Twelfth Annual Report

Intermountain Forest Tree Nutrition Cooperative

Part II

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Empirical Prediction Models for Douglas-fir Response to Nitrogen Fertilization

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Predicting six-year response to nitrogen fertilization for Douglas-fir:

Last year the Steering Committee directed the staff to concentrate analysis on understanding the causal relationships influencing response to nitrogen fertilization in the hope that this would improve our knowledge of nutrition and forest productivity in the region. Thus, we have not used the study's experimental design in this report analysis rather, we have attempted to directly predict nitrogen response from observations about site, stand, and soil conditions at each installation.

Analysis

A six year response period was used in this analysis since after this point we retreated about one-half of the Douglas-fir plots with nitrogen or nitrogen plus potassium. Thus, the six-year period is the longest that allows all of the plots to be used in developing response prediction models.

Models were developed for both absolute (cu. ft./Ac.) and relative (%) gross response to nitrogen fertilization after six-years. We used chapter 12 of Pritchett and Fisher (1987) as a general guide in initial model development. Model formulation was the same, with the exception of elevation, for both absolute and relative response as follows:

RESP = f(HAB, EL, RD, PM, TRT, MIN_N, AV_P, EX_K)

Where: RESP = is either absolute (cu. ft./ac.) or relative (%) six-year gross increase in growth due to nitrogen fertilization.

HAB = Habitat type series: Douglas-fir, grand fir, or western red cedar (+ a few hemlock).

EL = elevation in feet.

RD = relative density at the beginning of the period (ie. current basal area / maximum basal area for the site Zhang et al. 1992).

PM = soil parent material: granite, basalt, or other (other includes sedimentary or metasedimentary rocks or mixed parent materials).

TRT = nitrogen fertilizer rate: 200 or 400 lbs./Ac.

MIN_N = an index of surface soil nitrogen availability (PPM) (Powers 1980).

AV_P = an estimate of phosphorus availability in the surface soil (PPM) (Jackson 1958).

EX_K = an estimate of exchangeable potassium in the surface soil (MEQ/100G) (Chapman 1965).

All predictor variables estimate conditions prior to application of the nitrogen treatments. The analysis of variance results are provided in Table 1 (for absolute response) and Table 2 (for relative response). The first portion of each table gives the model sum of squares and "fit" statistics for the "ordinary least squares" solutions for the models. We can account for ≈ 41% of the variation in absolute response and ≈ 35% for relative response (ie. R^2 = .41 and .35 respectively). The second portion of the tables show the additional contribution of individual variables to explaining response variation. For both absolute and relative response, habitat series, parent material and treatment are not significant as individual variables but do provide significant interactions with the continuous variables. Further, elevation was non-significant for relative response and was dropped from the prediction model.

The remaining portion of these tables provide parameter estimates for the prediction models. These estimates require substantial explanation. At first, the prediction equations look complex, and they are. However, these models are actually reduced and simplified results of a lengthy statistical modeling process. However worthwhile, one major problem with our modeling approach is that we are analyzing association rather than causation. This typically presents statistical problems since many predictor variables are not only correlated with the dependent variable (response in our case) but also with other predictor variables as well. This is called multi-collinearity, and in severe cases ordinary least squares solutions can produce poor estimates of the parameters and their associated standard errors. Our data has extreme multi-collinearity problems. Thus, we used a statistical estimation procedure called "Ridge" regression that can help alleviate multi-collinearity. This is a "biased" regression procedure wherein a small amount of "bias" is incrementally added to the diagonal of the X'X matrix to artificially remove the correlation between the "independent" variables. This analysis is substantially documented in section 2 of the 1992 Technical Documentation Report. Ridge regression provides several advantages in our situation: first it allows identification of any variables that introduce "instability" into the parameter estimates, and second, once the parameter estimates have stabilized, they better reflect the relationships that exist in the data. For example, effective soil depth (ESD) was one variable that caused substantial problems in the analysis. ESD was significantly correlated with fertilization response, but it was also correlated with nearly every other predictor variable. The parameter estimates were highly unstable and when a small amount of "bias" was added to the X'X matrix, the parameter estimate for ESD went to zero and stabilized. This indicated that ESD was not adding any new information in explaining response above that already explained by variables in the model. Thus, ESD was dropped from the model. The parameter estimates for the remaining variables all stabilized at a bias (K) added value of .08. These are the estimates provided in the last portions of Tables 1 and 2. We feel these estimates reasonably reflect the relationships found in the development data rather than being a statistical artifact resulting from poor parameter estimates.

Results

The relationships between absolute response and elevation is shown in Figure 1. For Douglas-fir and grand fir habitat series as elevation increases response decreases, perhaps

Table 1. Analysis of Variance and parameter estimates for the Absolute Response Prediction Model

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	41	3774052.32394154	92050.05668150
ERROR	136	5488748.67847756	40358.44616528
CORRECTED TOTAL	177	9262801.00241911	

MODEL F = 2.28 PR > F = 0.0002

R-SQUARE	C.V.	ROOT MSE	RESPONSE MEAN
0.407442	108.5178	200.89411680	185.12549834

SOURCE	DF	TYPE III SS	F VALUE	PR > F
HABITAT	2	86870.01368468	1.08	0.3438
HABITAT*ELEV	3	270593.09990354	2.23	0.0870
HABITAT*RDO	3	759558.22914738	6.27	0.0005
PM	2	92833.81686532	1.15	0.3197
TREAT	1	65761.22492679	1.63	0.2040
PM*TREAT*MIN_N	6	847764.58044712	3.50	0.0030
PM*TREAT*EX_K	6	400896.09054166	1.66	0.1366
PM*TREAT*AVAIL_P	6	443531.90496901	1.83	0.0974
PM*TREAT*MIN_N*EX_K	6	603086.48058722	2.49	0.0256
PM*TREAT*MIN_N*AVAIL_P	6	564730.60094811	2.33	0.0356

RIDGE REGRESSION COEFFICIENTS AND STATISTICS FOR K=0.08

PARAMETER	ESTIMATE	STANDARD ERROR	STANDARIZED COEFFICIENT	VIF
INTERCEPT	+224.966		+0.0000	
HABITAT				
1	- 18.470	33.330	-0.0400	8.49
2	+ 9.809	36.057	+0.0200	8.35
3	+ 18.500	43.688	+0.0300	8.14
HABITAT*ELEV				
1	- 0.0189	0.0136	-0.1592	5.09
2	- 0.0280	0.0138	-0.2166	5.93
3	- 0.0011	0.0159	-0.0059	7.42
HABITAT*RDO				
1	+305.574	114.05	+0.3110	5.22
2	+403.057	140.32	+0.3220	4.35
3	+196.496	176.37	+0.1250	5.37
PM				
1	- 54.640	54.053	-0.0850	7.38
2	+ 15.263	34.664	+0.0320	7.46
3	+ 13.630	32.220	+0.0300	7.85

PARAMETER		ESTIMATE	STANDARD ERROR	STANDARIZED COEFFICIENT	VIF
TREAT					
1		- 14.640	28.790	-0.0300	8.20
2		+ 14.638	28.795	+0.0320	8.20
PM*TREAT*MIN_N					
1	1	- 2.015	1.6790	-0.1040	7.34
1	2	+ 0.019	1.6390	+0.0010	7.04
2	1	- 0.087	1.2442	-0.0071	5.99
2	2	- 3.328	1.2120	-0.2740	6.25
3	1	- 1.478	0.9486	-0.1514	6.40
3	2	- 1.710	0.9897	-0.1697	6.24
PM*TREAT*EX_K					
1	1	+ 7.770	81.690	+0.0100	5.52
1	2	+ 21.670	79.590	+0.0200	5.79
2	1	- 39.520	27.200	-0.1200	5.65
2	2	- 44.920	28.400	-0.1300	5.55
3	1	+ 1.790	50.930	+0.0000	5.72
3	2	+ 24.320	56.080	+0.0400	5.84
PM*TREAT*AVAIL_P					
1	1	- 0.733	1.3987	-0.0559	5.08
1	2	- 1.524	1.1330	-0.1260	4.73
2	1	+ 0.116	0.7793	+0.0137	5.31
2	2	+ 0.704	0.6821	+0.0982	5.24
3	1	+ 0.616	0.6829	+0.0839	4.36
3	2	+ 0.922	0.6440	+0.1280	4.38
PM*TREAT*MIN_N*EX_K					
1	1	+ 0.081	2.3810	+0.0030	6.45
1	2	- 0.260	2.4760	-0.0100	5.30
2	1	- 0.574	0.5068	-0.0929	5.47
2	2	+ 0.185	0.5358	+0.0292	5.27
3	1	- 0.816	0.8526	-0.0852	6.40
3	2	+ 0.522	0.9036	+0.0516	6.16
PM*TREAT*MIN_N*AVAIL_P					
1	1	+ 0.0138	0.0170	+0.0672	5.03
1	2	+ 0.0047	0.0190	+0.0180	5.20
2	1	+ 0.0043	0.0134	+0.0267	5.45
2	2	+ 0.0144	0.0097	+0.1189	5.35
3	1	- 0.0209	0.0125	-0.1486	5.62
3	2	- 0.0387	0.0136	-0.2596	5.46

Table 2. Analysis of Variance and parameter estimates for the Relative Response Prediction Model

DEPENDENT VARIABLE: REL_RESP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	38	5.52059892	0.14527892
ERROR	139	10.19052026	0.07331310
CORRECTED TOTAL	177	15.71111918	

MODEL F = 1.98 PR > F = 0.0022

R-SQUARE	C.V.	ROOT MSE	REL_RESP MEAN
0.351382	111.5989	0.27076391	0.24262233

SOURCE	DF	TYPE III SS	F VALUE	PR > F
HABITAT	2	0.06775228	0.46	0.6309
HABITAT*RD0	3	0.84367679	3.84	0.0112
PM	2	0.14054141	0.96	0.3860
TREAT	1	0.12182095	1.66	0.1995
PM*TREAT*MIN_N	6	1.36209758	3.10	0.0071
PM*TREAT*EX_K	6	0.95310331	2.17	0.0498
PM*TREAT*AVAIL_P	6	0.80052176	1.82	0.0994
PM*TREAT*MIN_N*EX_K	6	1.28625874	2.92	0.0102
PM*TREAT*MIN_N*AVAIL_P	6	0.93438227	2.12	0.0543

RIDGE REGRESSION COEFFICIENTS AND STATISTICS FOR K=0.08

PARAMETER	ESTIMATE	STANDARD ERROR	STANDARIZED COEFFICIENT	VIF
INTERCEPT	+0.20850		+0.0000	
HABITAT				
1	+0.01490	0.0437	+0.0250	7.34
2	-0.01375	0.0506	-0.0213	6.80
3	-0.00588	0.0673	-0.0073	6.25
HABITAT*RD0				
1	+0.35321	0.1448	+0.2760	4.61
2	+0.39021	0.1811	+0.2391	4.27
3	+0.14008	0.2136	+0.0683	4.79
PM				
1	-0.09074	0.0720	-0.1080	7.25
2	+0.00760	0.0465	+0.0121	7.41
3	+0.03852	0.0427	+0.0648	7.85
TREAT				
1	-0.01379	0.0382	-0.0232	8.20
2	+0.01379	0.0382	+0.0232	8.20

PARAMETER		ESTIMATE	STANDARD ERROR	STANDARIZED COEFFICIENT	VIF
PM*TREAT*MIN_N					
1	1	-0.00244	0.0020	-0.0970	7.32
1	2	-0.00026	0.0020	-0.0090	7.03
2	1	-0.00039	0.0017	-0.0247	5.98
2	2	-0.00401	0.0016	-0.2536	6.24
3	1	-0.00213	0.0013	-0.1674	6.39
3	2	-0.00247	0.0013	-0.1879	6.23
PM*TREAT*EX_K					
1	1	-0.00451	0.1090	-0.0040	5.48
1	2	+0.03306	0.1060	+0.0260	5.73
2	1	-0.05166	0.0360	-0.1222	5.64
2	2	-0.06711	0.0377	-0.1537	5.53
3	1	+0.03741	0.0676	+0.0557	5.72
3	2	+0.03105	0.0746	+0.0435	5.82
PM*TREAT*AVAIL_P					
1	1	-0.00087	0.0019	-0.0510	4.98
1	2	-0.00201	0.0015	-0.1276	4.71
2	1	+0.00047	0.0010	+0.0428	5.30
2	2	+0.00130	0.0009	+0.1391	5.23
3	1	+0.00089	0.0009	+0.0926	4.35
3	2	+0.00133	0.0009	+0.1416	4.36
PM*TREAT*MIN_N*EX_K					
1	1	+0.00069	0.0030	+0.0210	6.41
1	2	+0.00029	0.0033	+0.0087	5.26
2	1	-0.00062	0.0007	-0.0765	5.44
2	2	+0.00037	0.0007	+0.0447	5.26
3	1	-0.00099	0.0011	-0.0790	6.40
3	2	+0.00095	0.0012	+0.0723	6.15
PM*TREAT*MIN_N*AVAIL_P					
1	1	+0.00001	0.0000	+0.0473	5.02
1	2	+0.00001	0.0000	+0.0210	5.19
2	1	+0.00001	0.0000	+0.0504	5.43
2	2	+0.00002	0.0000	+0.1224	5.35
3	1	-0.00003	0.0000	-0.1805	5.62
3	2	-0.00005	0.0000	-0.2630	5.45

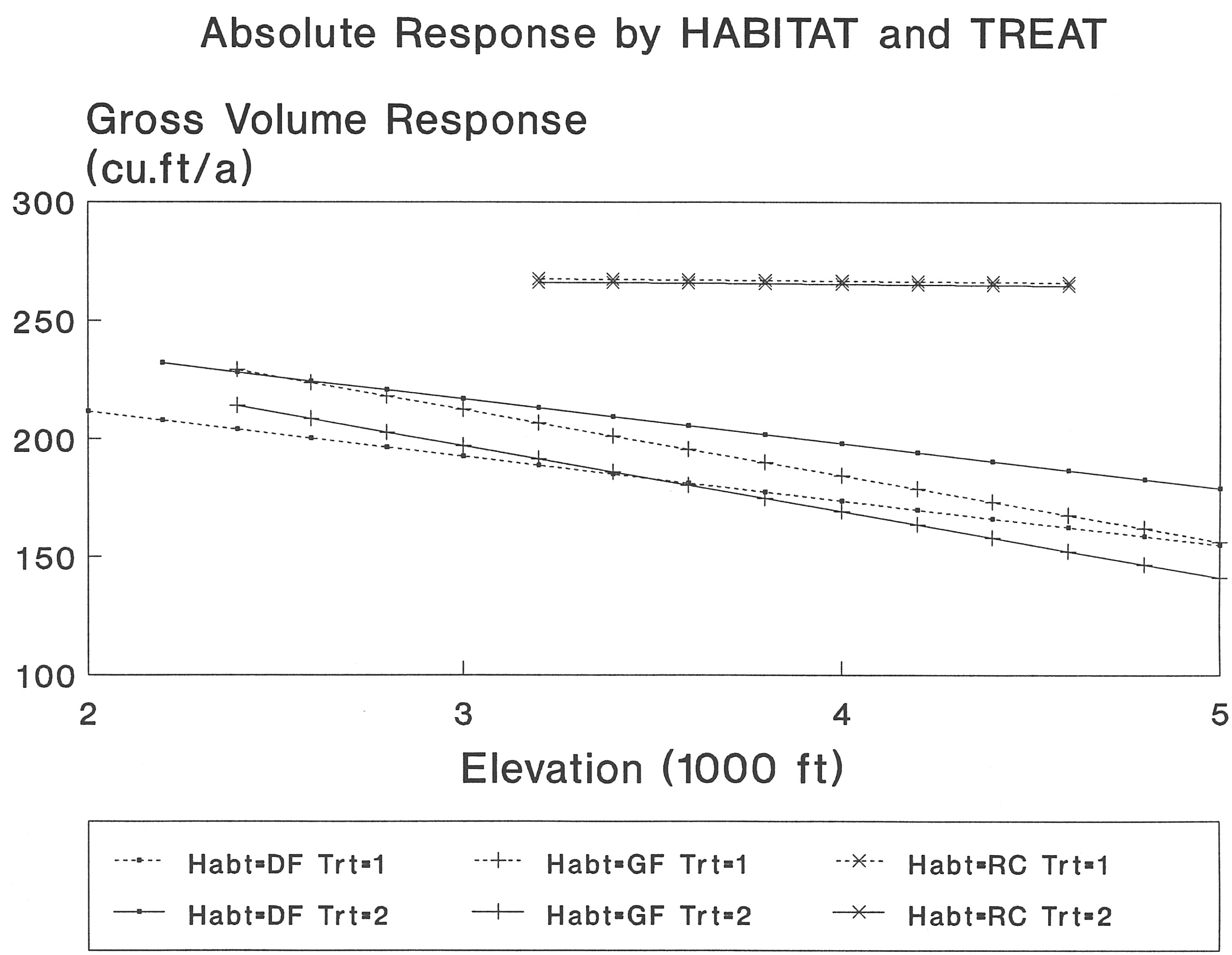

Figure 1. Predicted six-year gross Douglas-fir volume response versus elevation for various habitat type series and nitrogen treatment combinations.

because growing season length is less at higher elevations. However, elevation has no effect on response on western red cedar habitat series; however, the range of elevations for this habitat is much less than for the other two series. Treatment seems to have little effect on the form of response/elevation relationships.

As stand density increases absolute nitrogen response also increases (Figure 2). Douglas-fir and grand fir series are similar, but redcedar types have a different slope. This probably reflects the narrower range of stand densities sampled for the cedar habitat rather than anything "biological". Other measures of stand density, such as basal area per ac., also showed a positive relationship with absolute response. Treatment did not greatly influence the relationship between stand density and response.

The soil chemical variables; MIN_N, AV_P, and EX_K, are represented in the model by two and three-way interactions, and their influence on absolute nitrogen response can only be portrayed by response surfaces (Figures 3 through 10). Six-year response to the 200 lb. N treatment on grand fir types and granite parent material is substantially associated with MIN_N. Sites with lower MIN_N produce higher response than sites with higher MIN_N (Figure 3). EX_K has a small but quantifiable relationship with response, at lease for the narrow range of EX_K (0.6-1 (MEQ/100G) observed for this habitat parent material combination (Figure 3). However, when 400 lbs. of N was applied to this same habitat parent material combination, then neither MIN_K or EX_K have much relationship to absolute response (Figure 4).

The relationships between MIN_N, AV_P, and absolute response for the grand fir habitat/granite parent material combination are shown for the 200 N and 400 N treatments in Figures 5 and 6 for the 200 lb N treatment, lower MIN_N values are associated with higher response while higher soil AV_P sites showed lower response on this habitat/parent material

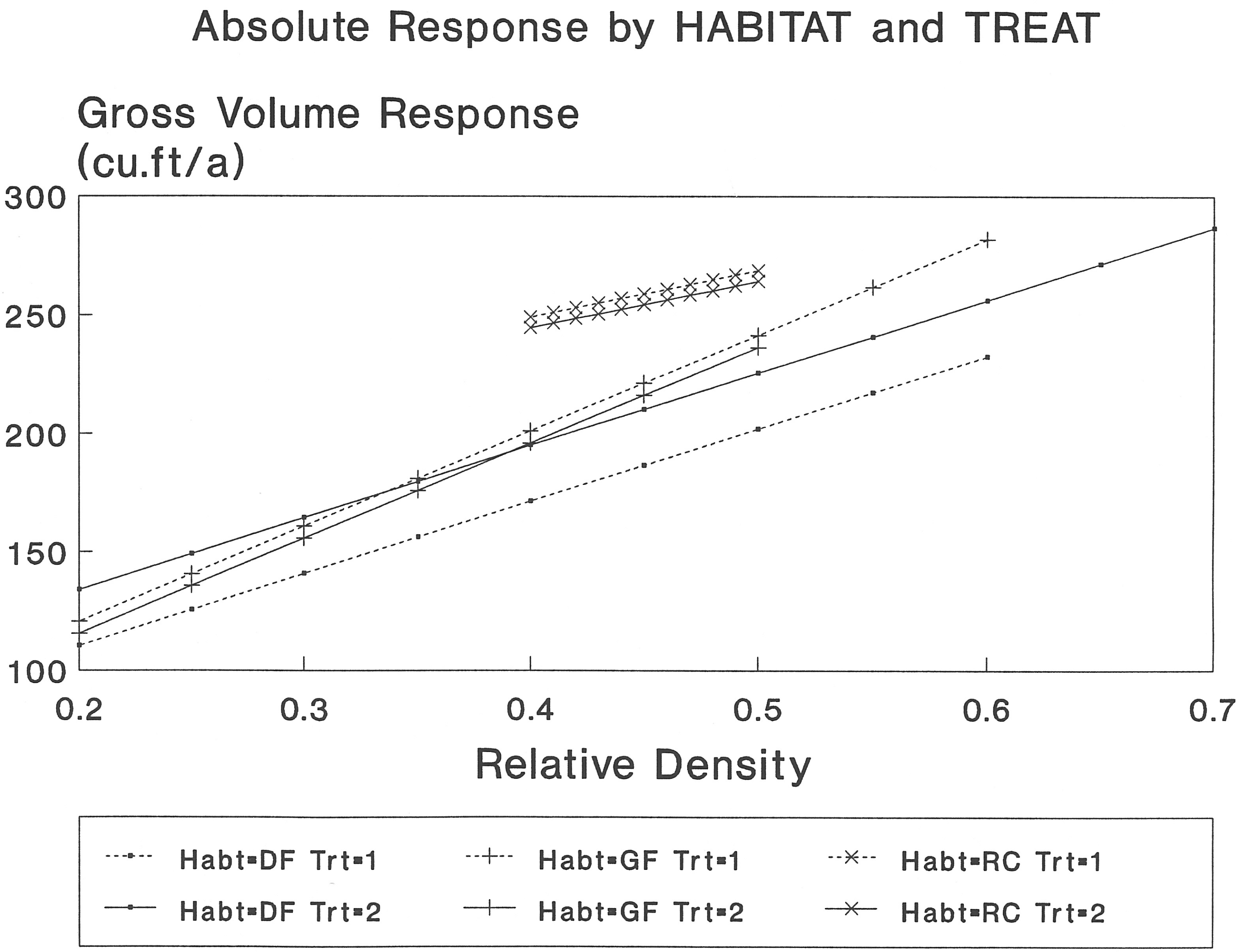

Figure 2. Predicted six-year gross Douglas-fir volume response versus relative stand density for various habitat type series and nitrogen treatment combinations.

combination. For the 400 lb. N treatment, MIN_N is no longer significantly related to response (as in Figure 4), but AV_P is more negatively correlated with response than for the 200 N treatment.

Figures 7 through 10 illustrate the relationships between absolute response and the same soil chemical attributes as in Figures 3 through 6 for basalt parent material and grand fir habitat series. The largest absolute response to the 200 lb. N treatment on basalt parent materials was associated with low MIN_N, similar to granitics. However, the relationship between EX_K and 200 lb. N response for basalts was opposite than it was for granitics; the highest response occurred on sites with low EX_K. One difference in the two parent materials is illustrated by comparing the X axis of figures 3 and 7, basalts had a much higher mean and wider range for EX_K than did granitics. Perhaps this difference in the data effects the relationship between 200 N response and EX_K by parent material. The 400 lb. N treatment showed a similar MIN_N and EX_K response surface (Figure 8) as for the 200 lb. N treatment. Again, the basalt results were different than those for granitics (compare figures 4 and 8). The parent material differences are further manifested in the response trends for AV_P seen by comparing Figures 5 and 6 with Figures 9 and 10. On basalt derived soils, high AV_P sites produced larger N responses, contrary to the trend observed on granitics. The relationships between EX_K and response and AV_P and response are opposite for basalt versus granite parent materials. At this point, we do not know why these relationships change by parent material, but one observation may help add to the uncertainty, EX_K and AV_P probably don't measure the same characteristic about K and P availability respectively. Binkley (1986) suggests that the laboratory methods we used for AV_P provides an index of P available to trees. However, he also suggests that EX_K may represent the total available K only in old highly weathered soils,

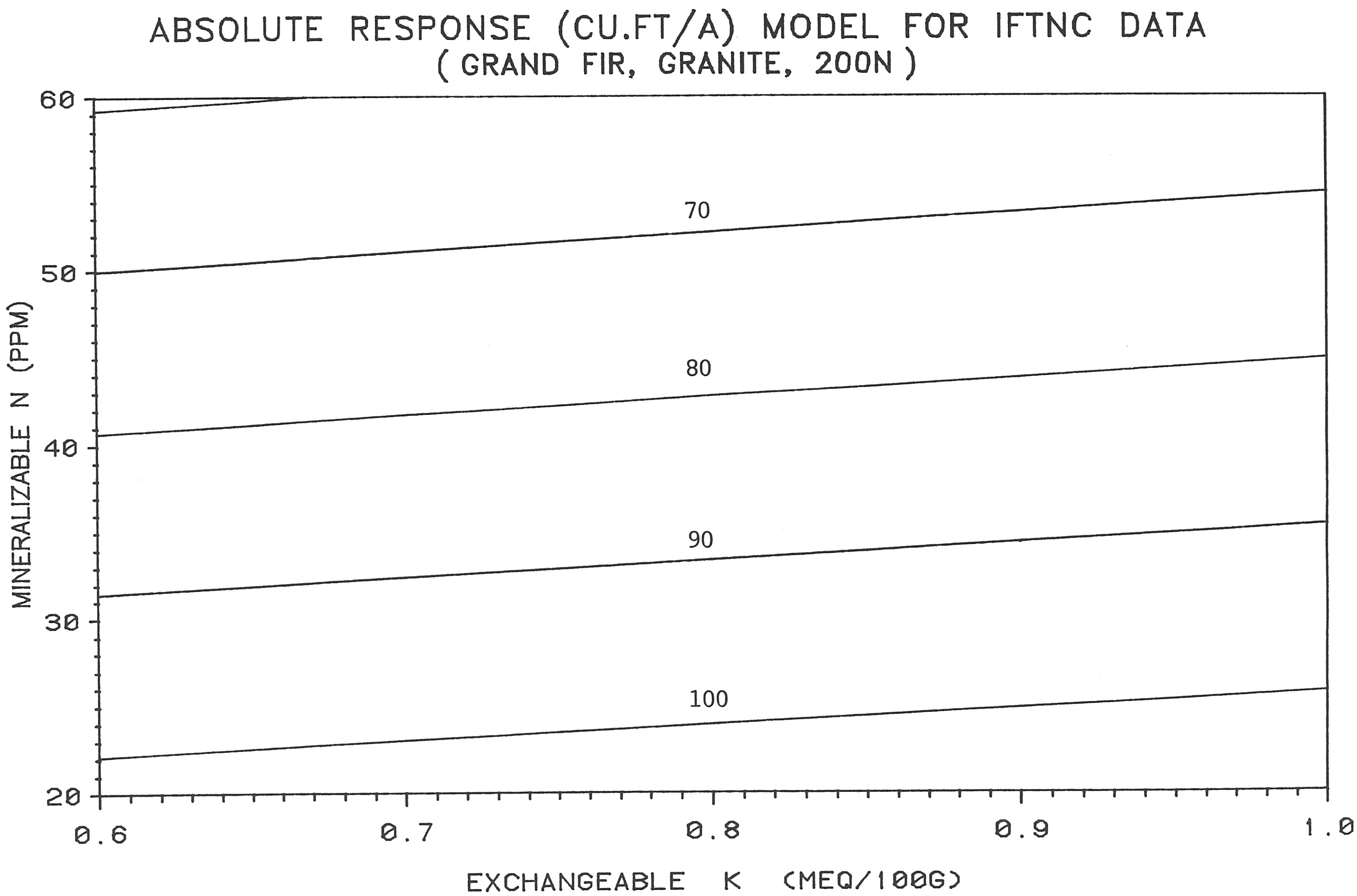

Figure 3. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

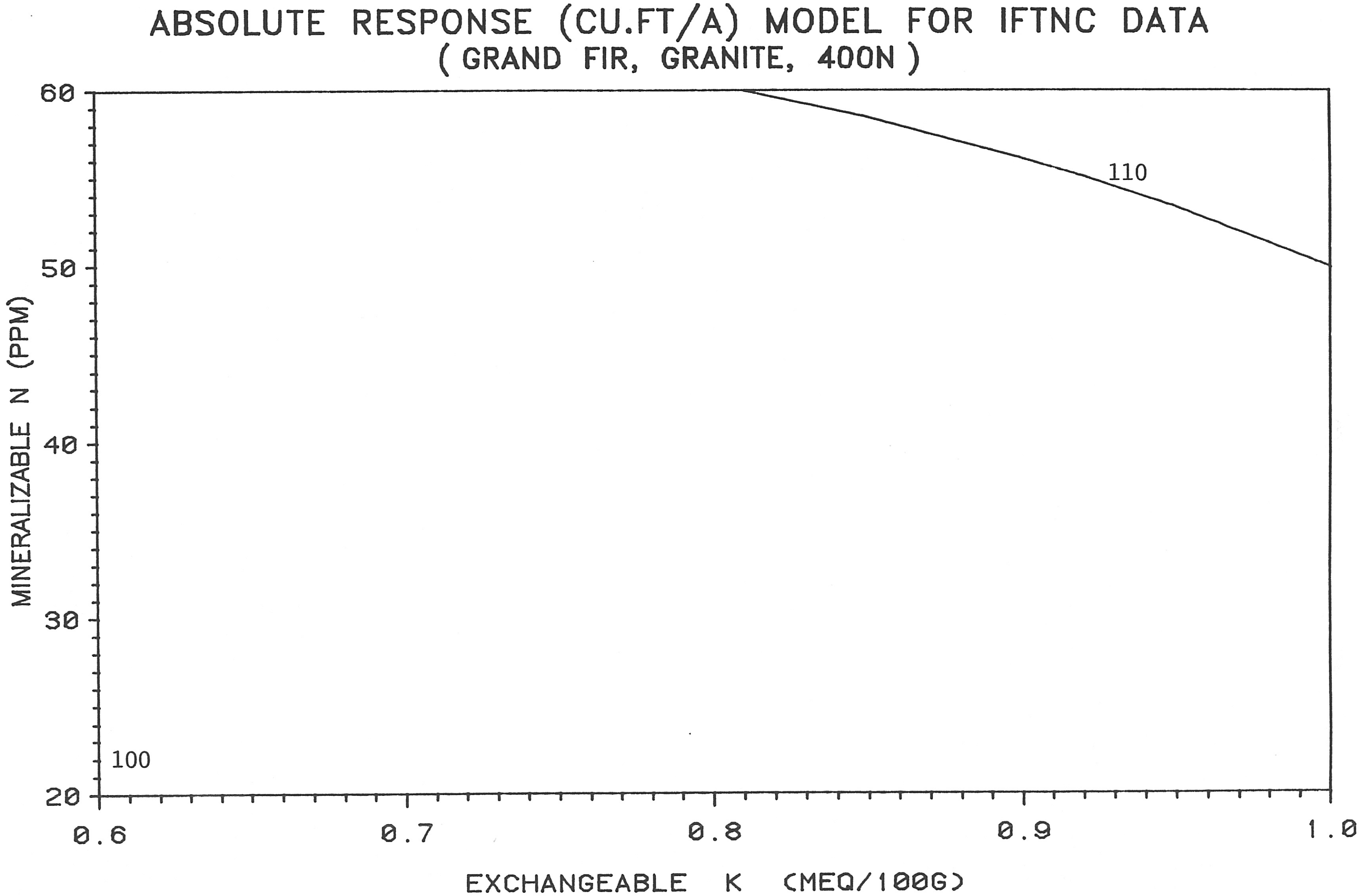

Figure 4. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and exchangeable potassium for the 400 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

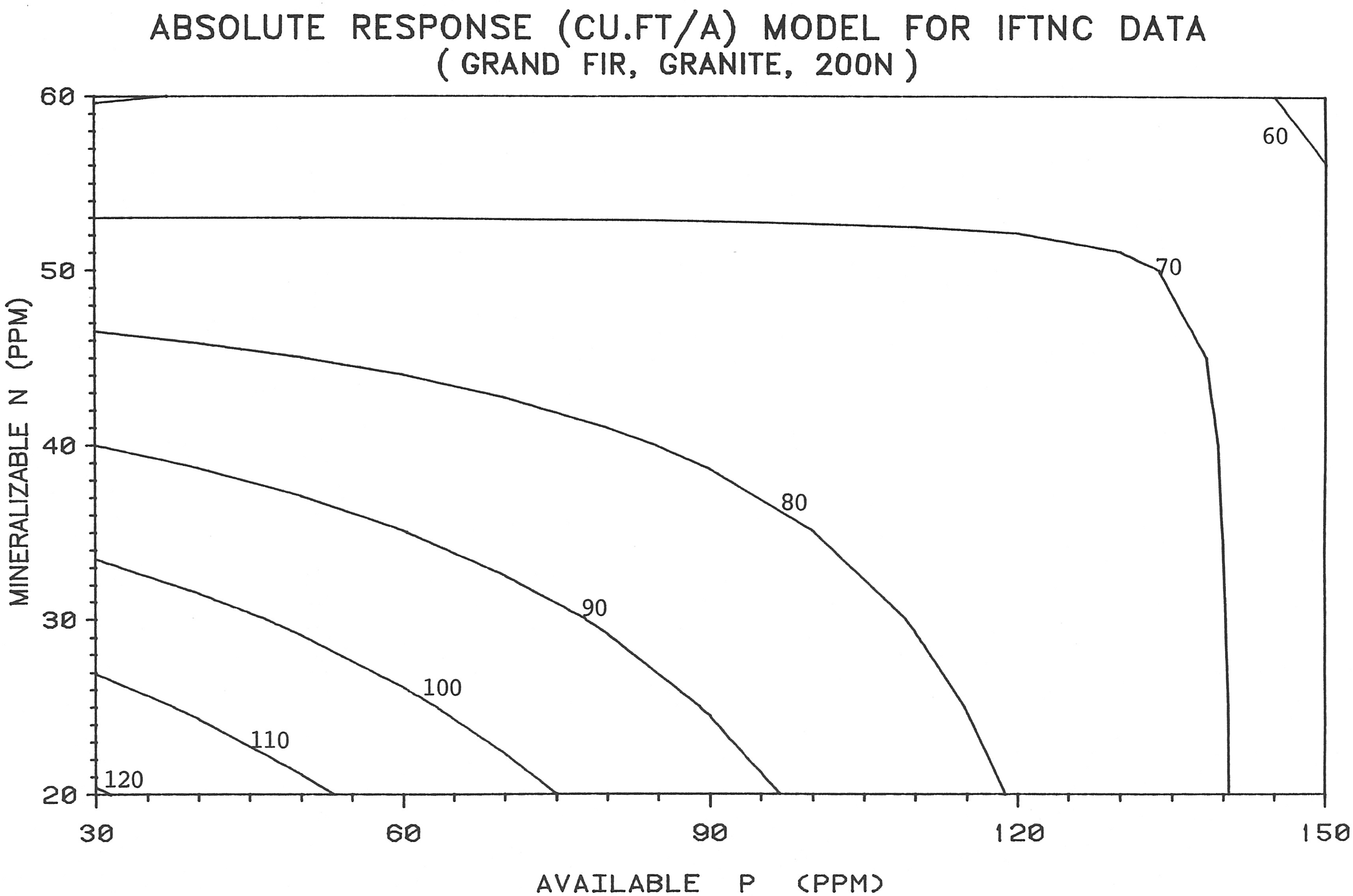

Figure 5. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and available phosphorus for the 200 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

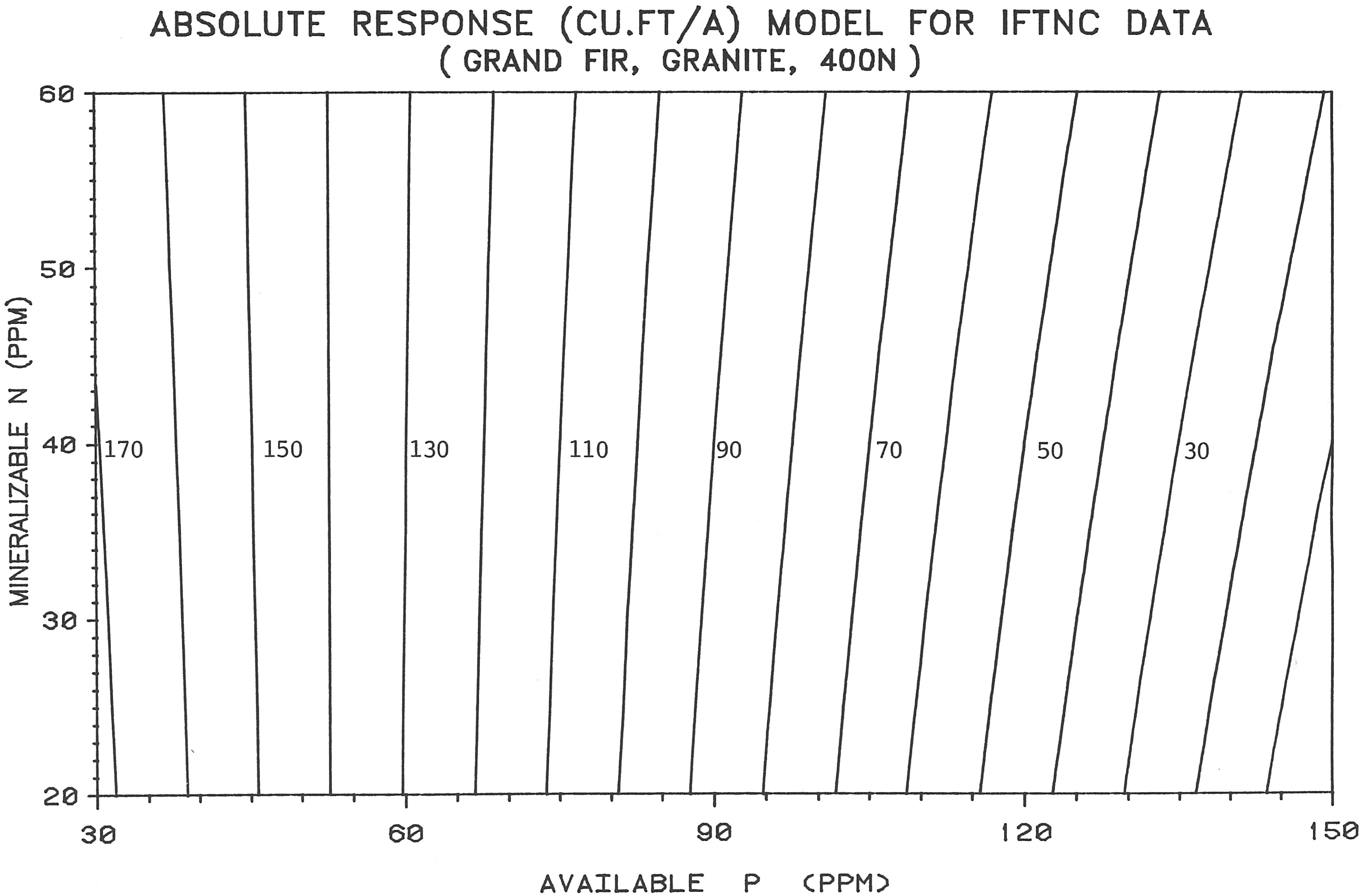

Figure 6. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and available phosphorus for the 400 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

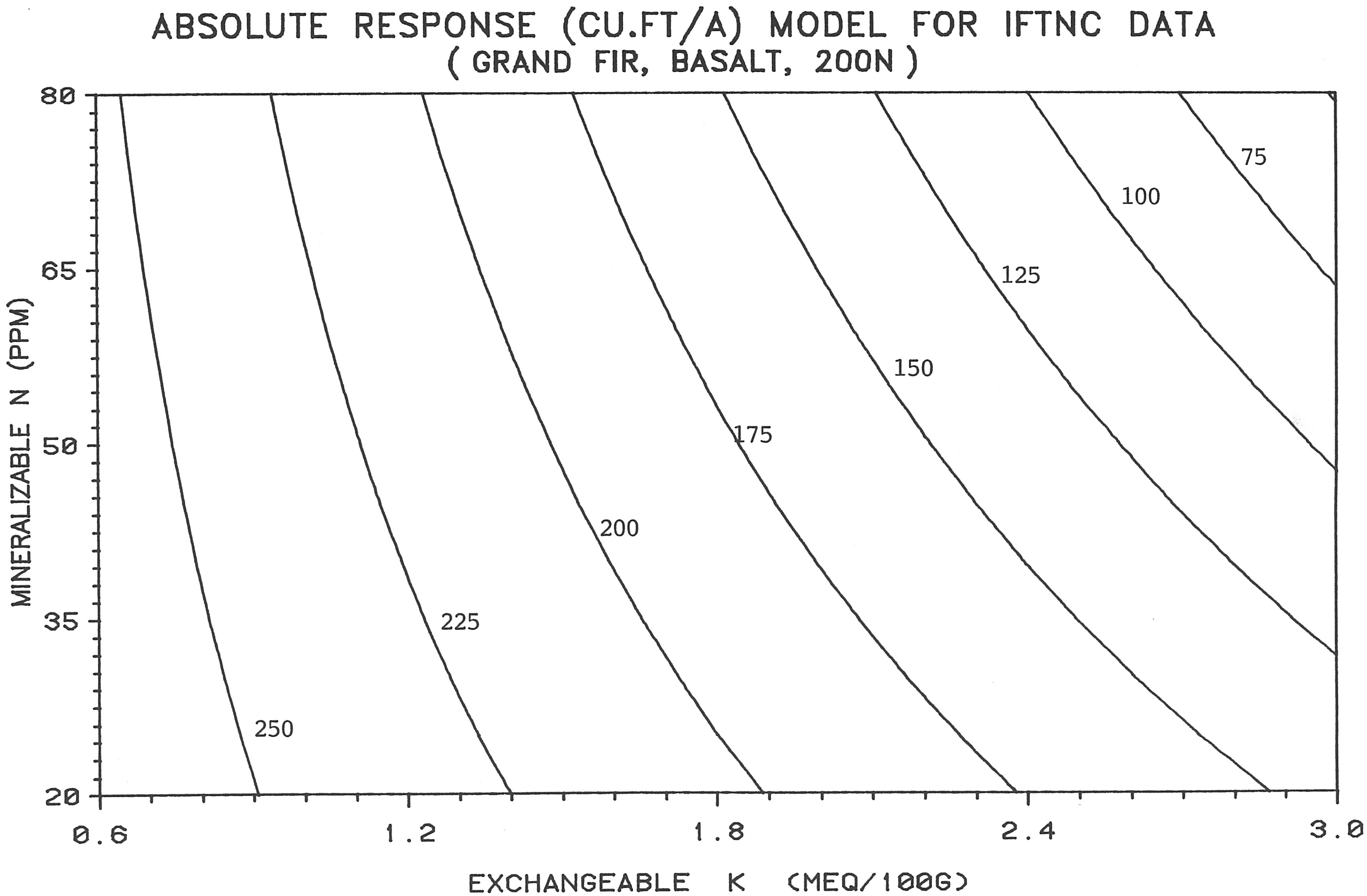

Figure 7. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

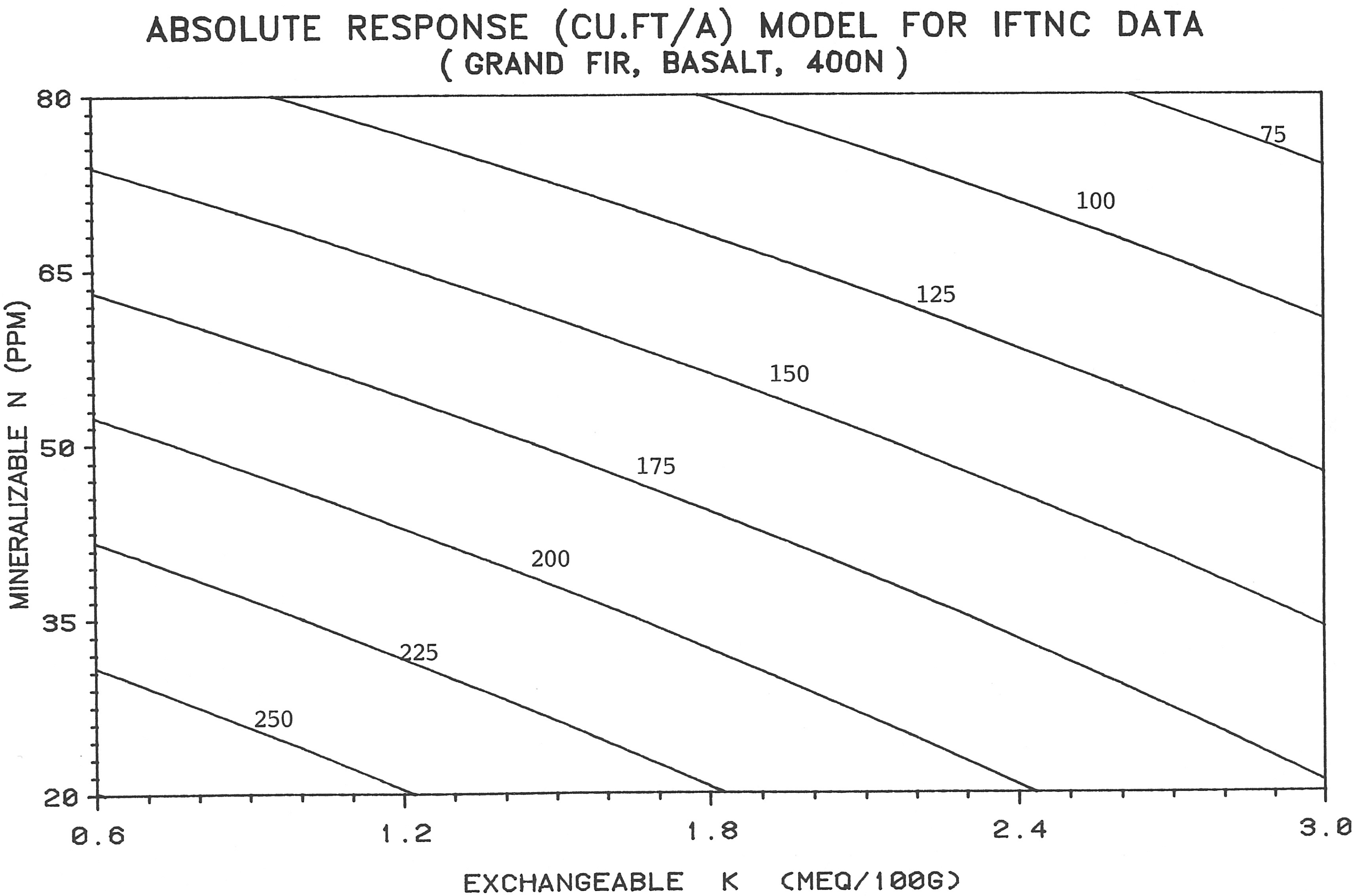

Figure 8. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and exchangeable potassium for the 400 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

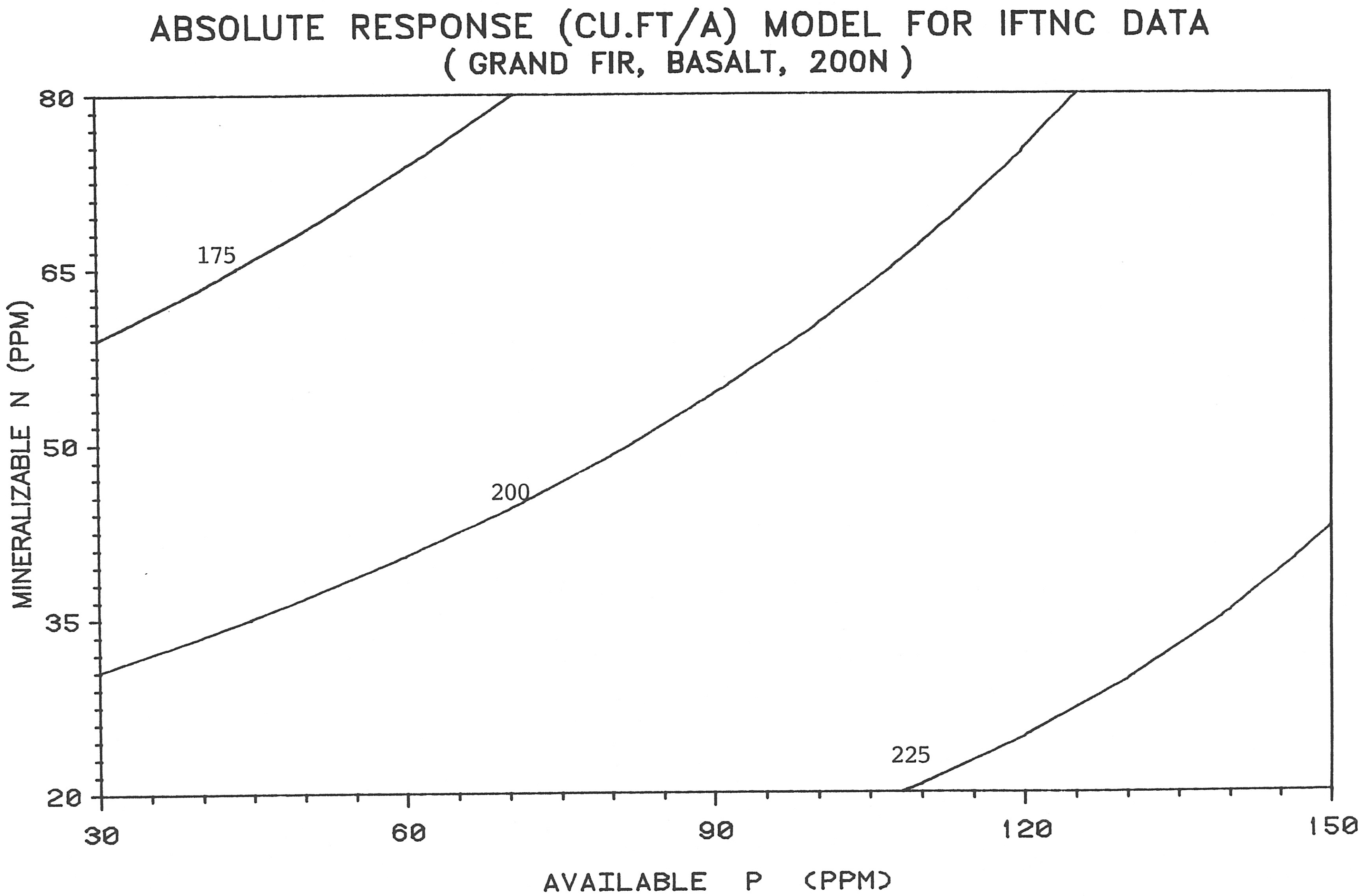

Figure 9. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and available phosphorus for the 200 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

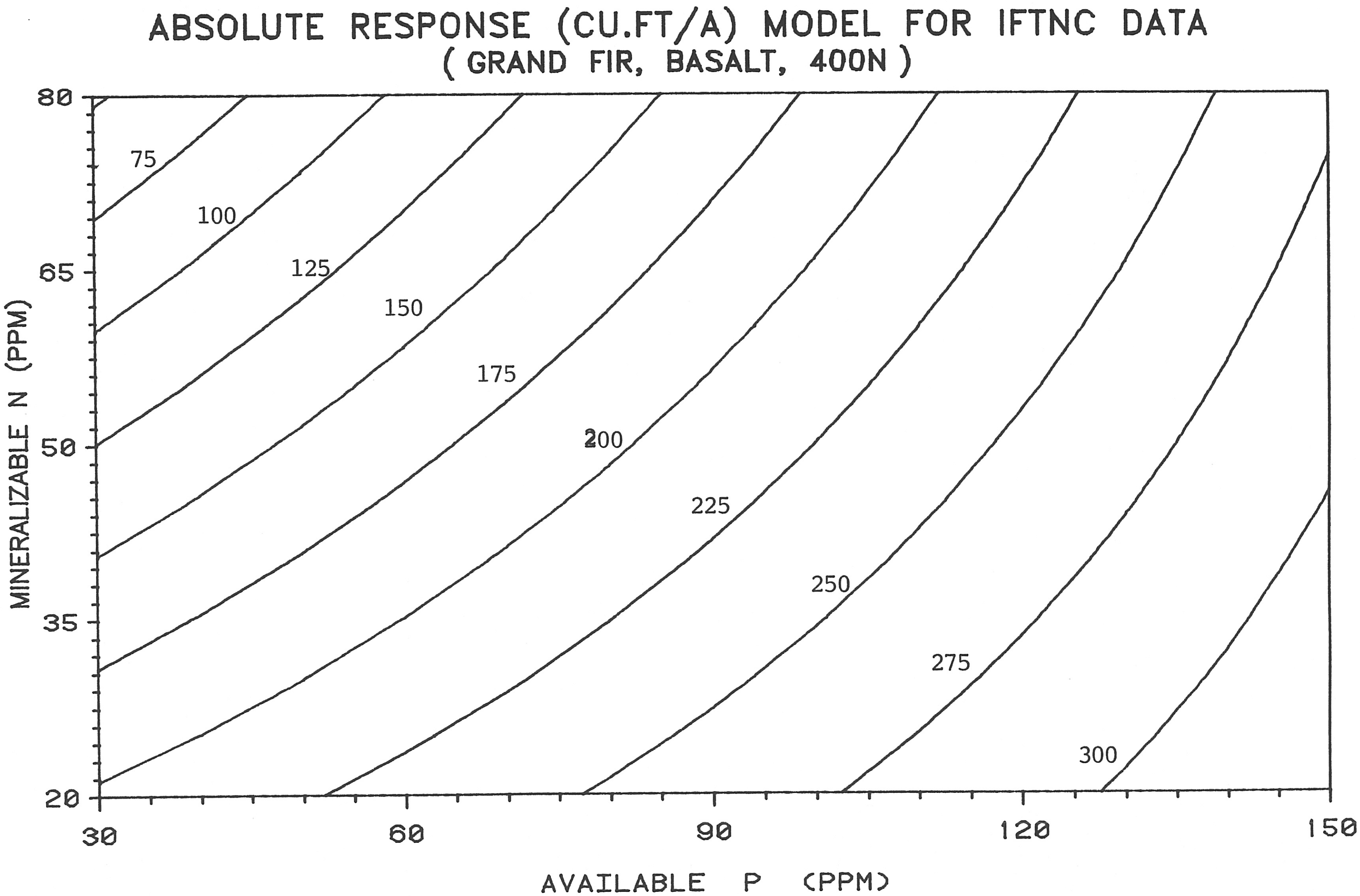

Figure 10. Predicted six-year gross Douglas-fir volume response versus soil mineralizable nitrogen and available phosphorus for the 400 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

but that the exchangeable pool is only part of the available pool in most (probably ours) forest soils.

Model behavior for relative (%) response and the various predictor variables is illustrated in Figures 11 through 19. Elevation was not a significant variable in explaining relative response to fertilization, although it was significant for absolute response. The relationship between six-year N response (%) and stand density (RDO) is shown in Figure 11. As density increases, so does response to both nitrogen treatments. This relationship is similar to absolute response and density (Figure 2). An interesting contrast between habitat series and fertilization response can be seen comparing Figures 2 and 11. Red cedar habitats show the highest absolute but lowest relative response, while Douglas-fir types show the highest relative response. Cedar types have higher untreated growth rates, thus a smaller relative increase translates to more absolute wood response to nitrogen fertilization; however, the difference between cedar and Douglas-fir absolute response may be smaller than expected because of the higher relative response to N fertilization on Douglas-fir habitats.

The relationships between the soil chemical variables and relative response (Figures 12 through 19) are similar to those previously discussed for absolute response. In summary, MIN_N is a consistent indicator of both absolute and relative response, lower soil MIN_N prior to treatment is associated with higher response to N fertilization. Other soil chemical properties, EX_K and AV_P are also significantly related to N response, but the these relationships change depending on soil parent material. The underlying causative factors for these results are currently unknown. Nevertheless, these stand, site, and soil attributes account for a substantial amount of the variation ($\simeq$ 40%) in six-year Douglas-fir response to N fertilization.

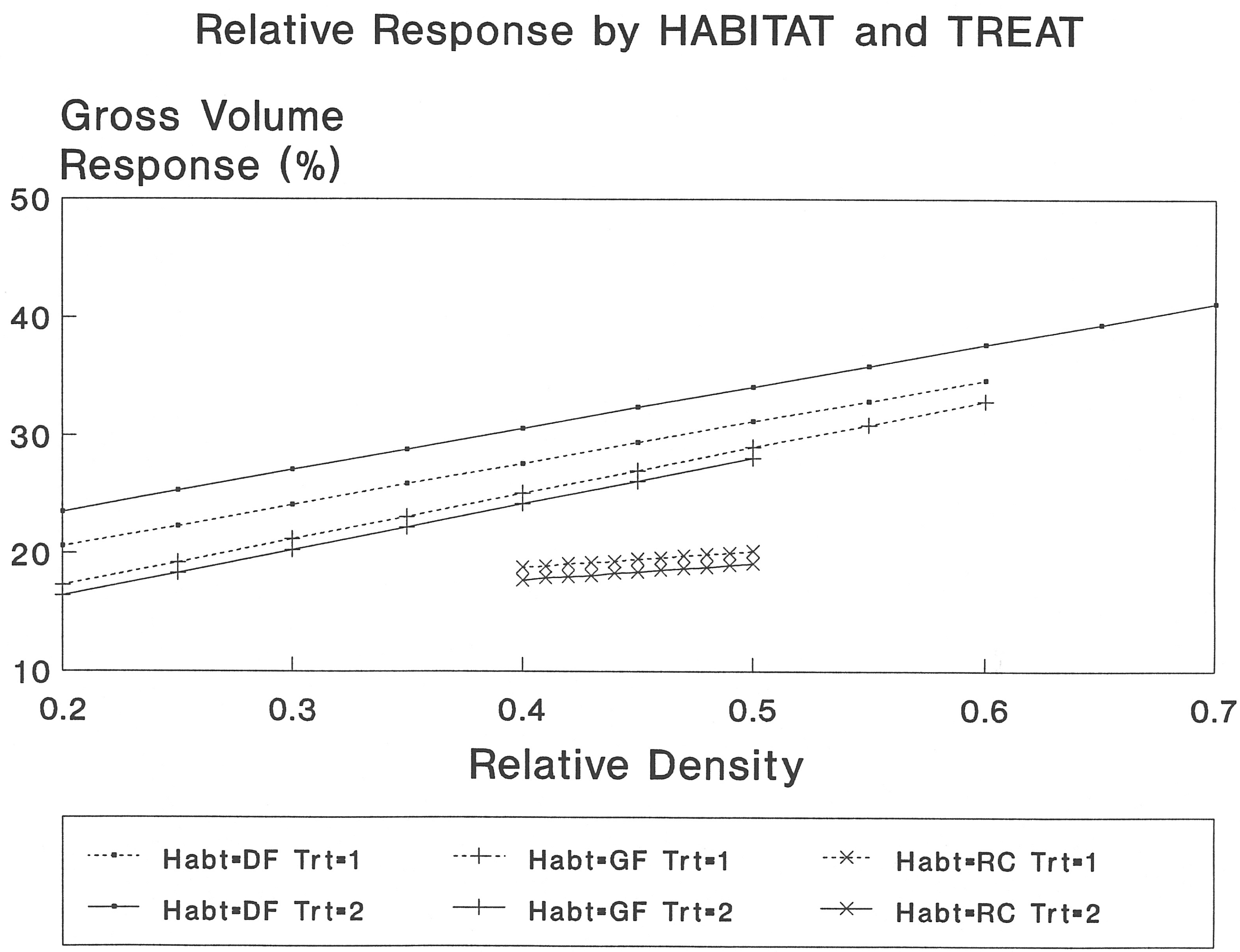

Figure 11. Predicted six-year gross Douglas-fir relative response versus relative stand density for various habitat type series and nitrogen treatment combinations.

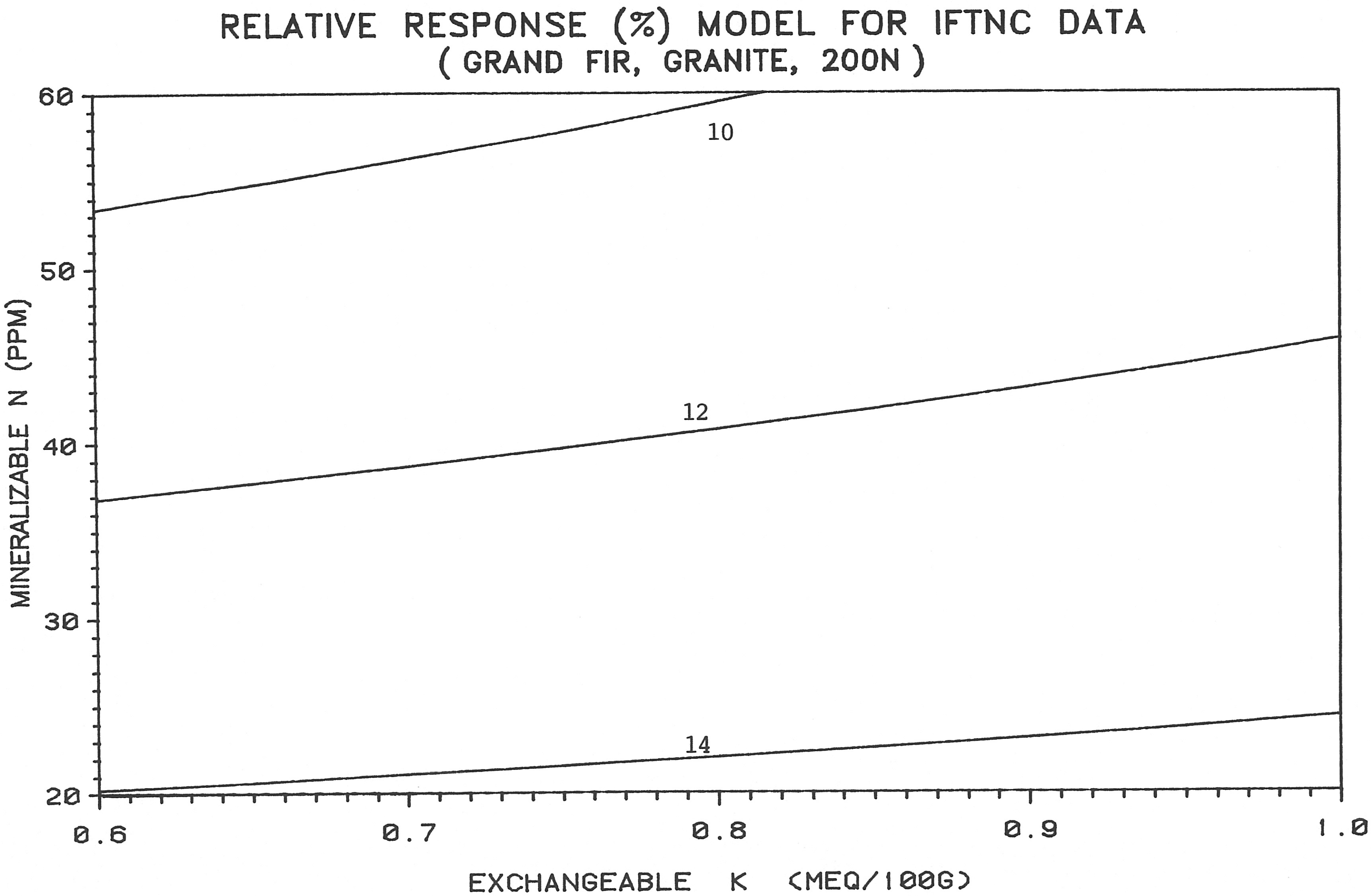

Figure 12. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

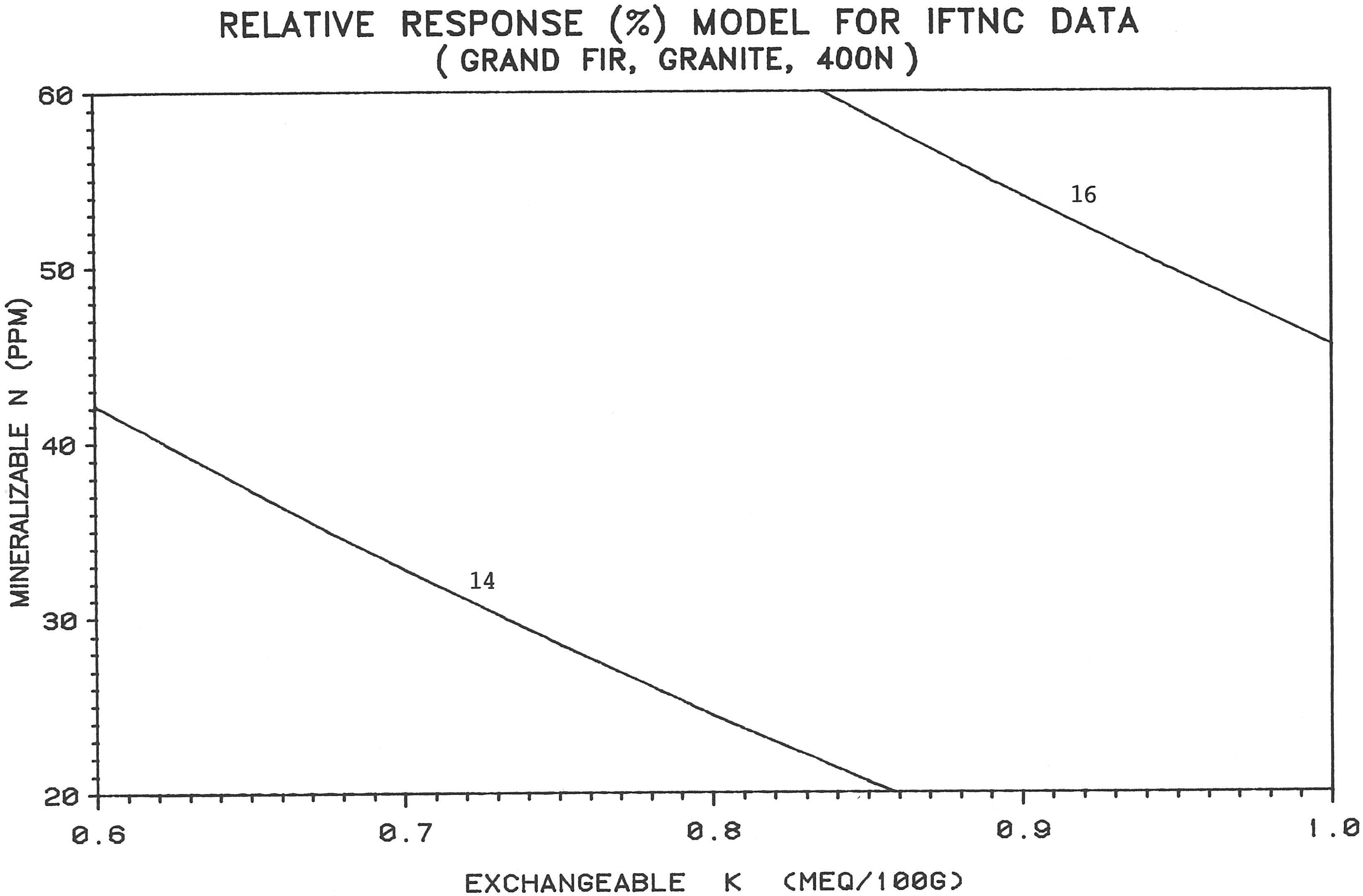

Figure 13. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

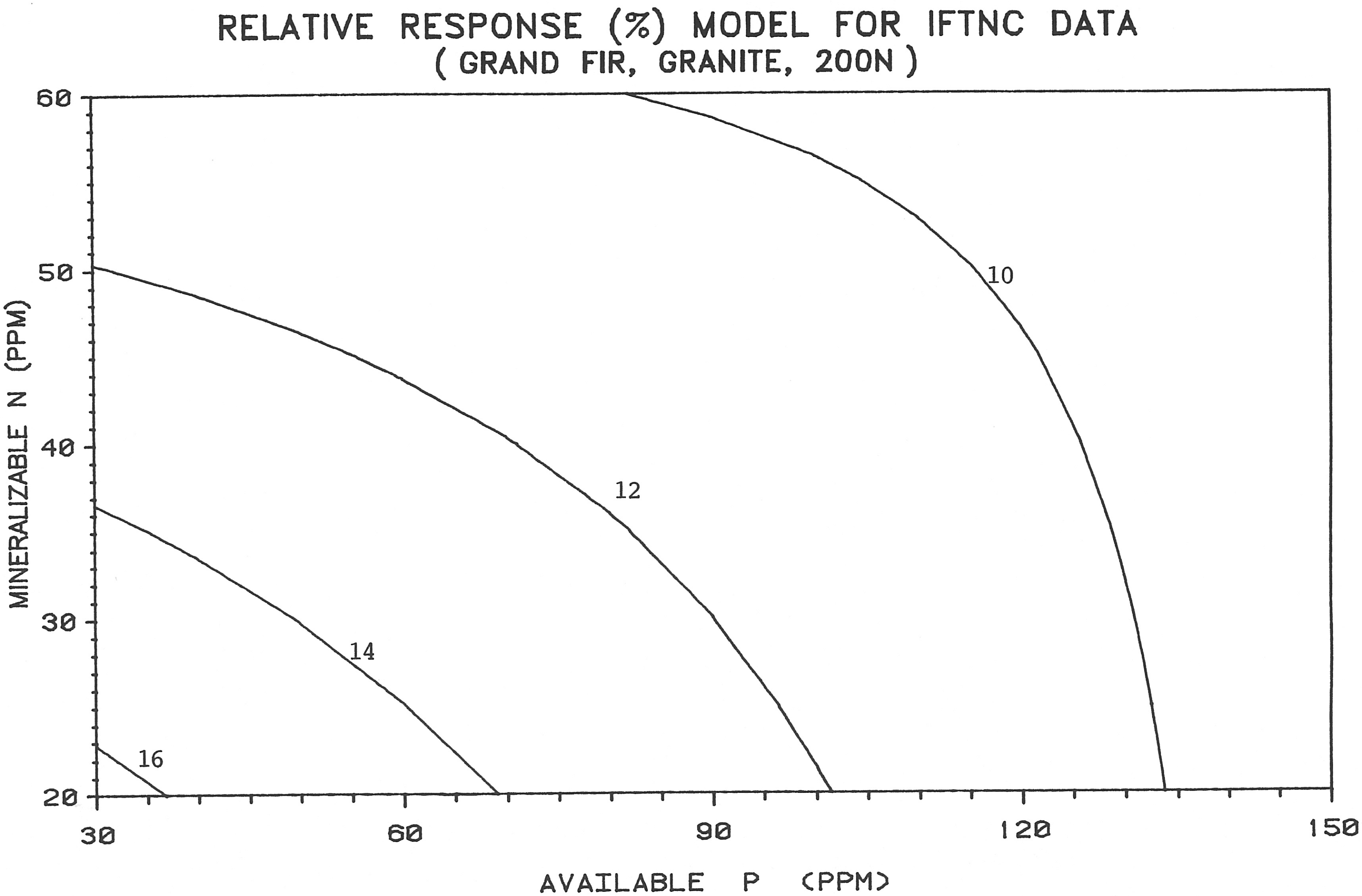

Figure 14. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and available phosphorus for the 200 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

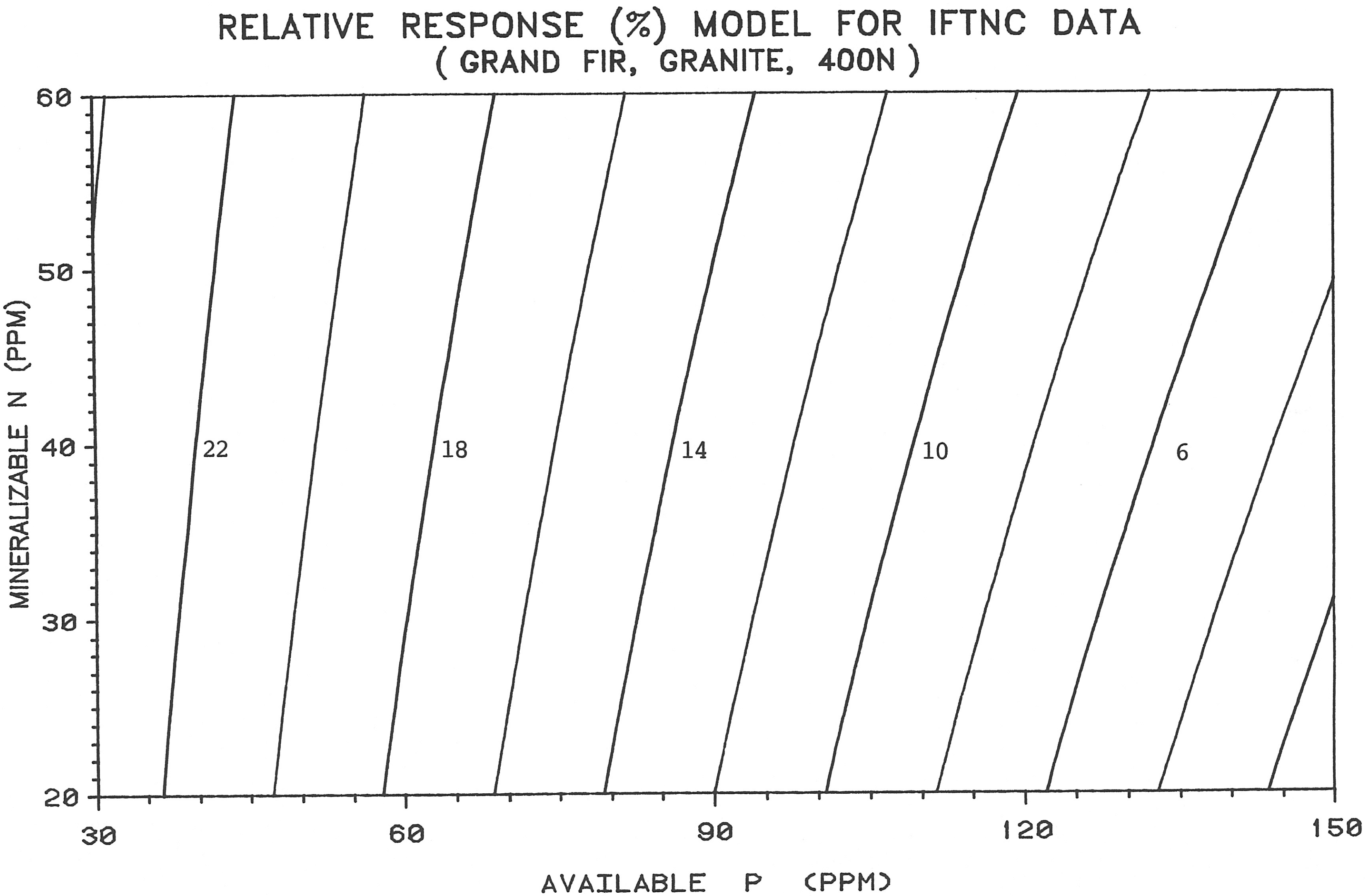

Figure 15. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and available phosphorus for the 400 hundred pound nitrogen treatment on grand fir habitat series and granite parent material.

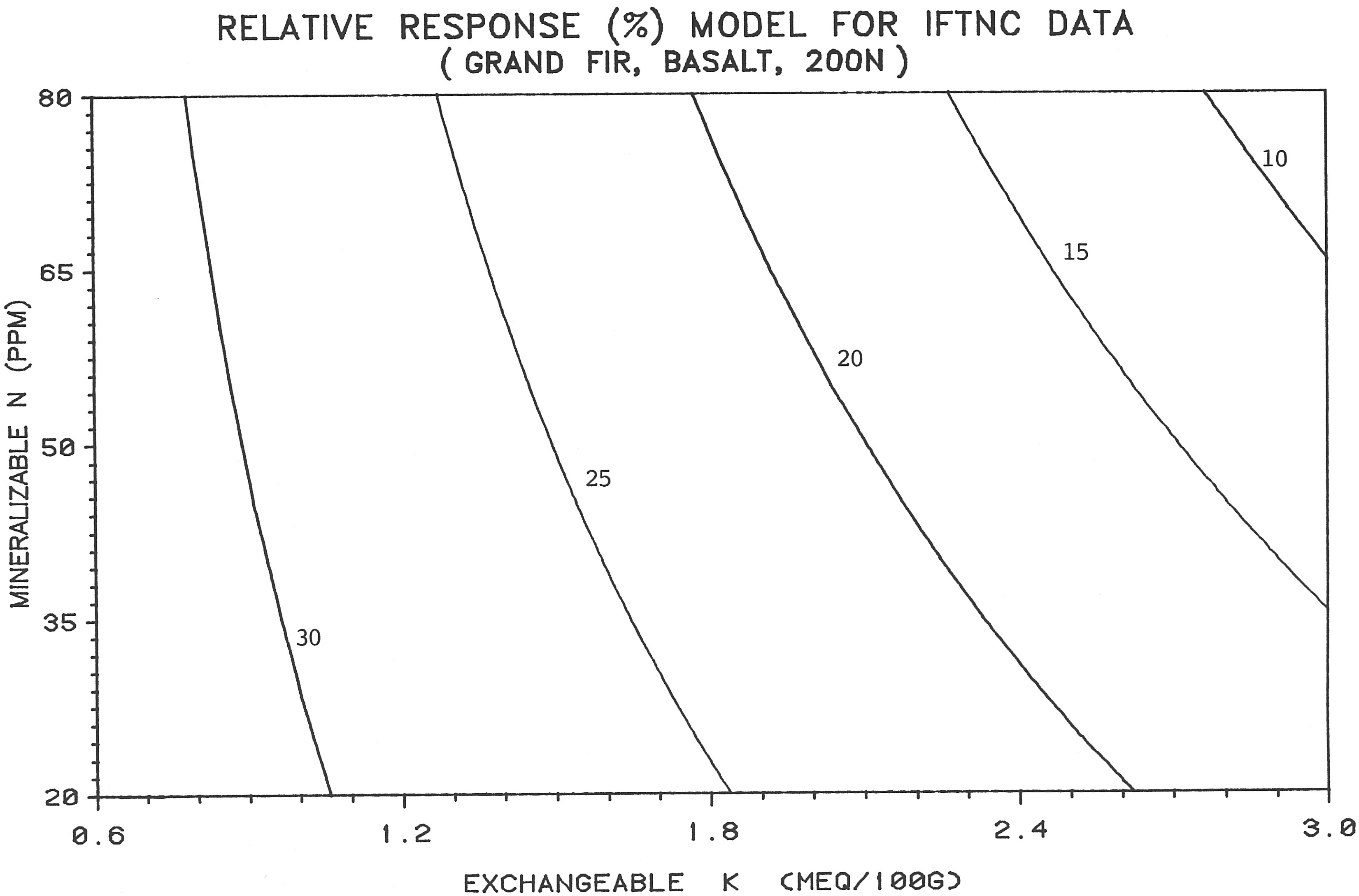

Figure 16. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

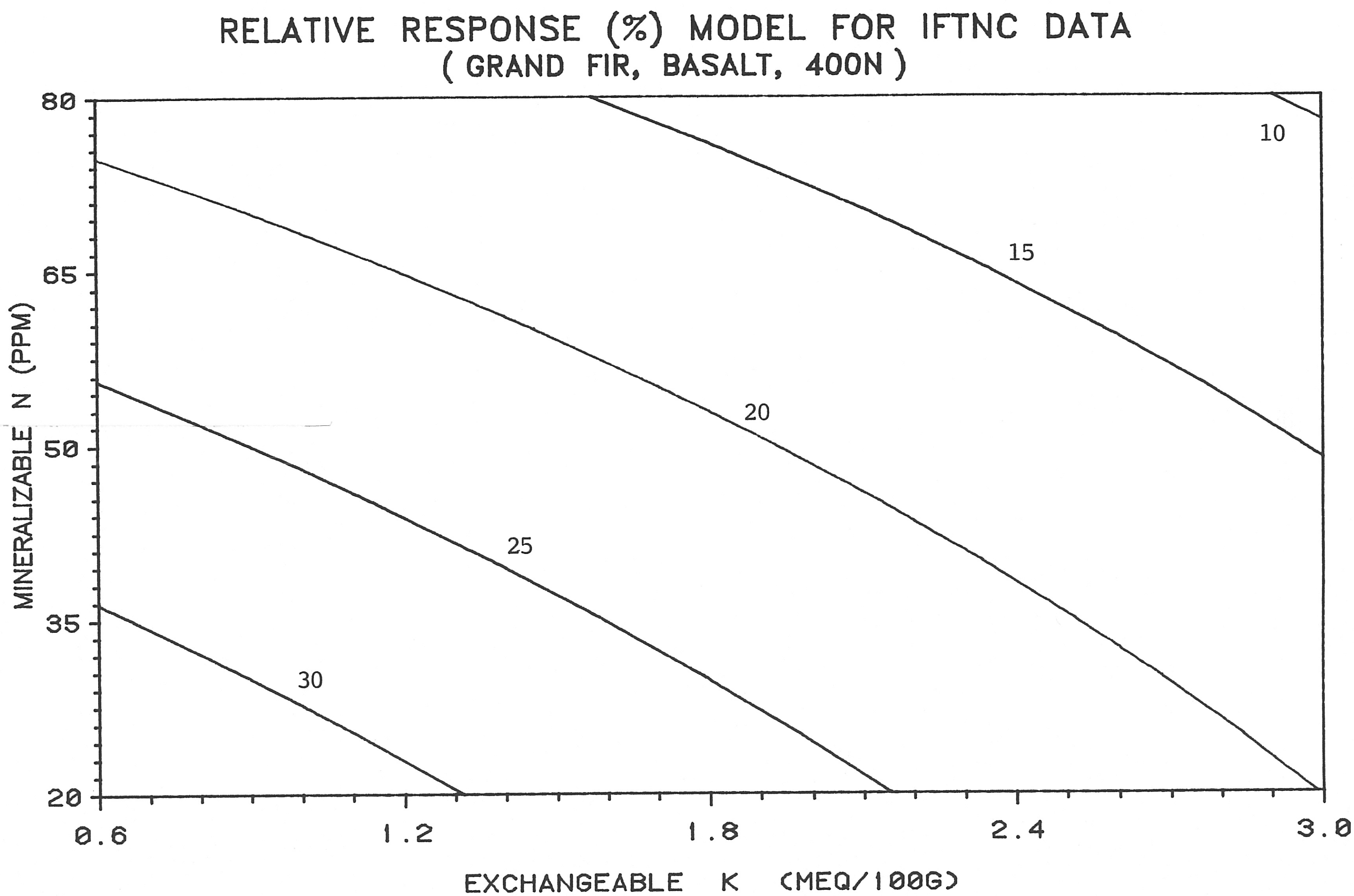

Figure 17. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 400 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

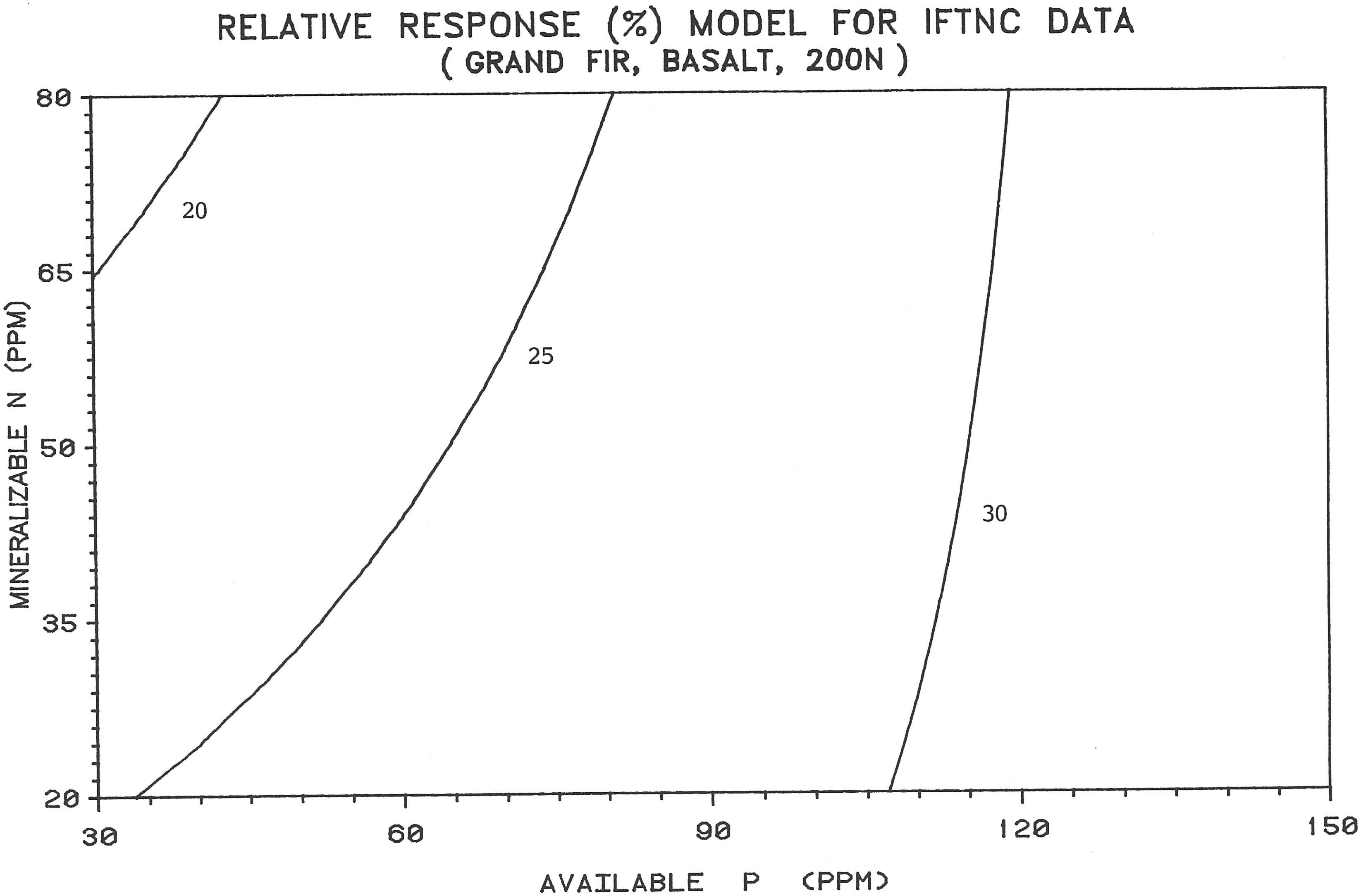

Figure 18. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 200 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

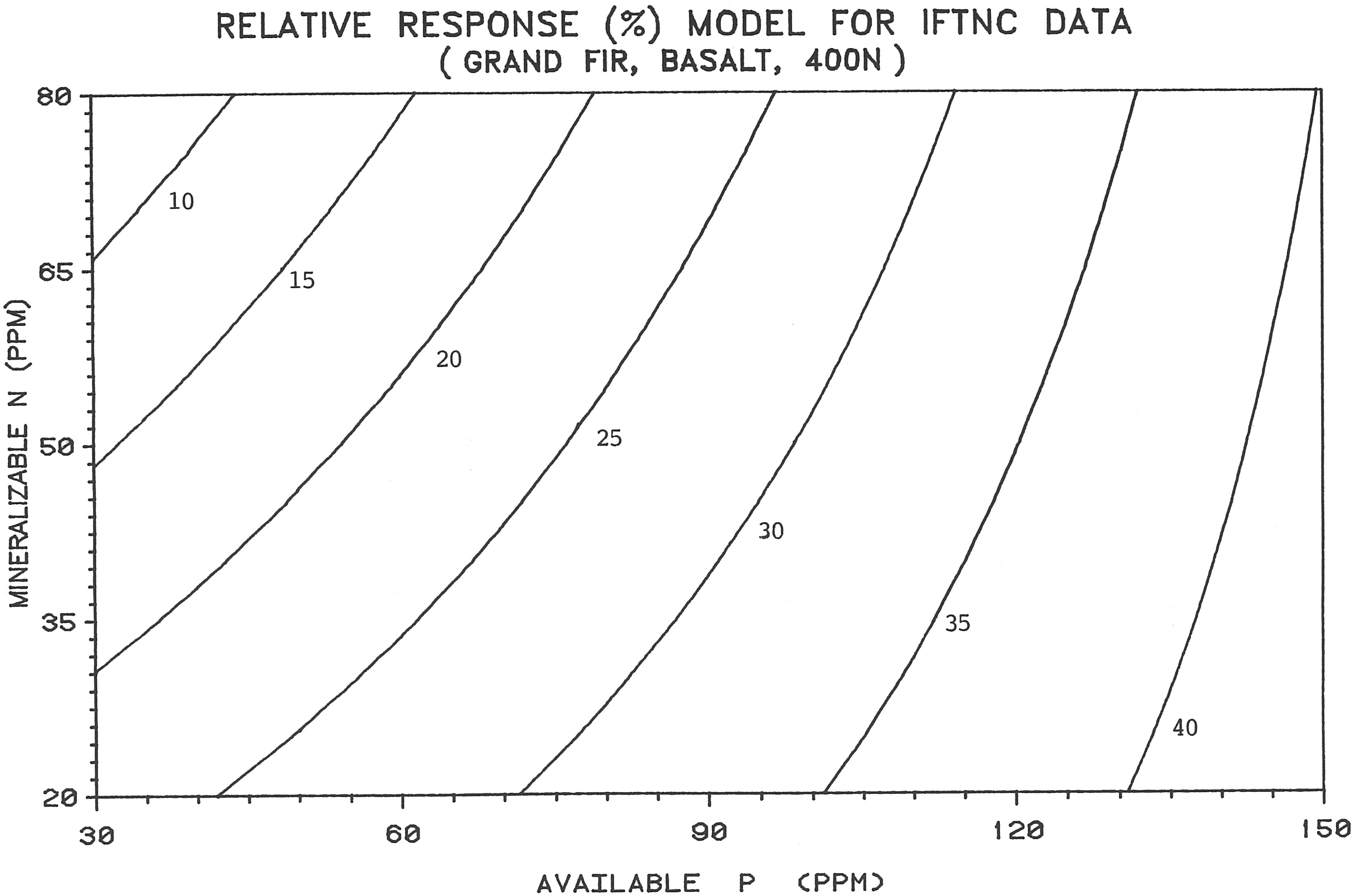

Figure 19. Predicted six-year gross Douglas-fir relative response versus soil mineralizable nitrogen and exchangeable potassium for the 400 hundred pound nitrogen treatment on grand fir habitat series and basalt parent material.

Predicting the Probability of a "Significant" Response to Nitrogen Fertilization

One portion of our analysis plan for this year was to develop a statistical model to predict the probability of μ fertilization response greater than a specified amount, such as 10% or 20% etc. These analyses were mostly unsatisfactory. Therefore, we decided to follow a different analytic approach as follows: we stratified the entire Douglas-fir experiment into two useful (ie significant) categorical variables, habitat type series, and soil parent material and then allow the data to directly make "probability statements" in the form of graphs and tables showing cumulative distributions of N fertilizer response. The "other" parent material class includes sedimentary, metasedimentary and mixed rocks. Absolute response probabilities for 200 lbs. N treatment are provided in Table 3 and Figure 20. Fertilizing with 200 lbs. of N on grand fir habitat types produced six-year responses greater than 277 ft^3/ac. 50% of the time (that's a lot of wood). Further, if the same treatment was applied to cedar habitat types, the chances of obtaining a very large response would be pretty good since 25% of installations on cedar types produced responses greater than 375 $ft.^3/Ac$. If we excluded granite soils from fertilization plans for grand fir types then we could expect responses greater than $\approx$305 $ft.^3/ac$. 50% of the time (Table 3). None of the high responders of the grand fir habitats are on granite soils (Figure 21). Overall the 400 lb. N treatment does not seem to produce increased growth response over the 200 lb. N treatment. This is primarily due to more large negative responses for the 400 lb. N treatment (Table 3). However, if we consider this treatment only on red cedar habitat types (Figure 22), there are no negative responders and 50% of the installations produced responses greater than 329 $ft.^3/Ac$. (That's a lot of additional wood in six years). One important aspect of Figure 23 is that red cedar habitat types were almost entirely located on the "other" soil parent material class (Table 3).

Table 3. Selected percentiles of the absolute six-year Douglas-fir response (ft^3/a) distribution by habitat type and soil parent material

Habitat Type and Parent Material	200 lb N/acre # of Plots	Min.	25%	50%	75%	Max.
DF - Granite	8	- 21	5	122	266	339
Basalt	16	-245	- 68	152	305	695
Other	25	-249	- 91	63	303	550
GF - Granite	6	-210	-162	9	125	226
Basalt	12	-205	- 13	302	423	694
Other	11	- 69	168	312	351	470
RC - Basalt	3	11	11	397	475	475
Other	13	-200	-121	163	274	653
Douglas-fir	49	-249	- 59	119	290	695
Grand fir	29	-210	- 2	277	348	694
Redcedar	16	-200	- 84	166	375	653
Granite	14	-210	- 26	76	191	339
Basalt	31	-245	- 18	213	386	695
Other	49	-249	- 67	168	323	653
Overall	94	-249	- 37	166	322	695

Habitat Type and Parent Material	400 lb N/acre # of Plots	Min.	25%	50%	75%	Max.
DF - Granite	8	116	186	216	281	432
Basalt	16	-151	95	166	455	808
Other	24	-217	45	143	297	853
GF - Granite	6	-325	- 96	-16	35	168
Basalt	12	-475	- 31	143	426	647
Other	11	- 45	126	260	345	482
RC - Basalt	3	164	164	425	481	481
Other	13	43	134	246	470	545
Douglas-fir	48	-217	95	166	301	853
Grand fir	29	-475	- 16	138	325	647
Redcedar	16	43	143	329	471	545
Granite	14	-325	- 15	176	243	432
Basalt	31	-475	93	164	455	808
Other	48	-217	114	179	401	853
Overall	93	-475	95	168	391	853

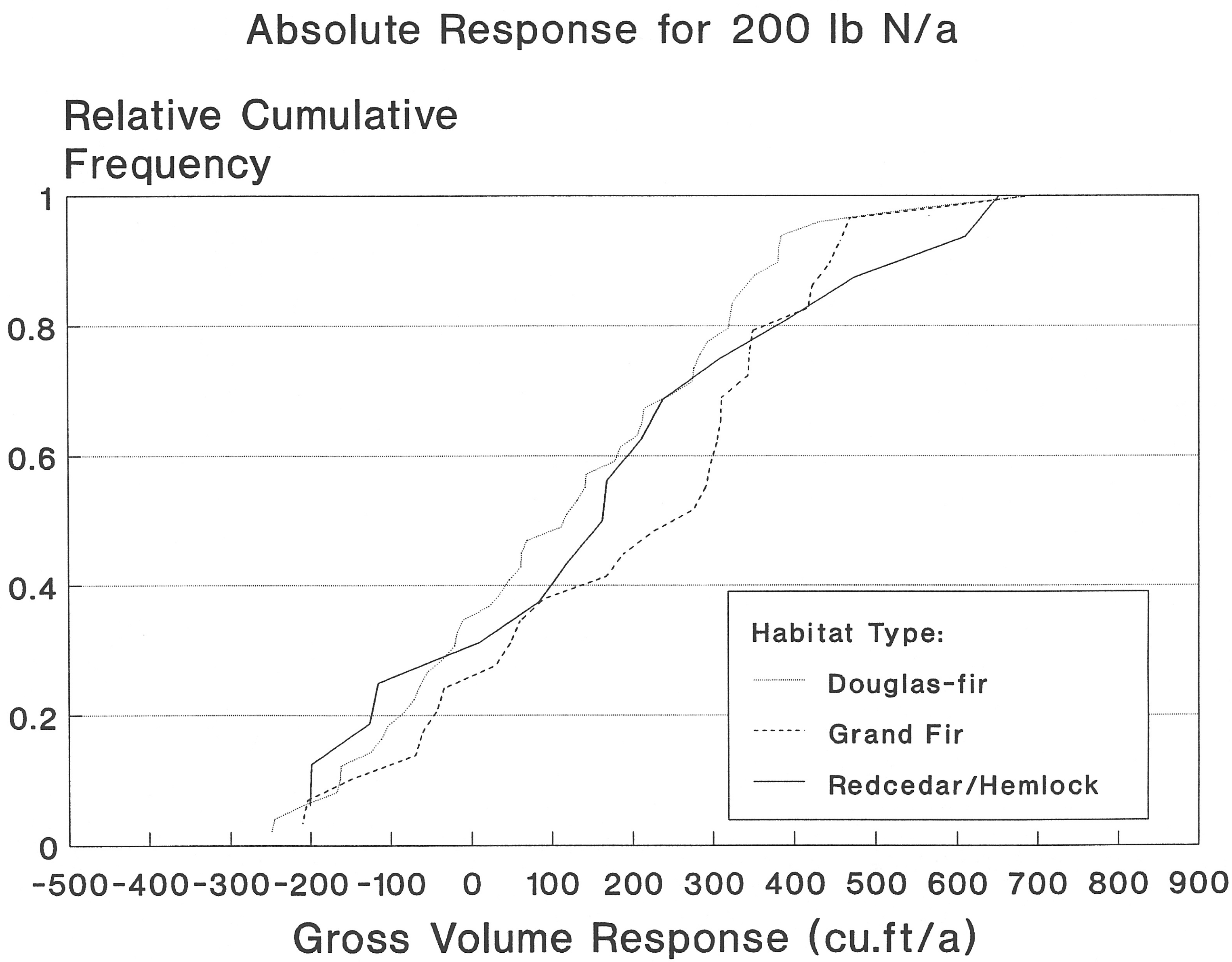

Figure 20. The relative cumulative frequency distribution of six-year Douglas-fir gross volume response (ft^3/A) for three habitat type series for the 200 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

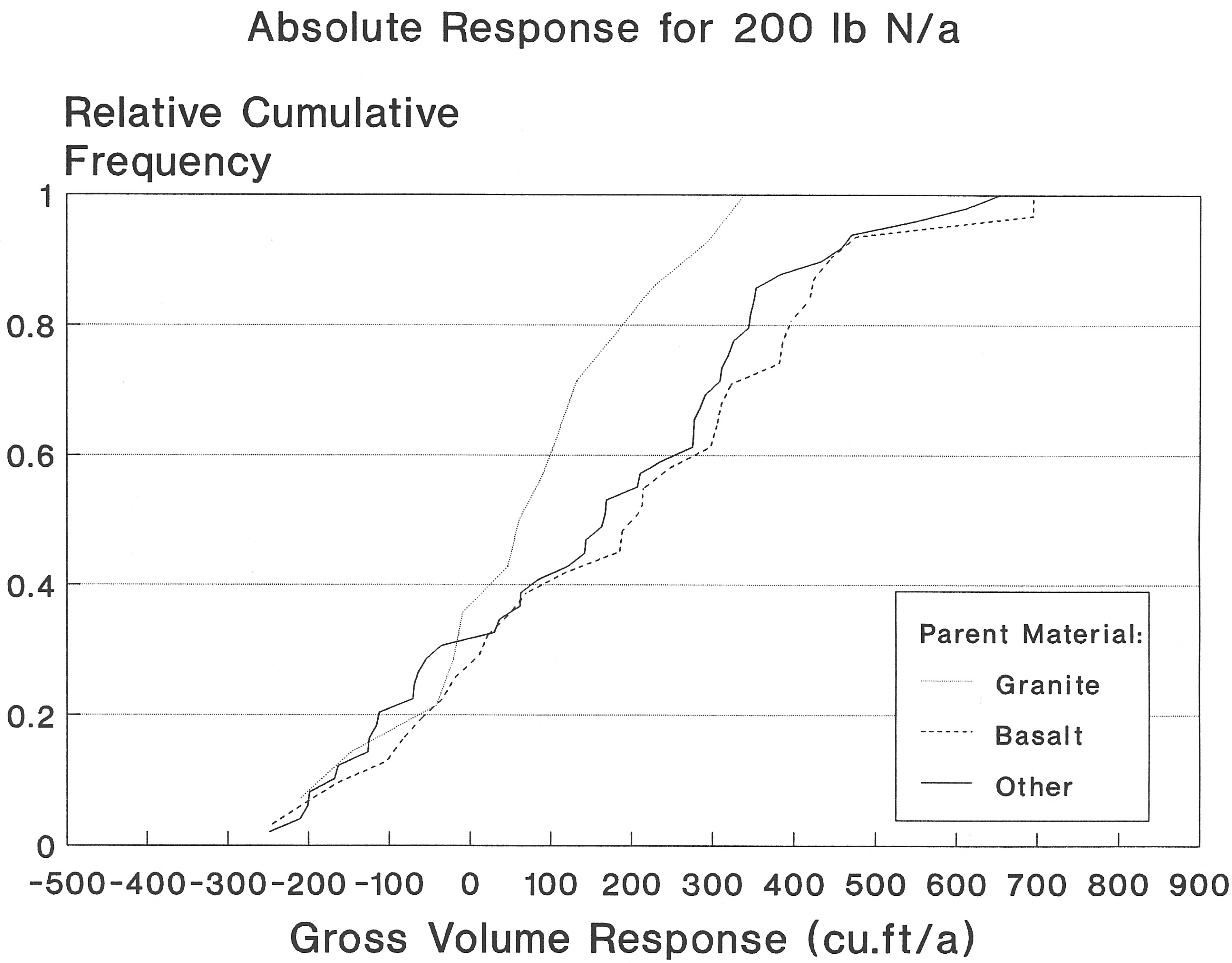

Figure 21. The relative cumulative frequency distribution of six-year Douglas-fir gross volume response (ft^3/A) for three soil parent materials for the 200 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

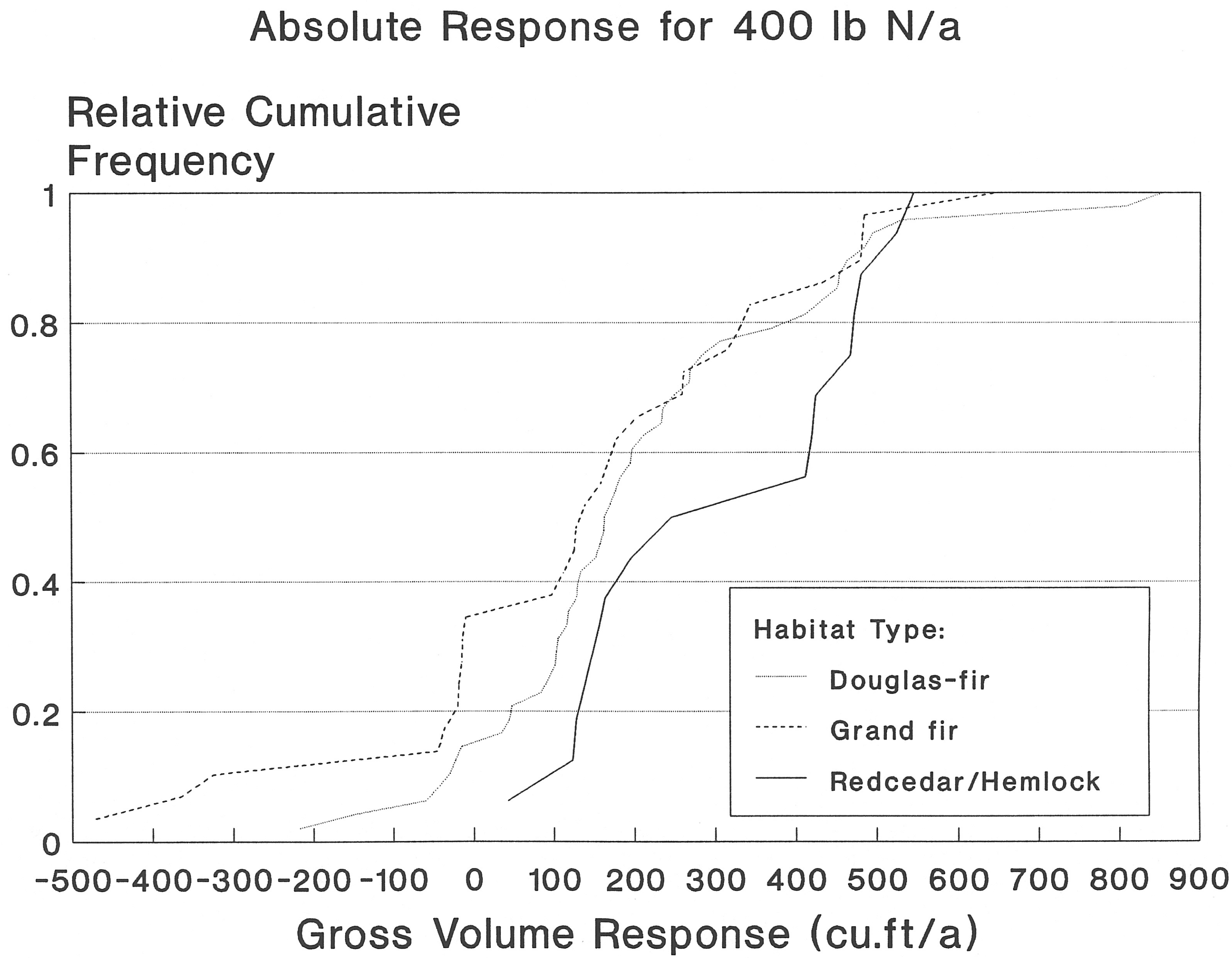

Figure 22. The relative cumulative frequency distribution of six-year Douglas-fir gross volume response (ft^3/A) for three habitat type series for the 400 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

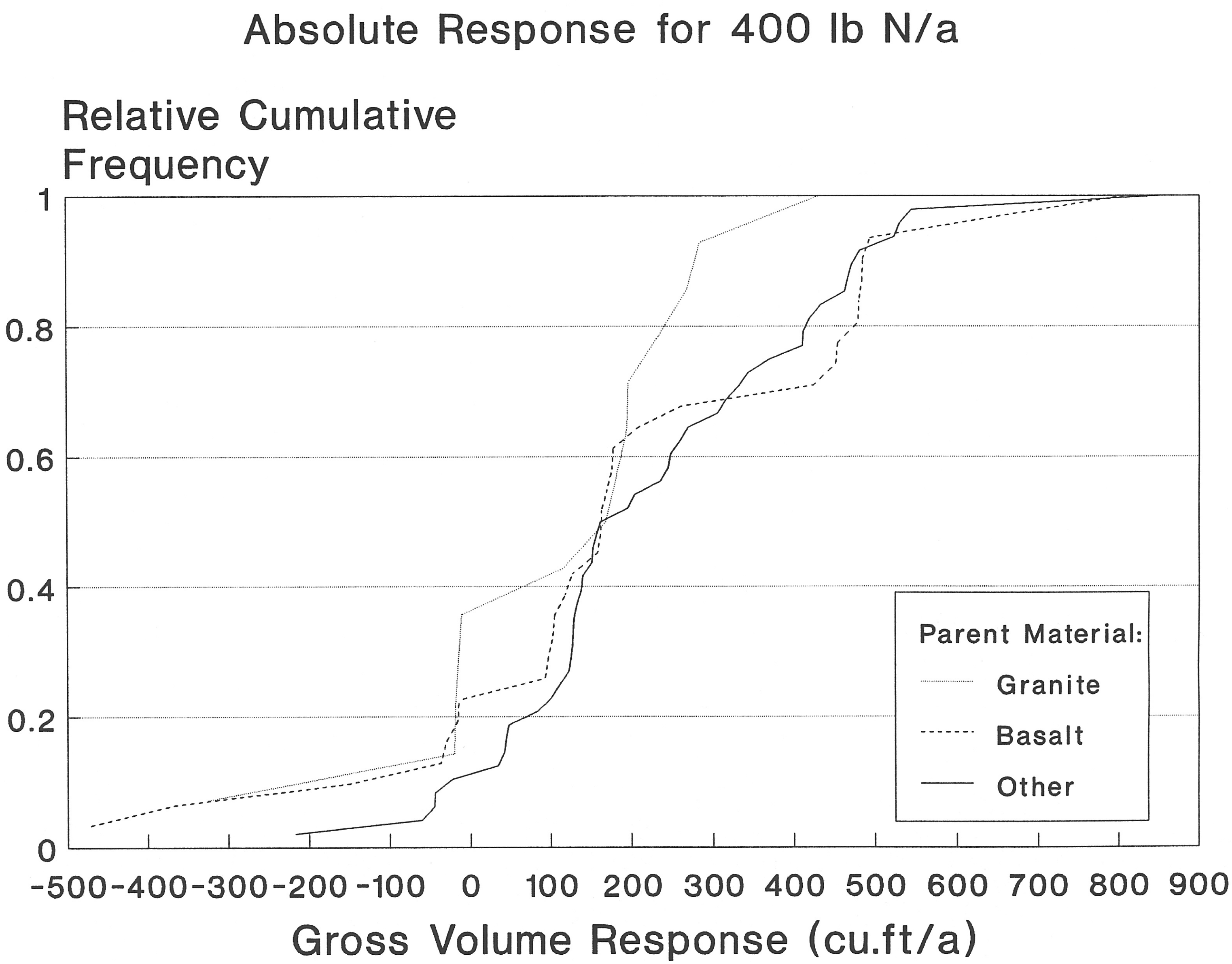

Figure 23. The relative cumulative frequency distribution of six-year Douglas-fir gross volume response (ft^3/A) for three soil parent materials for the 400 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

Cumulative distributions for relative growth response are provided in Table 4 for the same habitat series - soil parent material classes in Table 3. Relative fertilization response can be used to evaluate N fertilization in a different fashion than absolute response. For example, the expected value (50th percentile) for the 200 lb. N treatment relative response is 34.1% for grand fir habitat types (Figure 24 and Table 4). This value could be used as a growth multiplier for stand growth projection models or yield tables in evaluating 200 lbs. N fertilization as a silvicultural treatment during management planning. Red cedar types tend to have lower relative response than the other two habitats. As with absolute response, high relative responders do not occur on granite parent material (Figure 25). Red cedar habitats show less variation in relative 400 lb. N response than grand fir or Douglas-fir types (Figure 26). Douglas-fir series had a few very large positive responding installations as well as some negative responders. The distribution was similar for grand fir types. Fertilizing with 400 lbs. of N per acre on granite derived soils did not produce the very largest relative responses (Figure 27). This result is similar to the 200 lb. N treatment.

Individual cooperators manage different combinations of habitats and soils in their respective forest land bases. Each cooperator can use these Tables and Figures to estimate the probability of a specified fertilization response for habitat and parent material combinations of particular interest.

Table 4 Selected percentiles of the relative six-year Douglas-fir response (%) distribution by habitat type and soil parent material

Habitat Type and Parent Material	200 lb N/acre					
	Plot	Min.	25%	50%	75%	Max.
DF - Granite	8	- 0	1	17	35	45
Basalt	16	-30	- 8	22	41	124
Other	25	-32	-10	18	52	76
GF - Granite	6	-28	-15	1	24	34
Basalt	12	-24	1	36	54	76
Other	11	- 9	28	36	44	55
RC - Basalt	3	0	0	28	47	48
Other	13	-21	-14	13	23	61
Douglas-fir	49	-32	- 4	18	42	124
Grand fir	29	-28	- 1	34	42	76
Redcedar	16	-21	-10	13	27	61
Granite	14	-28	- 3	14	24	45
Basalt	31	-30	- 2	28	42	124
Other	49	-32	- 4	18	43	76
Overall	94	-32	- 3	20	41	124

Habitat Type and Parent Material	400 lb N/acre					
	Plot	Min.	25%	50%	75%	Max.
DF - Granite	8	14	22	31	47	60
Basalt	16	-14	10	19	57	134
Other	24	-30	8	23	51	121
GF - Granite	6	-42	-14	-3	10	23
Basalt	12	-49	- 2	16	42	78
Other	11	- 4	15	33	44	51
RC - Basalt	3	13	13	40	46	46
Other	13	1	9	21	40	46
Douglas-fir	48	-30	12	25	53	134
Grand fir	29	-49	- 2	23	39	78
Redcedar	16	1	12	23	41	46
Granite	14	-42	- 3	22	35	60
Basalt	31	-49	9	20	46	134
Other	48	-30	10	25	42	121
Overall	93	-49	9	23	43	134

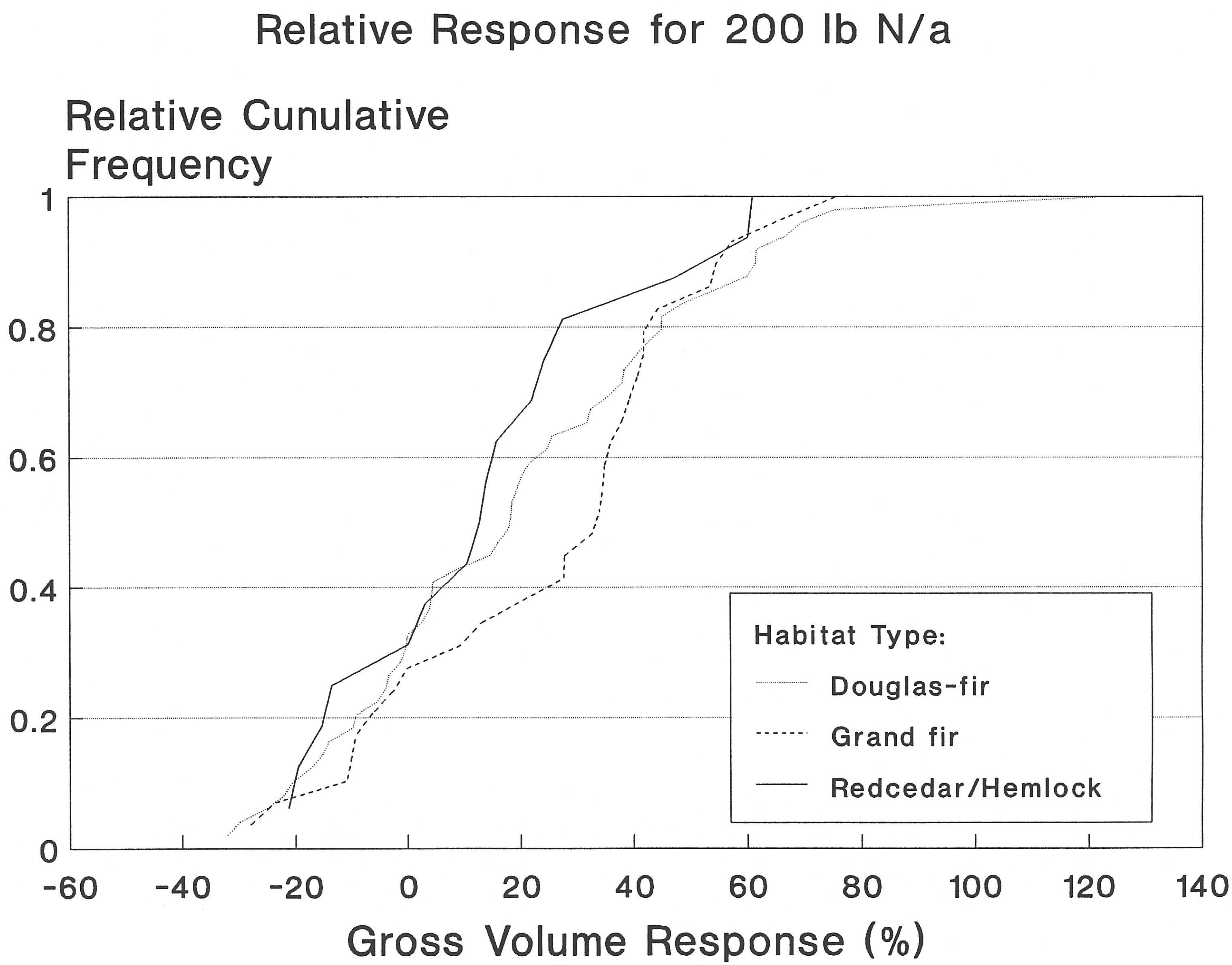

Figure 24. The relative cumulative frequency distribution of six-year Douglas-fir gross relative response % for three habitat type series for the 200 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

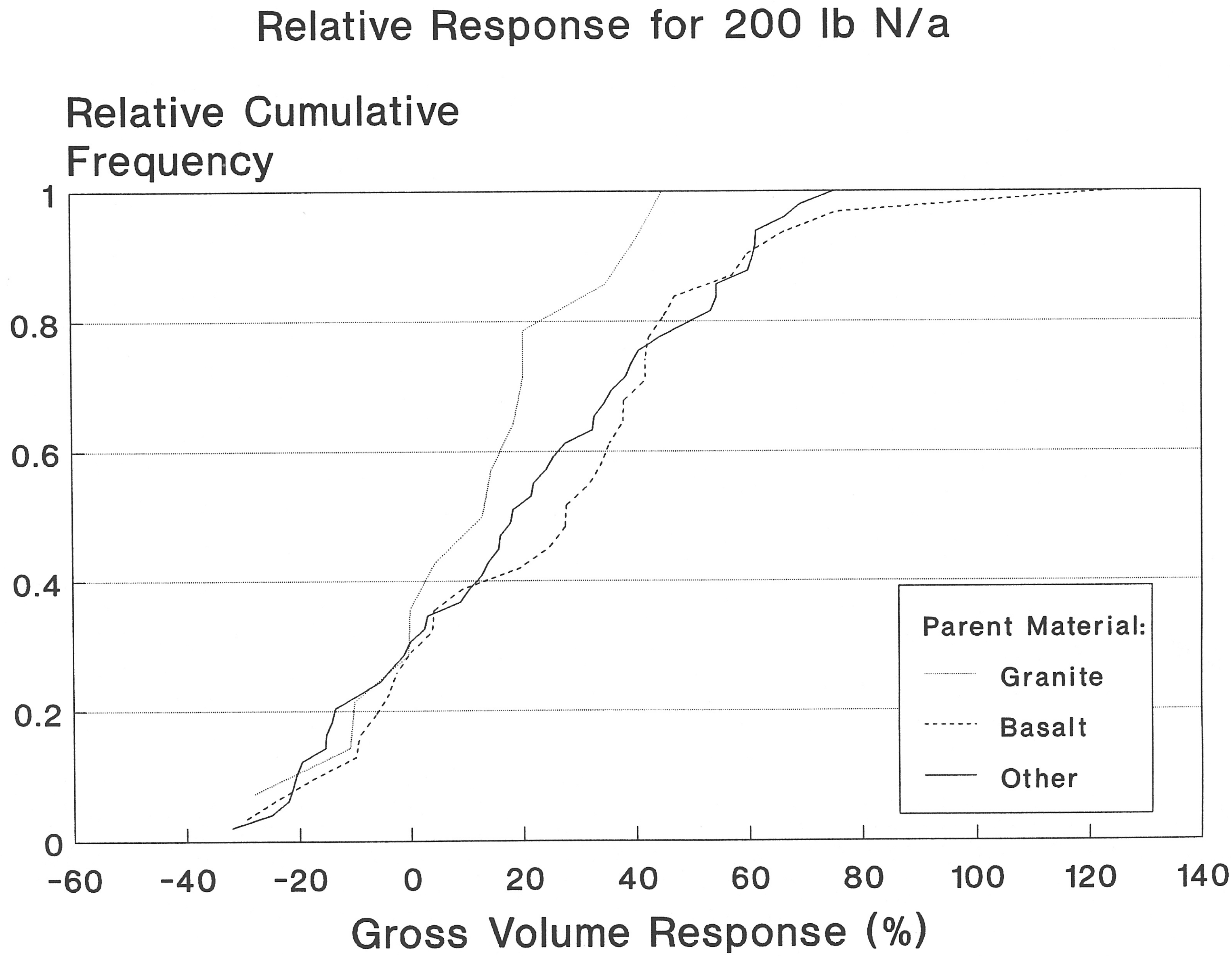

Figure 25. The relative cumulative frequency distribution of six-year Douglas-fir gross relative response % for three soil parent materials for the 200 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

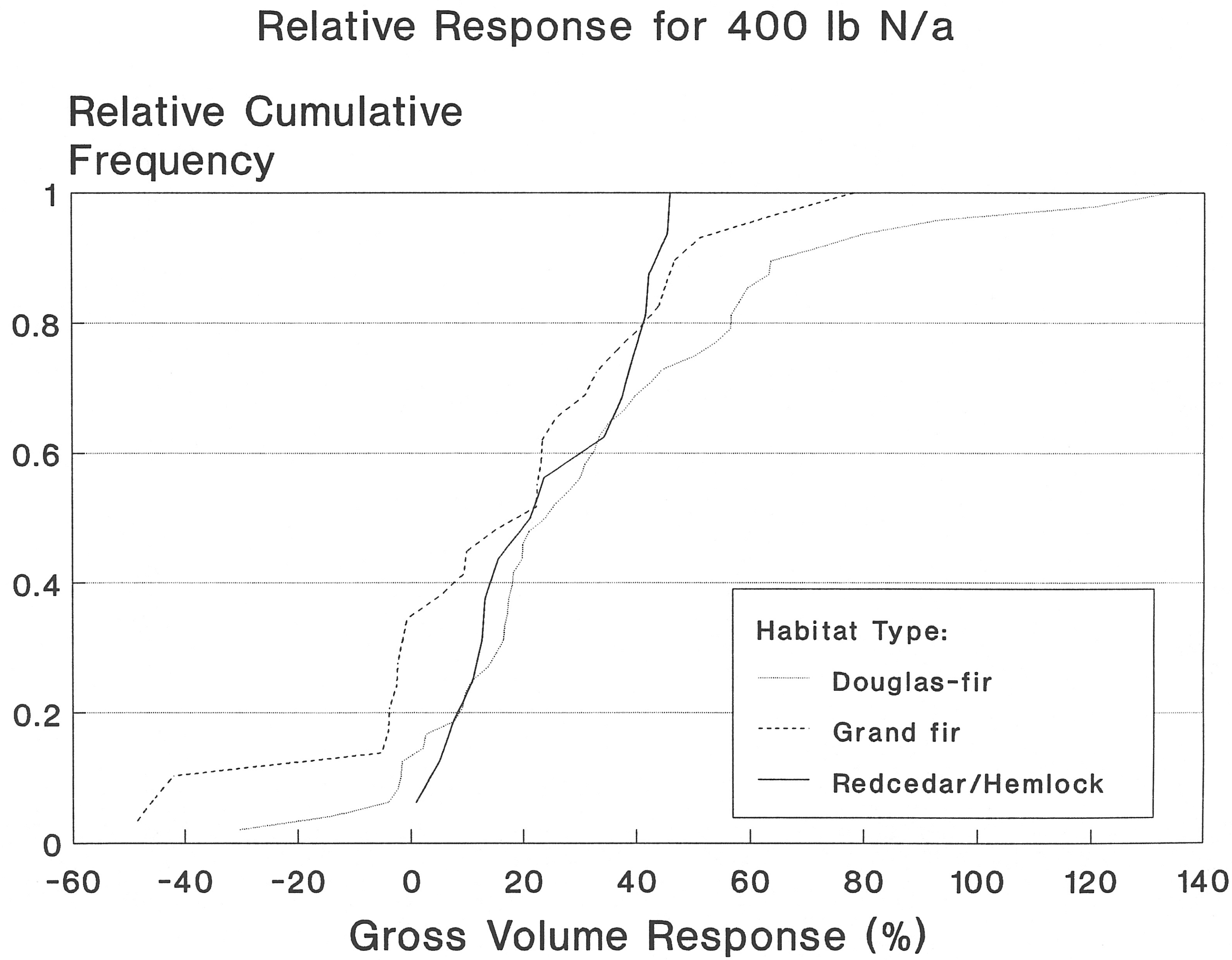

Figure 26. The relative cumulative frequency distribution of six-year Douglas-fir gross relative response % for three habitat type series for the 400 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

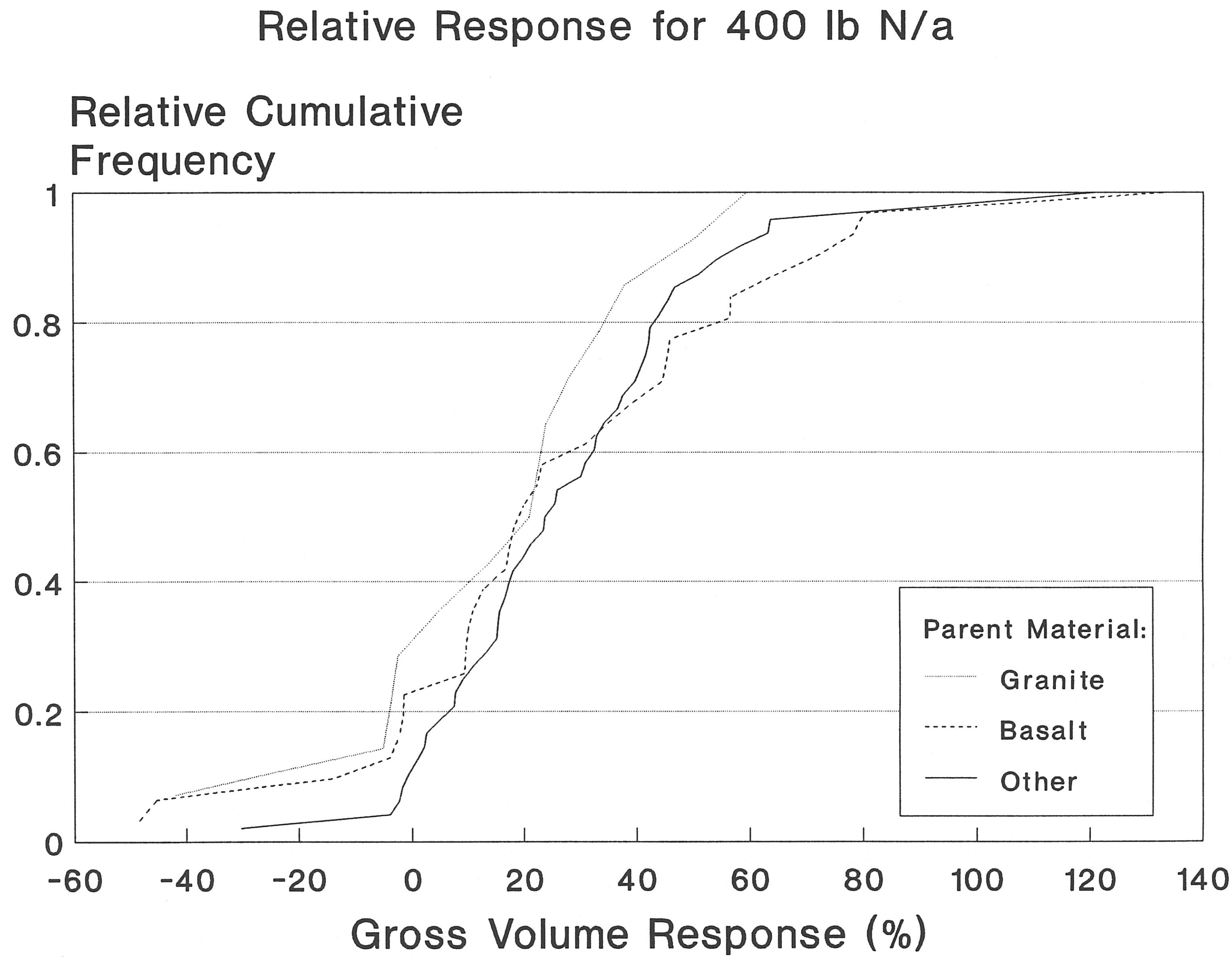

Figure 27. The relative cumulative frequency distribution of six-year Douglas-fir gross relative response % for three soil parent materials for the 400 pound nitrogen treatment. Values on the vertical axis are the proportions of responses that were less than or equal to particular response values on the horizontal axis.

Literature Cited

Binkley, D. 1986. Forest Nutrition Management. Wiley and Sons. New York. 290 p.

Chapman, H.D. 1965. Cation exchange capacity. In: C.A. Black, et al (ed.) Methods of soil analysis. Part 2. Agronomy (: 891-895. Amer. Soc. Agro. Inc., Madison, WI.

Jackson, M.L. 1958. Soil chemical analysis. Prentice-Hall, Inc. Englewood Cliffs, NJ.

Powers, R.F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest trees. Soil Sci. Soc. Amer. J. 44: 1314-1320.

Pritchett, W.L. and R.F. Fisher. 1987. Properties and management of forest soils. Wiley and Sons, New York. 494 p.