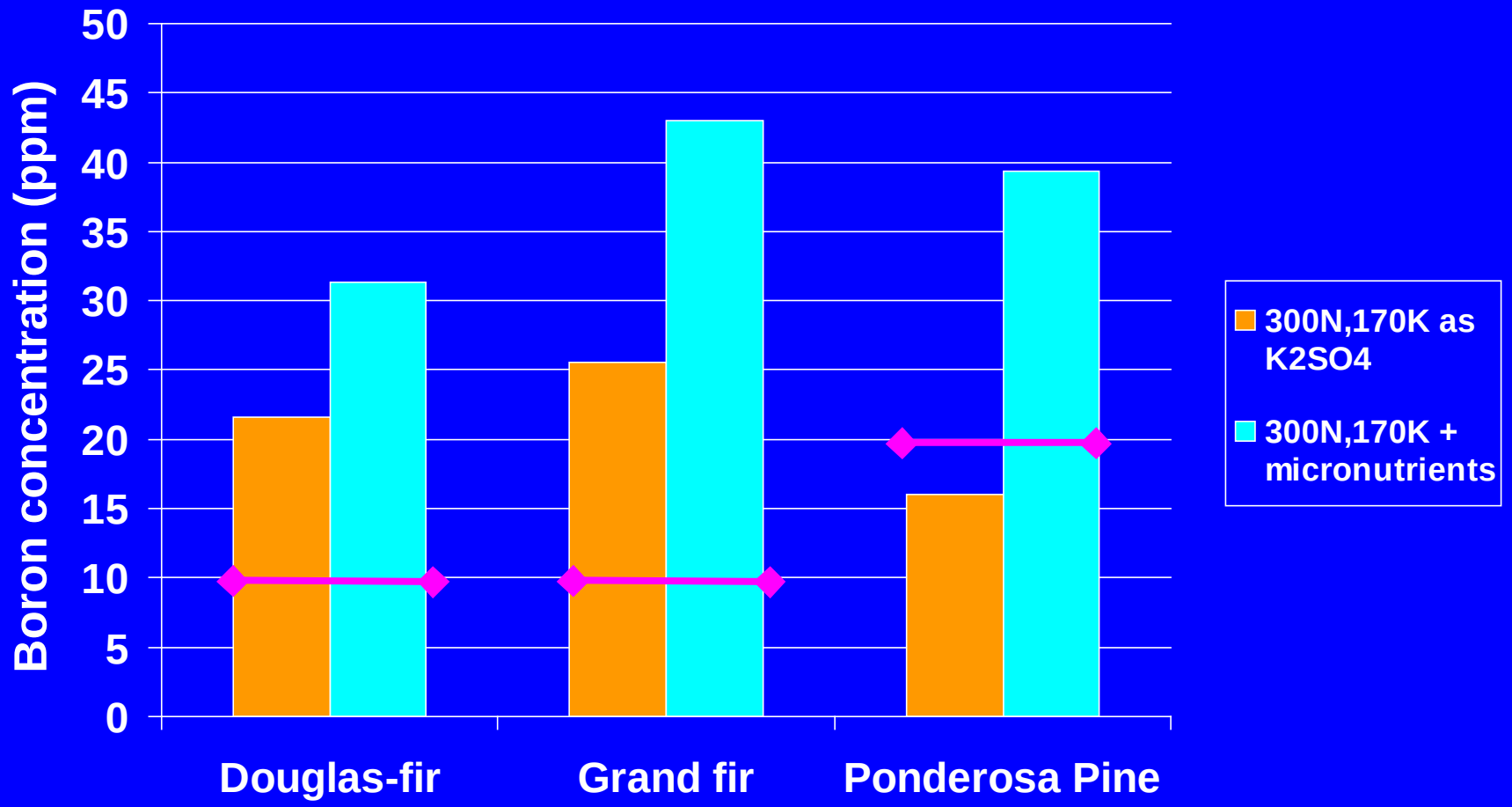
Sulfur Effect: KCl vs. K_2SO_4



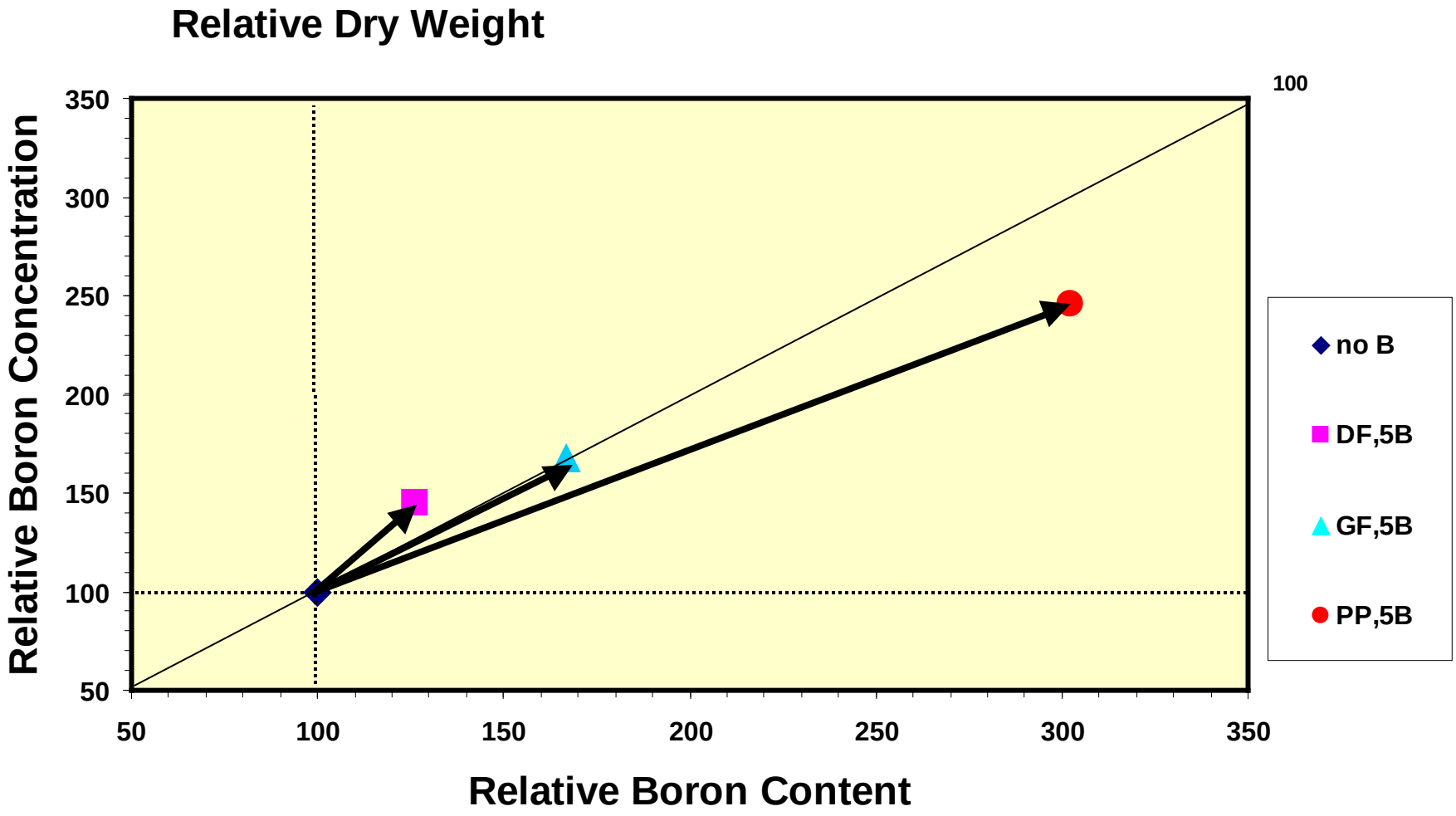
Micronutrient Effects: Needle Weight



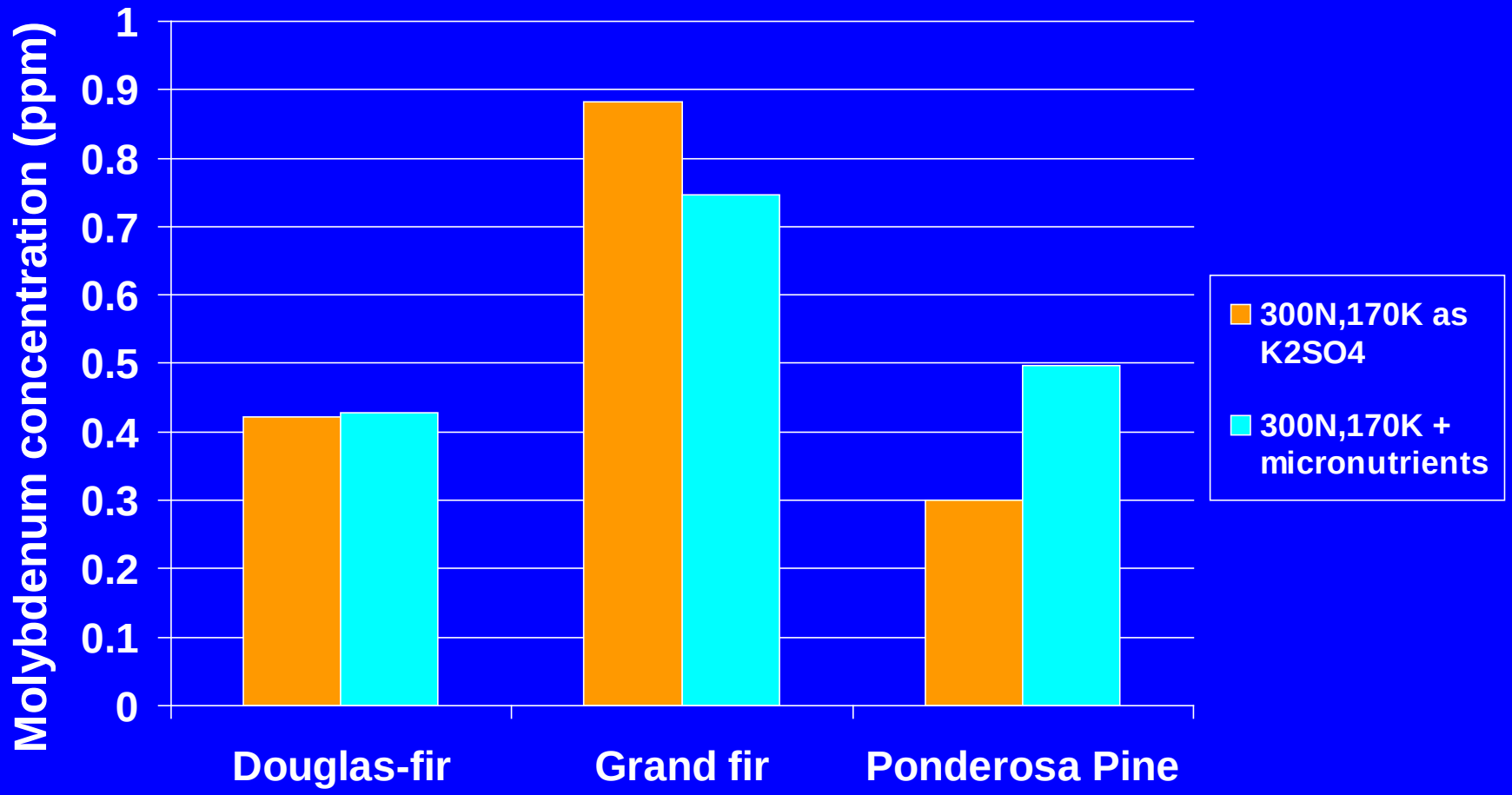
Micronutrient Effects: Boron Concentration



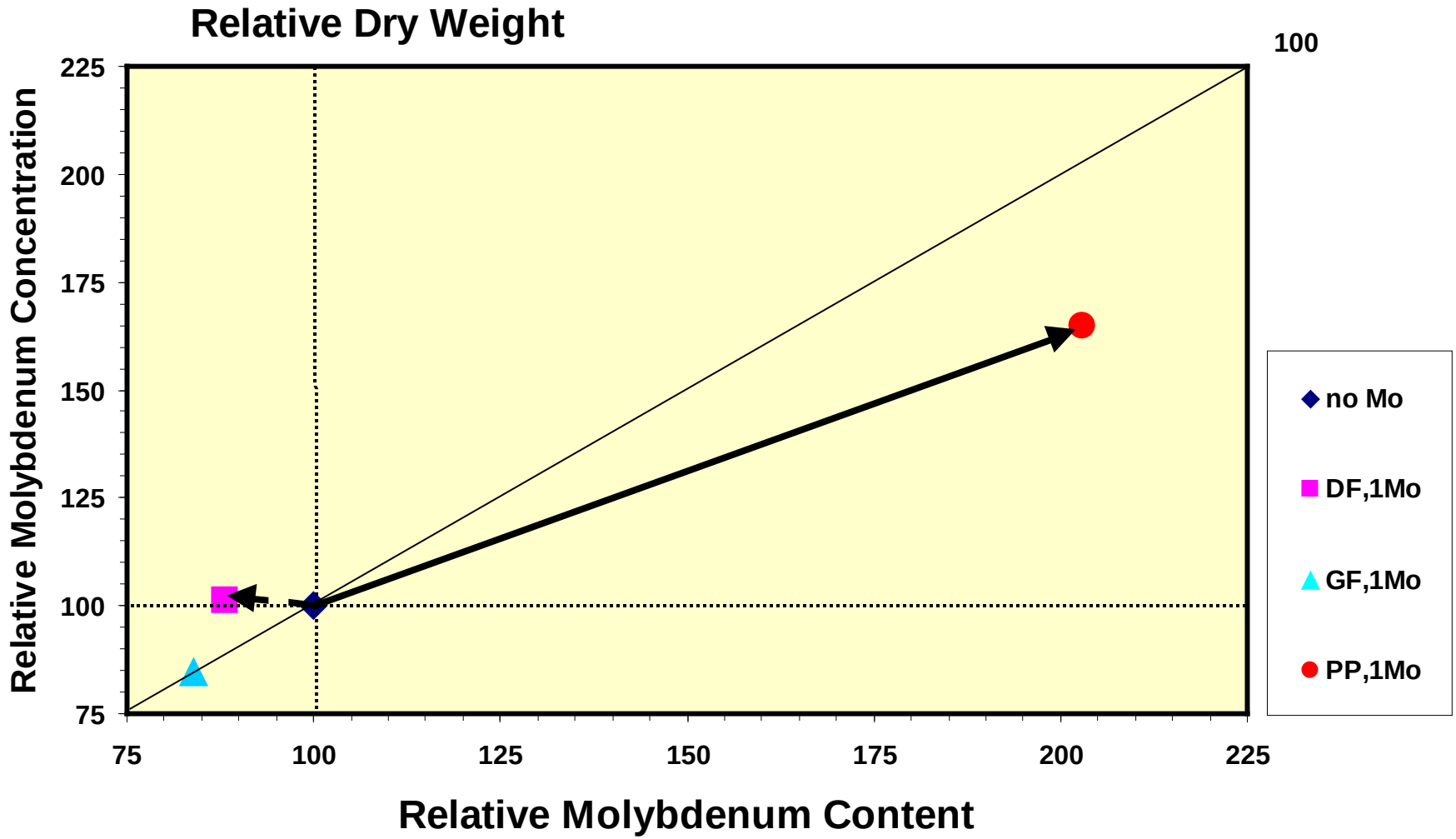
Micronutrient Effect: Boron



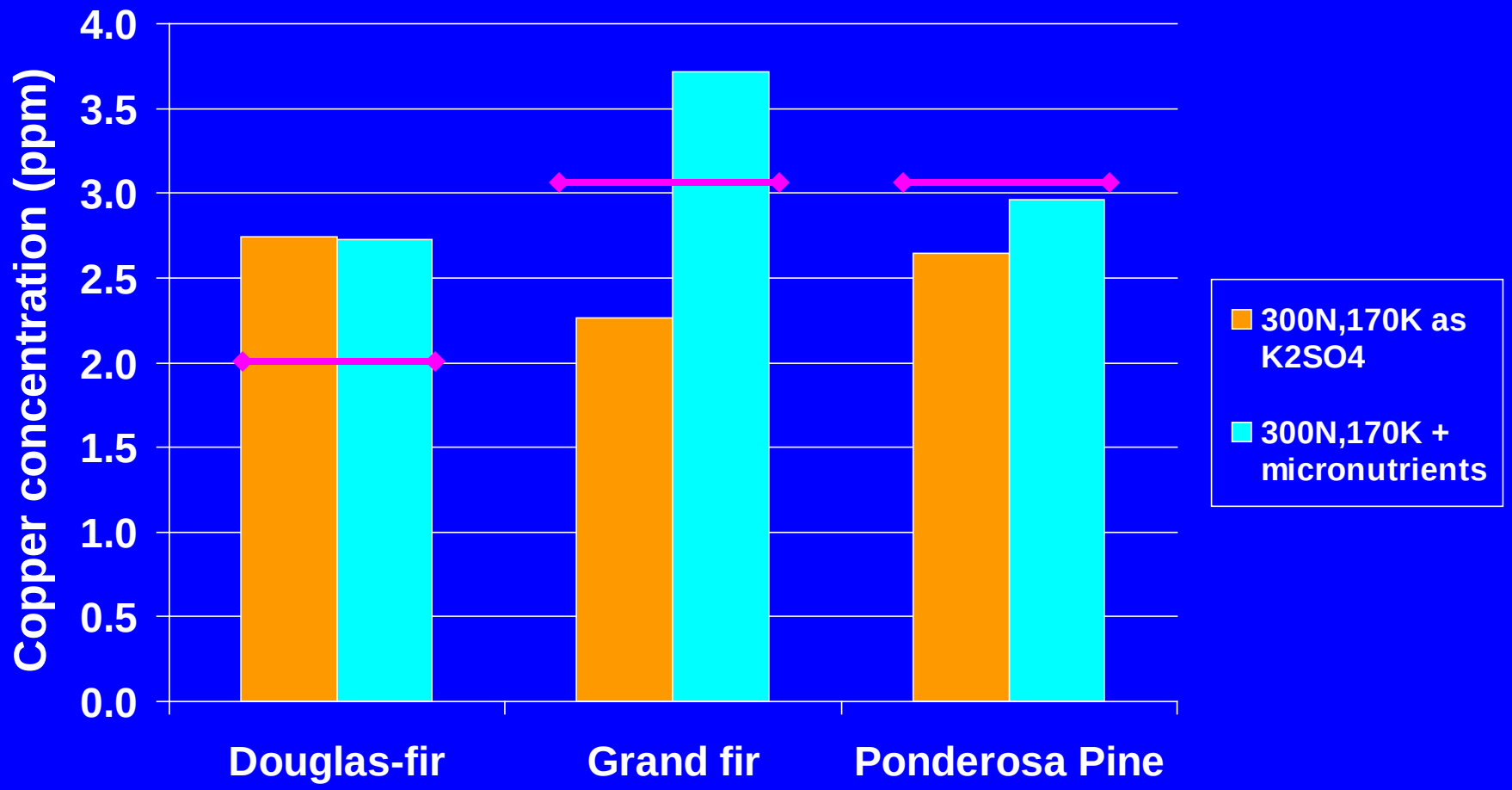
Micronutrient Effects: Molybdenum Concentration



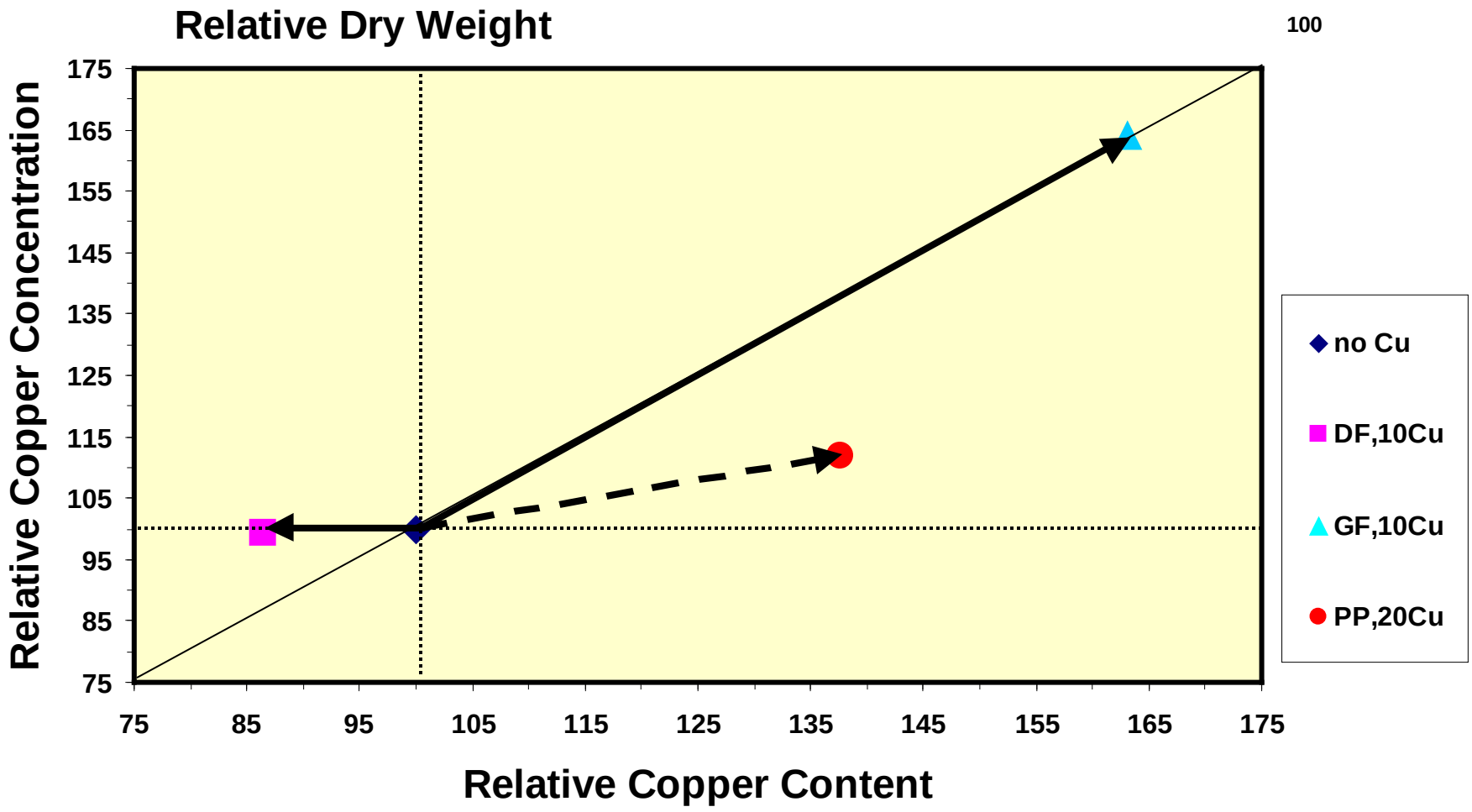
Micronutrient Effect: Molybdenum



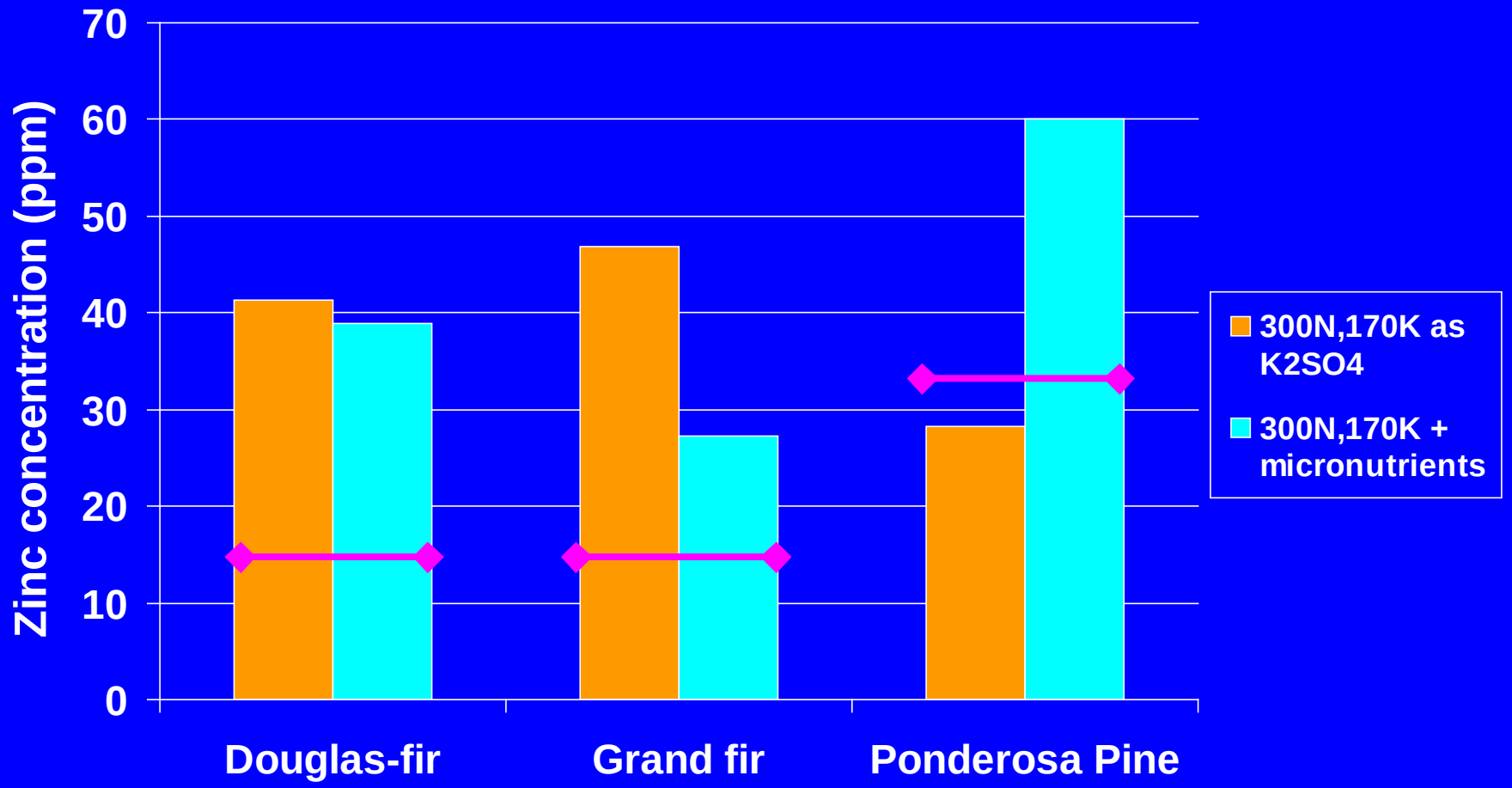
Micronutrient Effects: Copper Concentration



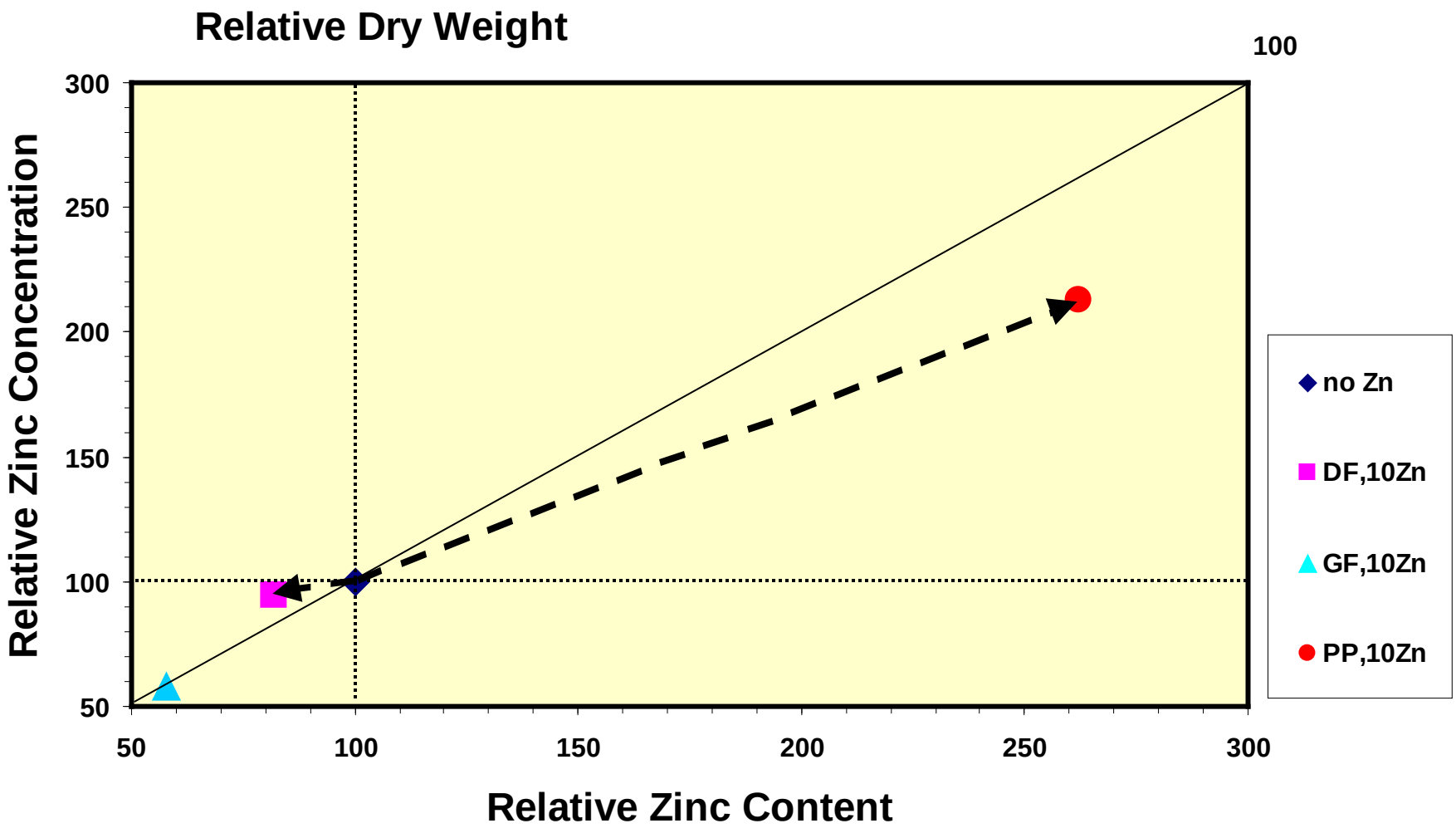
Micronutrient Effect: Copper



Micronutrient Effects: Zinc Concentration



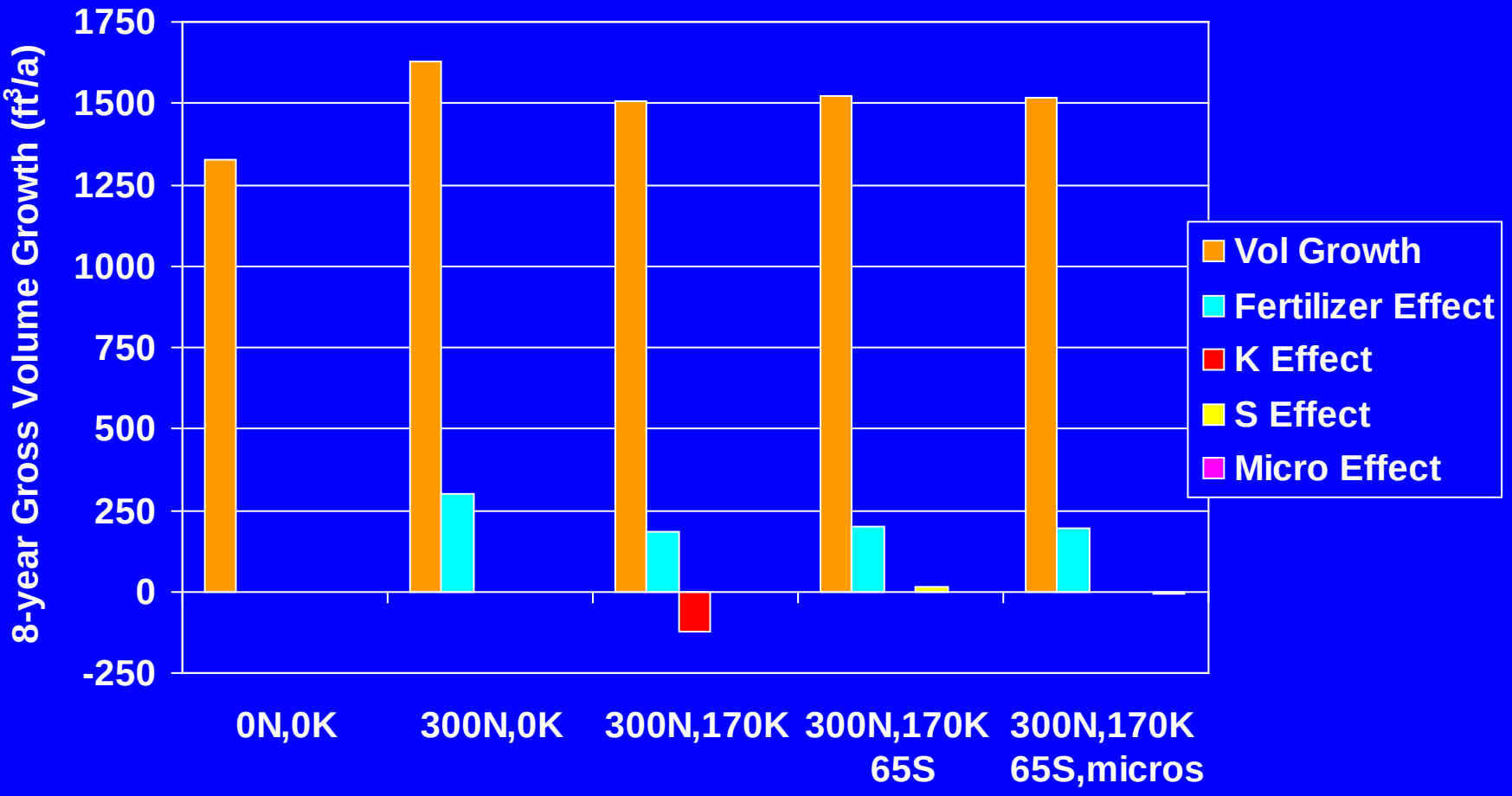
Micronutrient Effect: Zinc



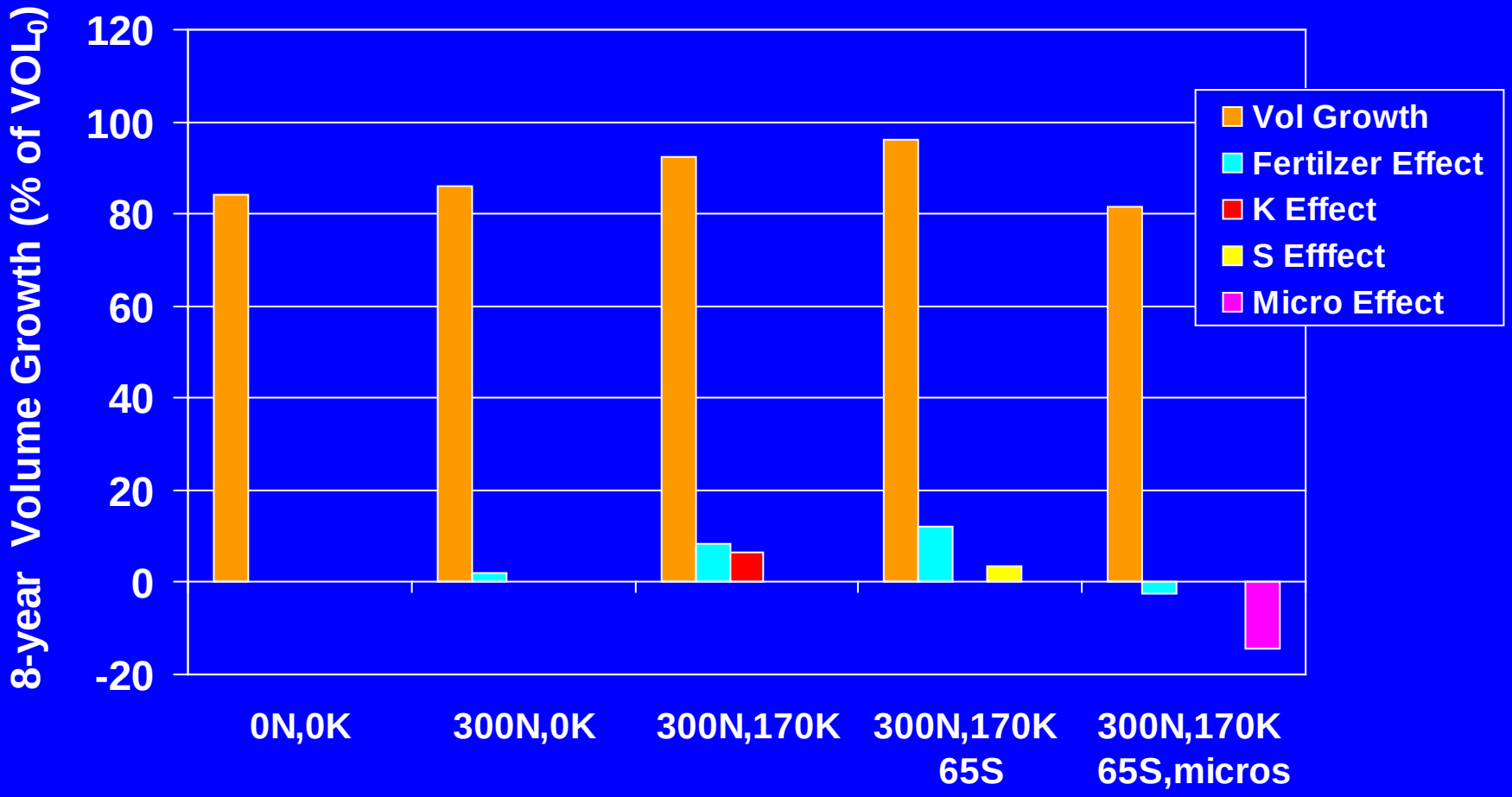
Sulfur and Micronutrient Expectations

- Sulfur additions should produce a growth response in GF and DF, but not in PP
- Micronutrient treatment growth effects should be limited to PP.

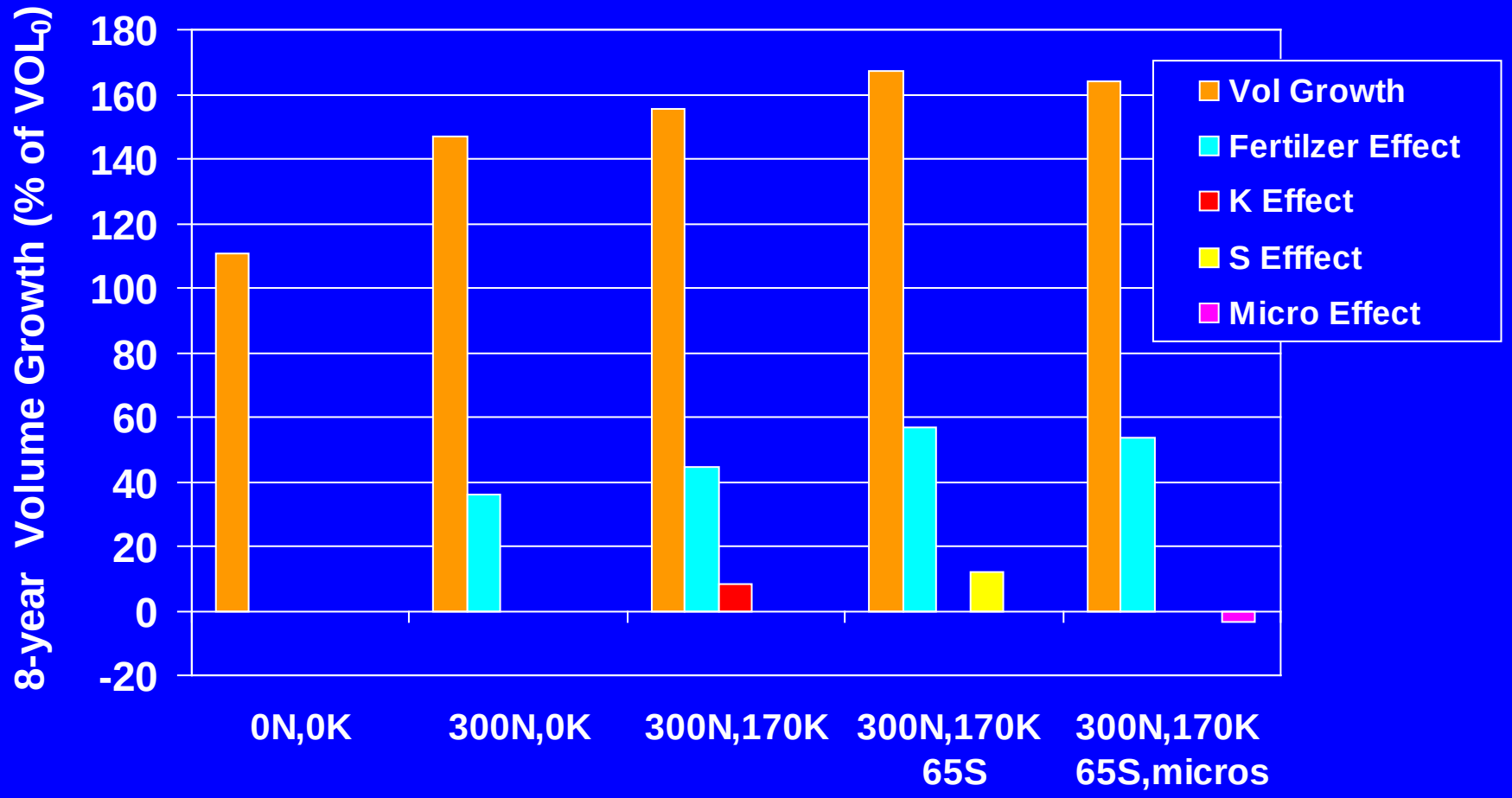
Sulfur and Micronutrients: effects on 8-year Volume Growth



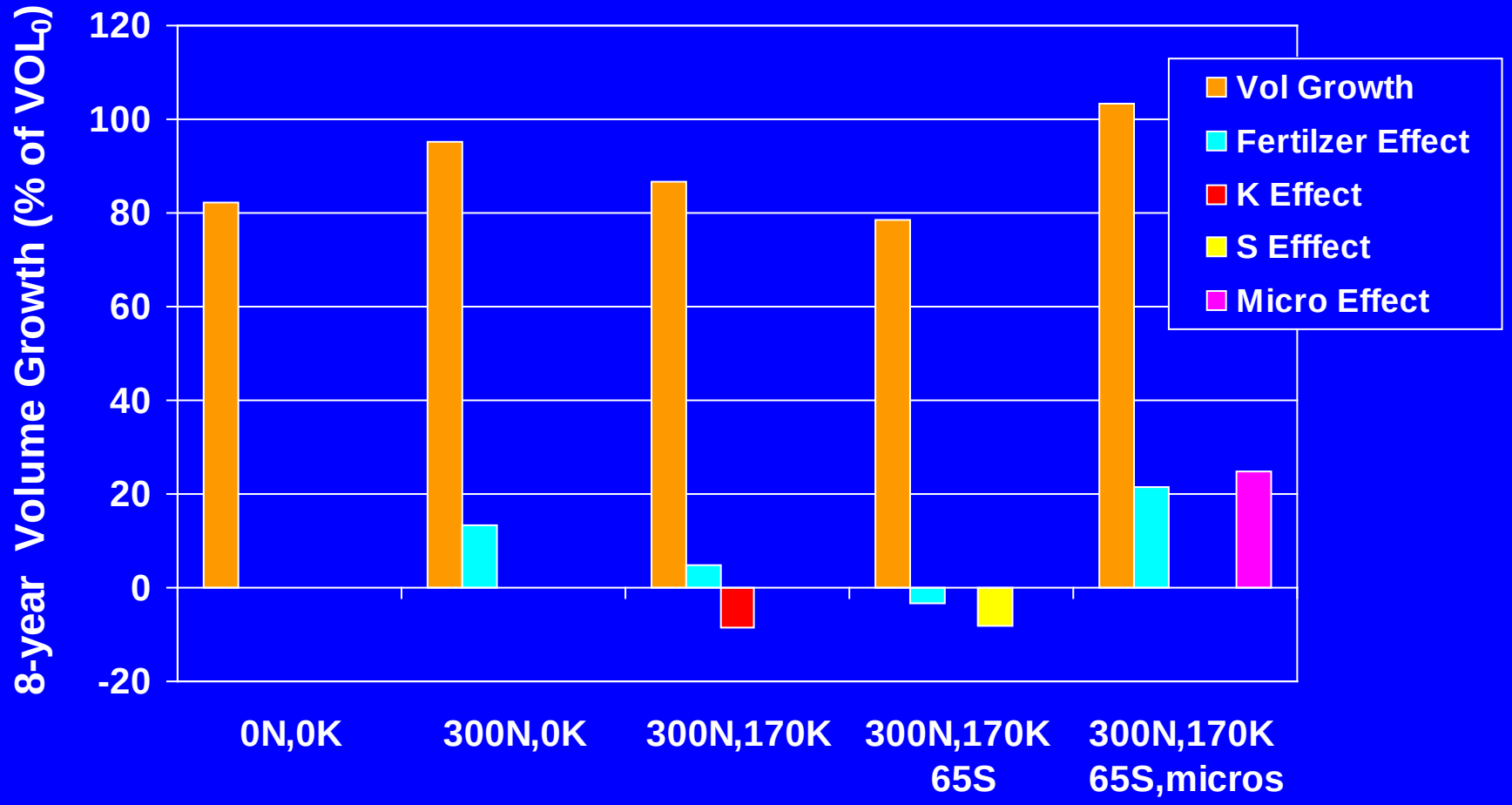
Sulfur and Micronutrients Effects: 8-year Volume Response — Douglas-fir



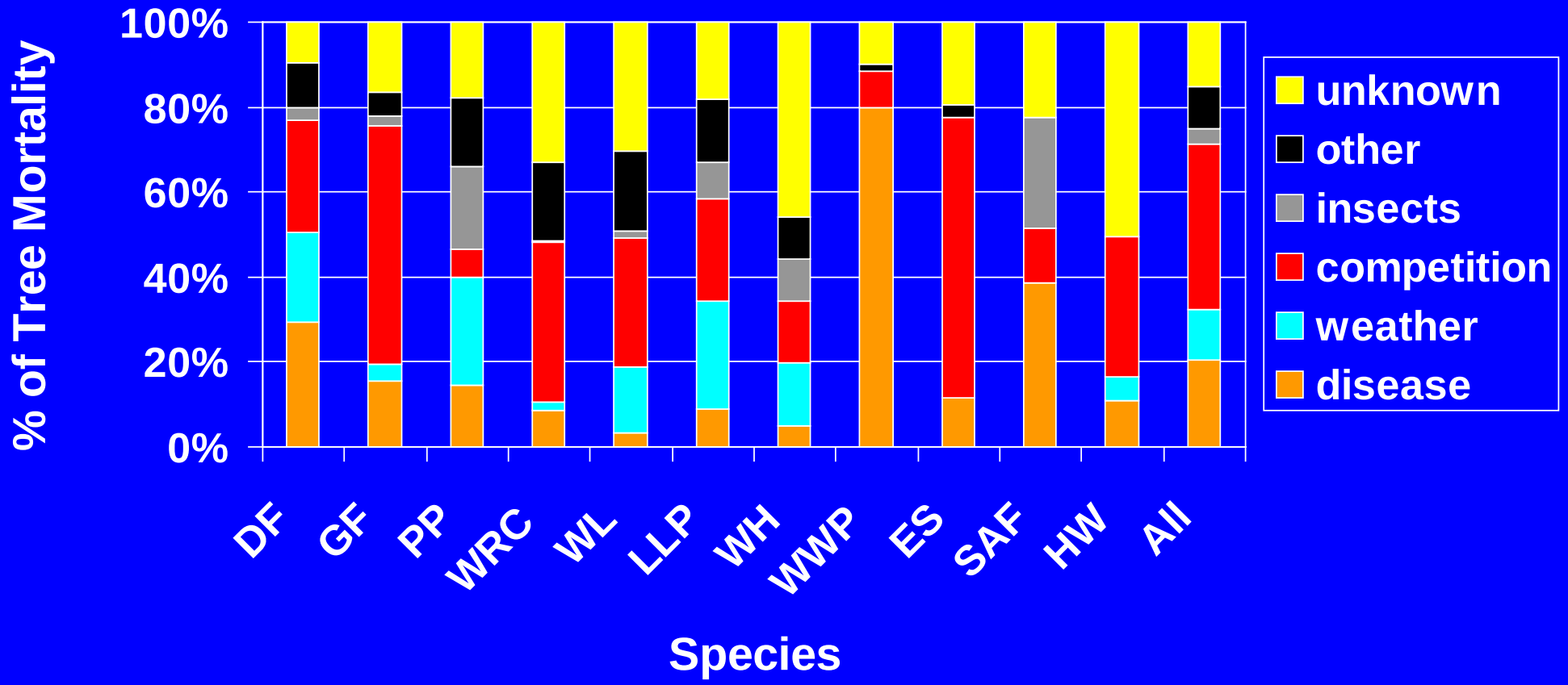
Sulfur and Micronutrients Effects: 8-year Volume Response — Grand Fir



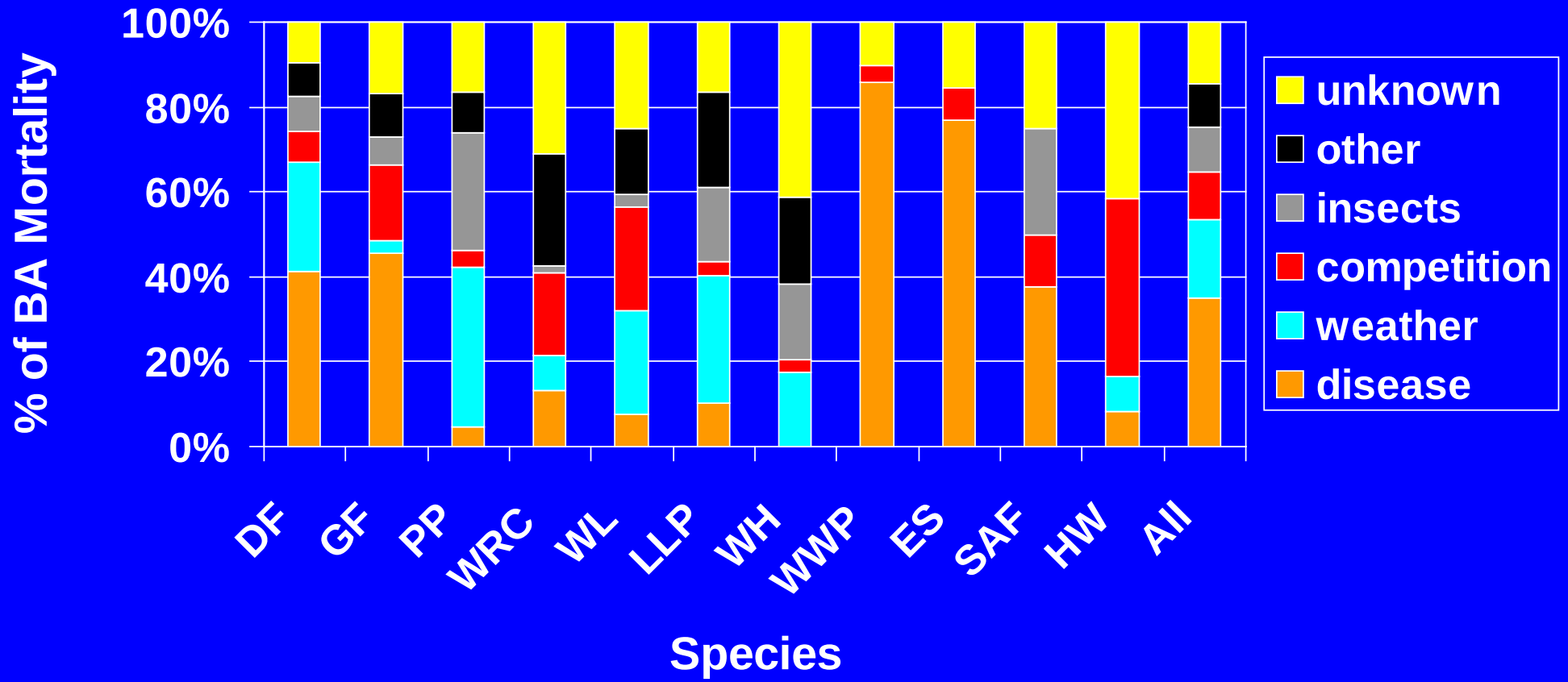
Sulfur and Micronutrients Effects: 8-year Volume Response — Ponderosa Pine



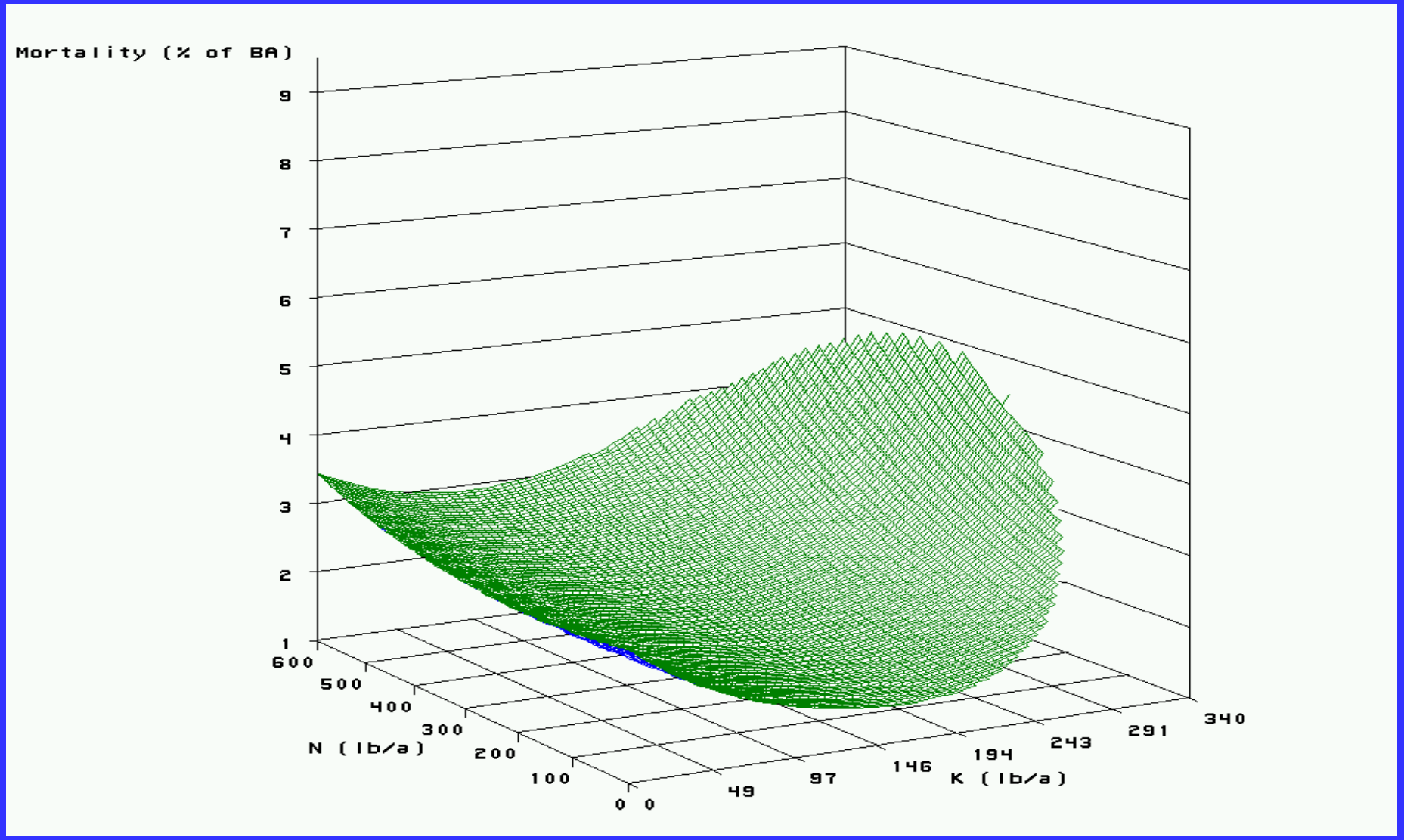
Mortality Causes : Trees



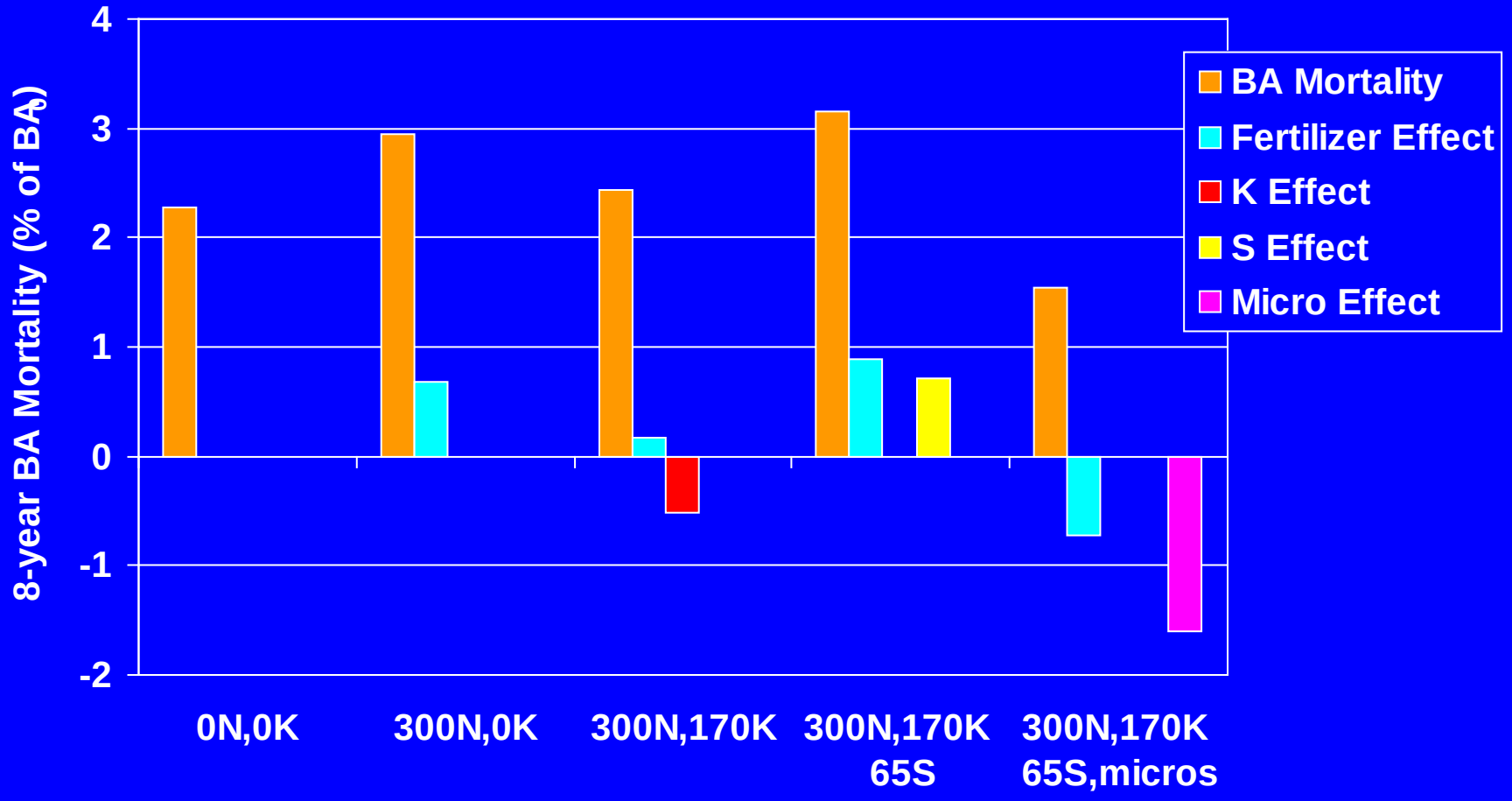
Mortality Causes : BA



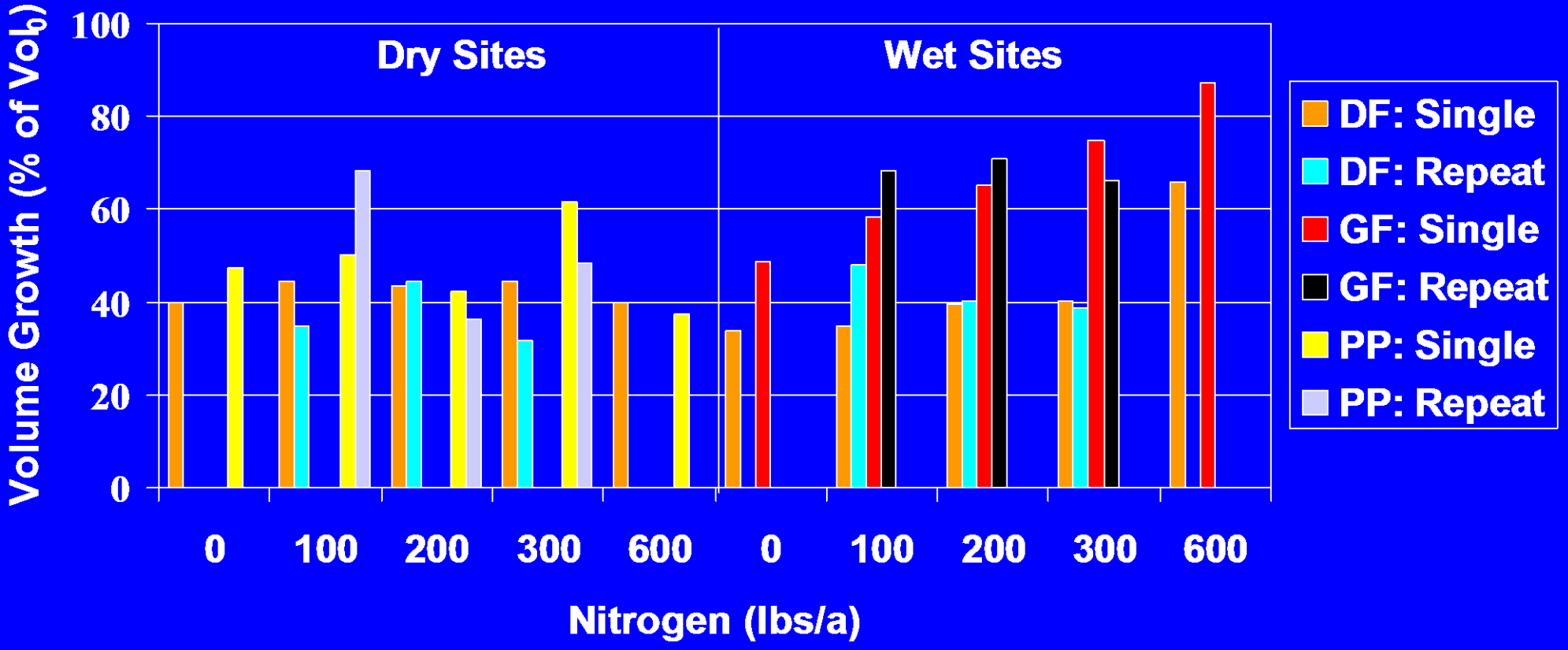
N and K fertilizer effects on 6-year mortality (% of BA) in Grand Fir



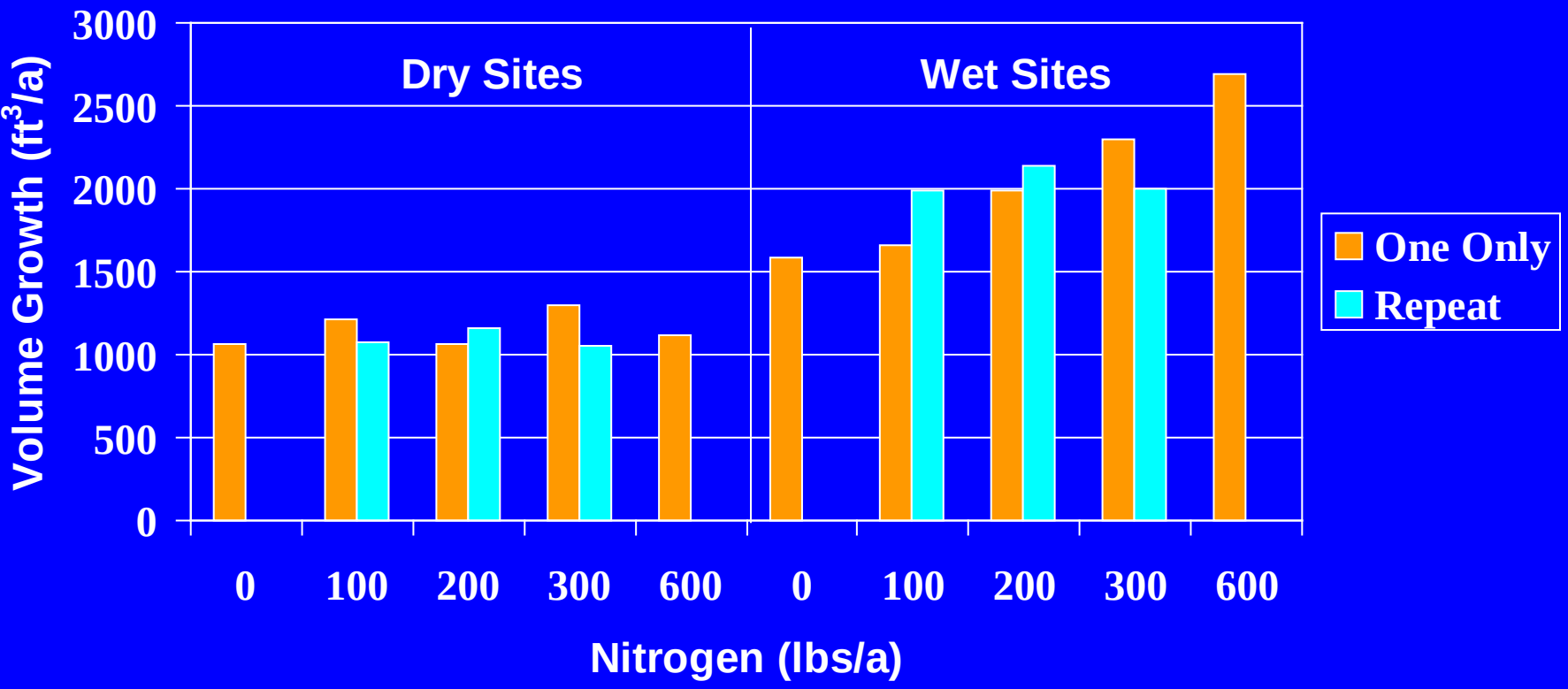
Sulfur and micronutrients: effects on 8-year BA Mortality



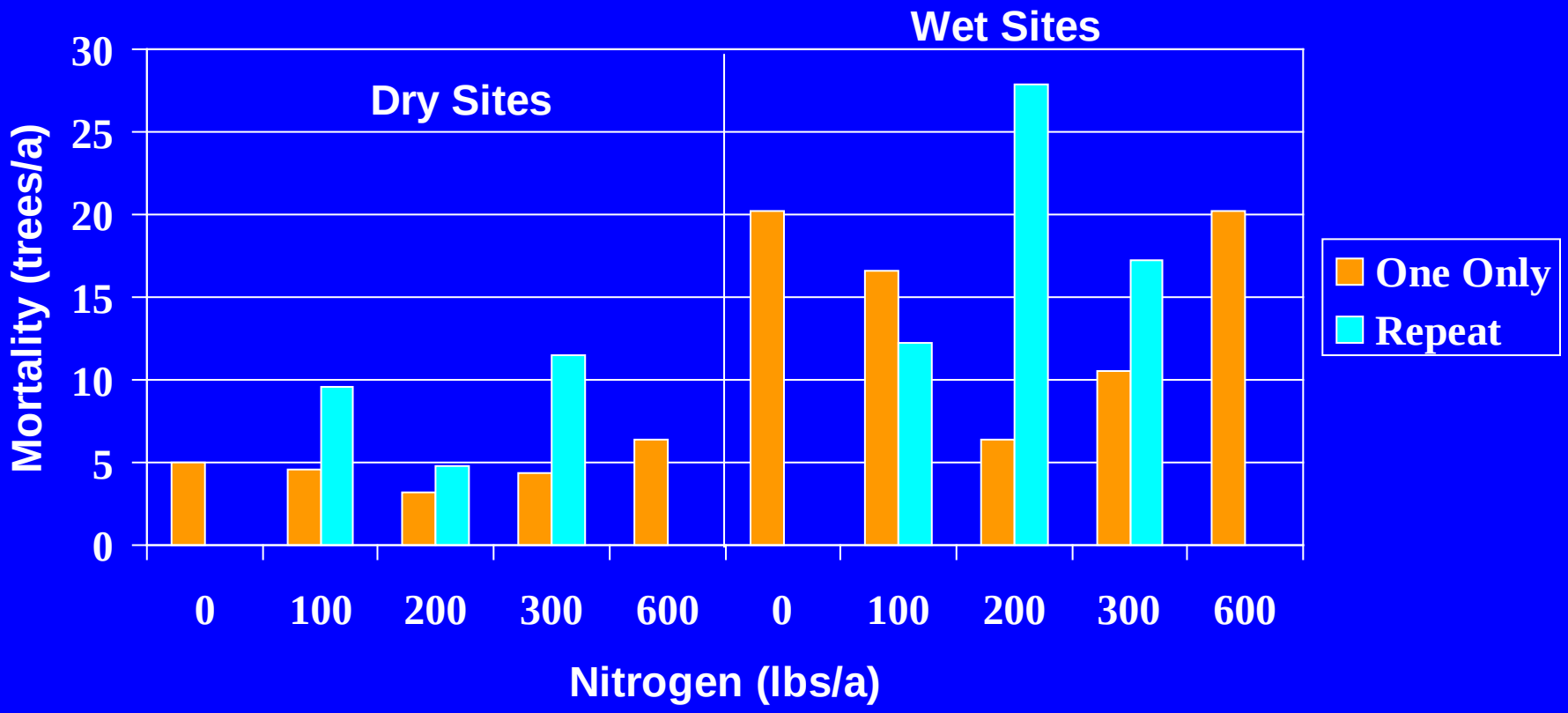
Repeated N Application Effects: 8-year Volume Growth by Species



Repeated N Application Effects: 8-year Volume Growth



Repeated N Application Effects: 8-year TPA Mortality



Repeated N Application Effects: 8-year Tree Mortality by Species