Nutrient Limitations to Growth of Western Oregon Douglas-fir Forests: A Look Beyond Nitrogen

Doug Mainwaring
Department of Forest Engineering, Resources, and Management
Oregon State University

Doug Maguire
Department of Forest Engineering, Resources, and Management
Oregon State University

Steve Perakis
FRESC
USGS

Background

- Nitrogen has been the nutrient of choice for intensive Douglas-fir management
  - Major research effort by RFNRP, SMC concluded that ~70% of westside DF stands will respond positively to nitrogen
  - Identification of stand or site characteristics indicative of response have been incomplete
  - Shotgun approach not satisfactory as fertilizer costs have increased
- Very little research has addressed response of Douglas-fir to nutrients other than nitrogen

Background

- Fertilization has been used in SNC-infected stands to try to counteract growth loss
  - Coastal soils generally have high soil N concentration and are low in base cations
  - Negative correlation between foliage retention and foliar N
  - Positive correlation between foliage retention and foliar Ca
- Very little research has addressed response of SNC-infected Douglas-fir to nutrients other than nitrogen

Beyond N Fertilization Trials

- Trials initiated in fall of 2006
- 16 locations, 10 landowners

  Cascade Timber
  Giustina Land and Timber
  Hampton (2)
  Lone Rock
  Campbell Group (2)
  ODF
  OSU
  Port Blakely
  Starker Forests
  West Fork Timber
  Weyerhaeuser (2)

Target stands

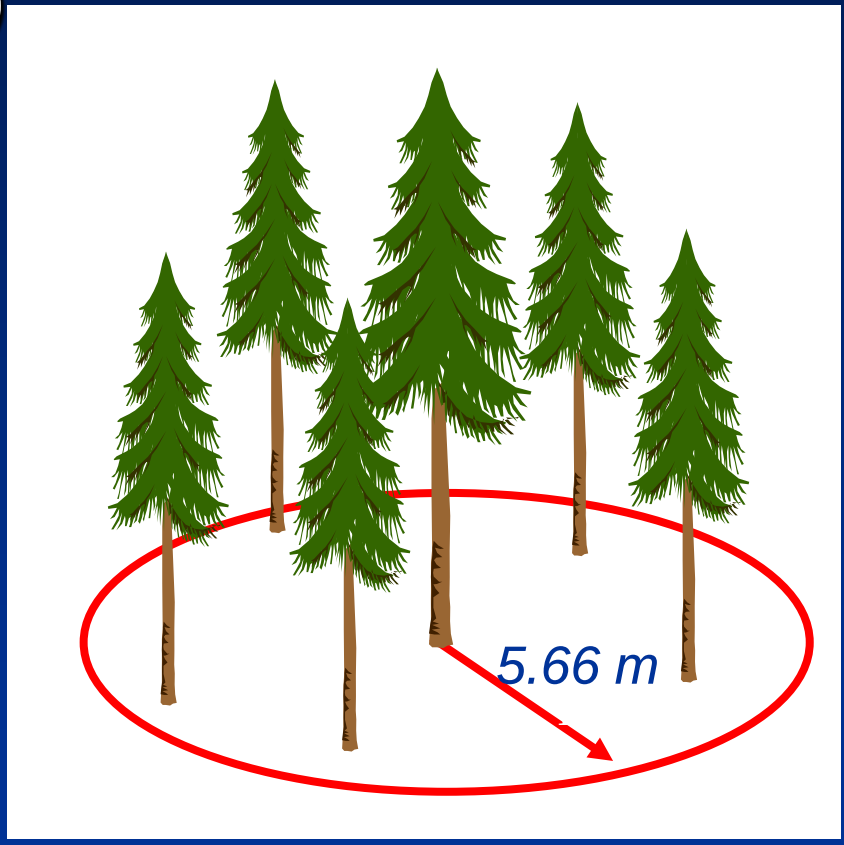
- **Target stands**
  - **20 yrs of age (+/- 5 yrs)**
  - **750 tph (+/- 250 tph)**
  - **No pct or fertilization in last 8 years**
  - **< 20% salal cover**

Stand Attributes

	Tree attributes									Plot attributes		
Plot	**QMD (cm)**	**Ht. (m)**	**Crown ratio**	**Foliage retention (yrs)**	**BH age (years)**	**Site Index (m @ 50 yrs)**	**Fol. N (%)**	**Fol. P (%)**	**Fol. Ca (%)**	**DF density (trees/ha)**	**DF basal area (m^2/ha)**	**pH**
CTC	**27.9**	**23.1**	**0.57**	**3.38**	**23**	**41.8**	**1.3**	**0.145**	**0.54**	**977**	**35.4**	**5.34**
GDE	**39.1**	**28.1**	**0.51**	**2.77**	**27.1**	**46**	**1.46**	**0.115**	**0.205**	**512**	**43.4**	**4.86**
GDH	**29.2**	**21.1**	**0.64**	**1.62**	**19.8**	**41.3**	**1.43**	**0.115**	**0.185**	**724**	**32.6**	**4.74**
GPH	**23.4**	**17.2**	**0.64**	**3.64**	**15**	**47.5**	**1.26**	**0.15**	**0.53**	**921**	**24.9**	**5.97**
HAGR	**27.2**	**16.6**	**0.75**	**2.22**	**15.9**	**46.5**	**1.51**	**0.14**	**0.31**	**683**	**27.9**	**5**
HAK	**32**	**23.9**	**0.6**	**2.36**	**21.8**	**46.9**	**1.31**	**0.135**	**0.295**	**630**	**37.3**	**5.05**
LRT	**36.8**	**22.6**	**0.65**	**3.35**	**21.1**	**43.1**	**1.24**	**0.175**	**0.54**	**435**	**36.3**	**5.84**
MNN	**27.4**	**17.8**	**0.7**	**2.22**	**13.3**	**54.1**	**1.42**	**0.11**	**0.205**	**782**	**31.4**	**4.93**
MNS	**29.5**	**20.9**	**0.61**	**2.66**	**20**	**46.6**	**1.43**	**0.11**	**0.3**	**768**	**33.9**	**5.23**
ODF	**25.9**	**16.9**	**0.69**	**2.34**	**14.7**	**48.9**	**1.56**	**0.135**	**0.29**	**877**	**30.2**	**4.79**
OSU	**25.9**	**18**	**0.67**	**3.31**	**14.8**	**46.9**	**1.27**	**0.179**	**0.608**	**819**	**32.6**	**6.46**
PB	**26.4**	**21.5**	**0.47**	**3.41**	**20.4**	**45.1**	**1.3**	**0.175**	**0.455**	**1186**	**36.5**	**5.8**
STR	**29.2**	**20.2**	**0.65**	**2.71**	**17.7**	**48.7**	**1.27**	**0.175**	**0.49**	**754**	**35.8**	**5.3**
WE	**19.6**	**12.9**	**0.71**	**2.13**	**13**	**44.1**	**1.44**	**0.19**	**0.52**	**1544**	**31.4**	**6**
WF	**35.1**	**20.2**	**0.79**	**3.65**	**20**	**42.7**	**1.23**	**0.17**	**0.415**	**476**	**39.7**	**4.95**
WW	**29.5**	**23**	**0.59**	**2.28**	**28.4**	**36.2**	**1.19**	**0.21**	**0.35**	**708**	**35.4**	**5.58**
Mean	**29**	**20.3**	**0.64**	**2.75**	**19.1**	**45.4**	**1.35**	**0.15**	**0.39**	**799.8**	**34**	**5.37**

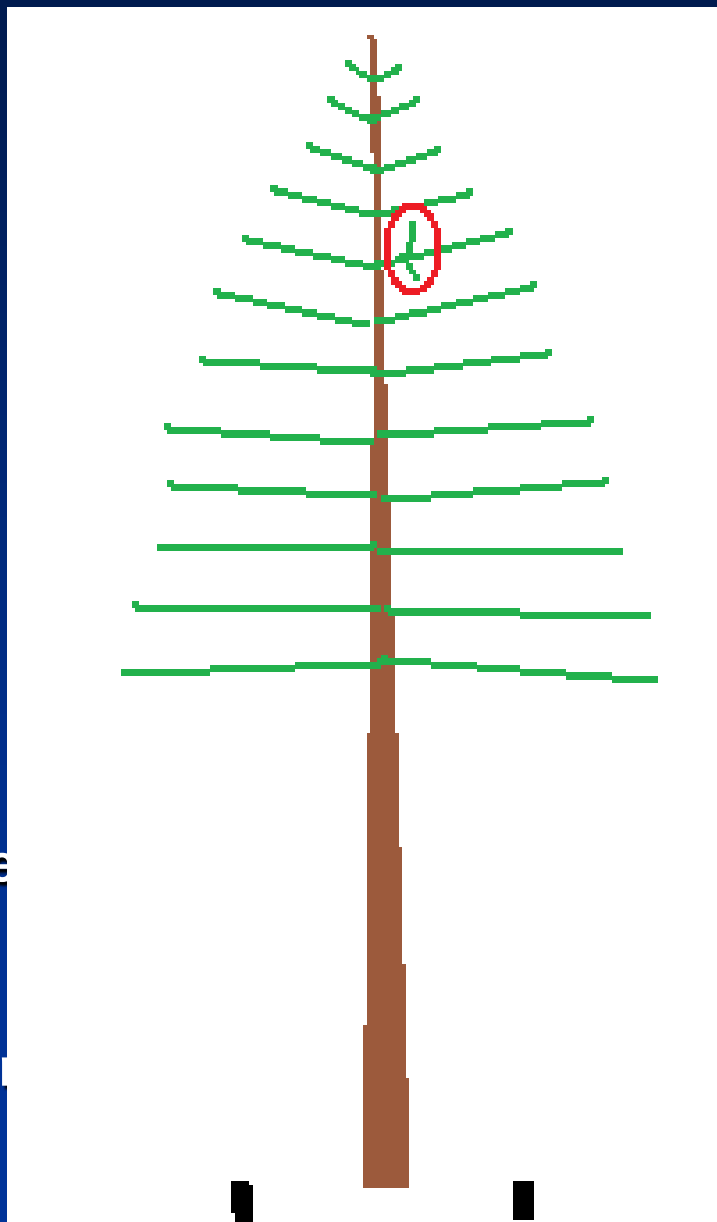
Study design

- Individual tree plots (0.01 ha)
- Centered on subjectively chosen dom/codom tree
- 5 or 7 treatments per site, randomly assigned
- 10 plots per treatment
- 50 or 70 plots per site



Measurements and Sampling

- Subject Tree
  - Dbh
  - Height, height to lowest live branch
  - Sapwood width
  - Diameter at 5.5 m
  - Foliage (4-yr old lateral from 5 yr old whorl branch)
  - Soil (two 10 cm cores)
- Plot
  - All plot trees measured for dbh (plot-le
- Treatment
  - Foliage, soil composite for chemical a



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  - Soil (two 10 cm cores)
- **Plot**
  - All plot trees measured for dbh (plot-level basal area)
- **Treatment**
  - Foliage, soil composite for chemical analysis

Treatments

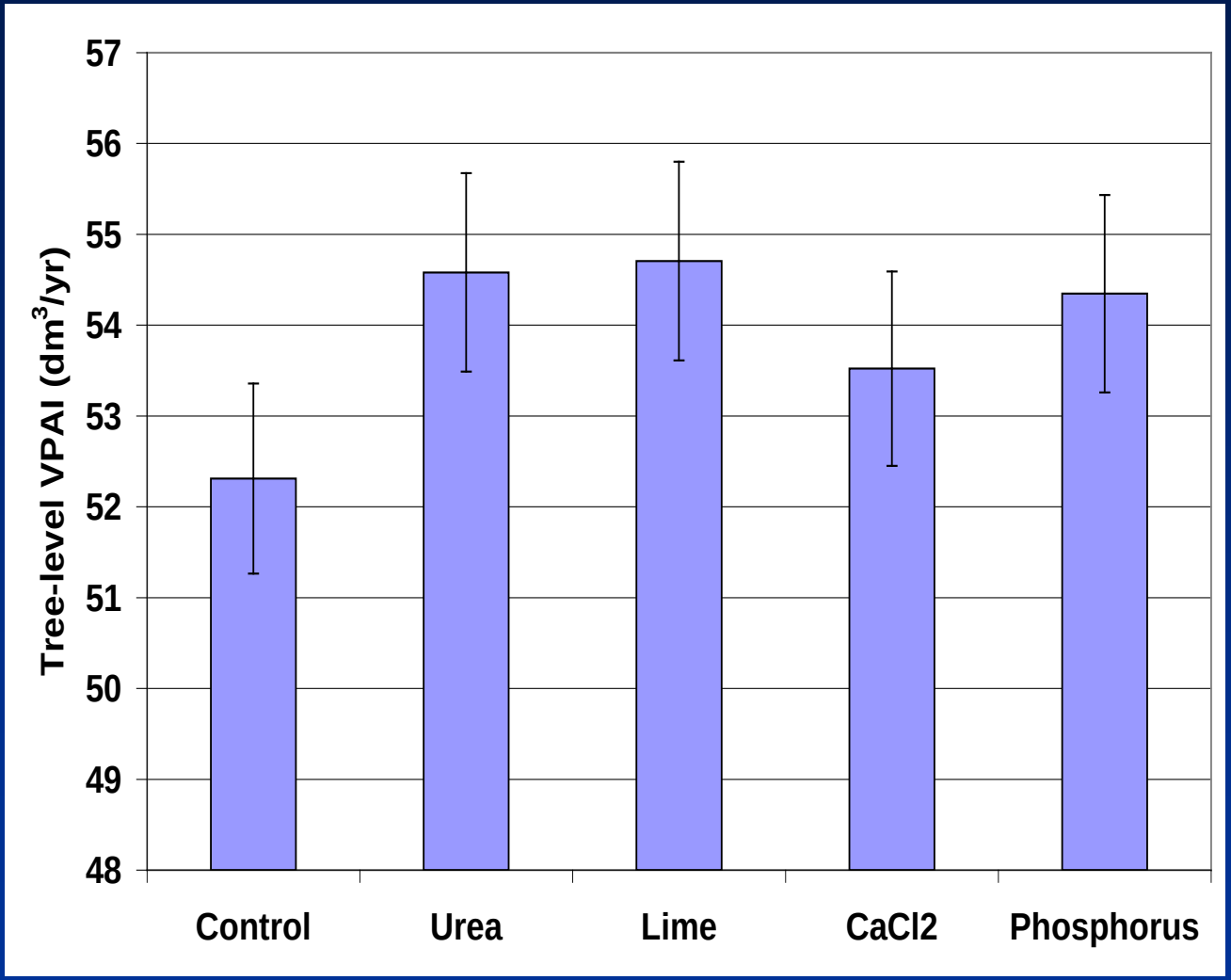
Treatment	Form	Amount	Reason for inclusion
Control	- -	- -	Statistical reference for treatments
N	Urea	225 kg N / ha	Standard approach
Lime	$CaCO_3$	1000 kg Ca / ha	Elevates pH, reduces Al, adds Ca: compare to Ca-only treatment
Ca	$CaCl_2$	100 kg Ca / ha	Low soil and foliar Ca is common at our sites, attributable to high soil N
P	NaH_2PO_4	560 kg P / ha	Can limit growth in highly weathered soils, some sites have P-fixing soils
Kinsey	Blend	Site specific	Scientific and industry interest in overall nutritional limits to productivity
Fenn	Blend	Site specific	Scientific and industry interest in overall nutritional limits to productivity

Stem volume growth response, regional

- Response variable: stem volume increment
- Response tested with ANCOVA, regression
- ANCOVA: analyzed as a randomized complete block
- Regression: Tested for correlation between treatment response and site-specific factors (soil and foliar chemistry)

Stem volume response, ANCOVA

- Significant covariates : initial volume, plot-level basal area
- Marginally significant response:
  - N (p=0.069)
  - Lime (p=0.051)
  - P (p=0.10)



Growth response, site specific

	N	Lime	$CaCl_2$	Phos	Kinsey	Fenn
CTC	**35.0**	15.8	15.0	***18.3***	***16.1***	1.4
GDE	9.1	2.6	12.3	-7.1	3.1	14.4
GDH	-11.7	2.4	0.5	-12.0	-3.6	-9.4
GPH	6.4	3.5	7.9	7.5		
HAGR	-3.2	1.8	-12.0	1.2	-2.0	-2.7
HAK	-2.6	-4.3	3.6	-4.0	-3.1	1.6
LRT	-0.1	-0.9	-5.9	-1.7		
MNN	-7.4	9.6	7.3	-0.1	-11.1	2.4
MNS	6.7	12.6	-9.7	**17.5**	5.9	9.0
ODF	0.8	-0.3	-3.1	***12.0***	8.4	10.0
OSU	0.5	6.8	7.4	6.4	5.8	8.1
PB	-6.6	-0.1	3.0	4.2	-3.1	1.8
STR	1.3	-8.6	-6.6	5.2	-8.0	-5.4
WE	10.3	13.3	**20.8**	***14.8***		
WF	4.0	-4.7	-8.0	-4.5	-2.0	6.1
WW	**26.3**	9.4	8.2	-4.2		

3-yr Volume Growth, N treatment

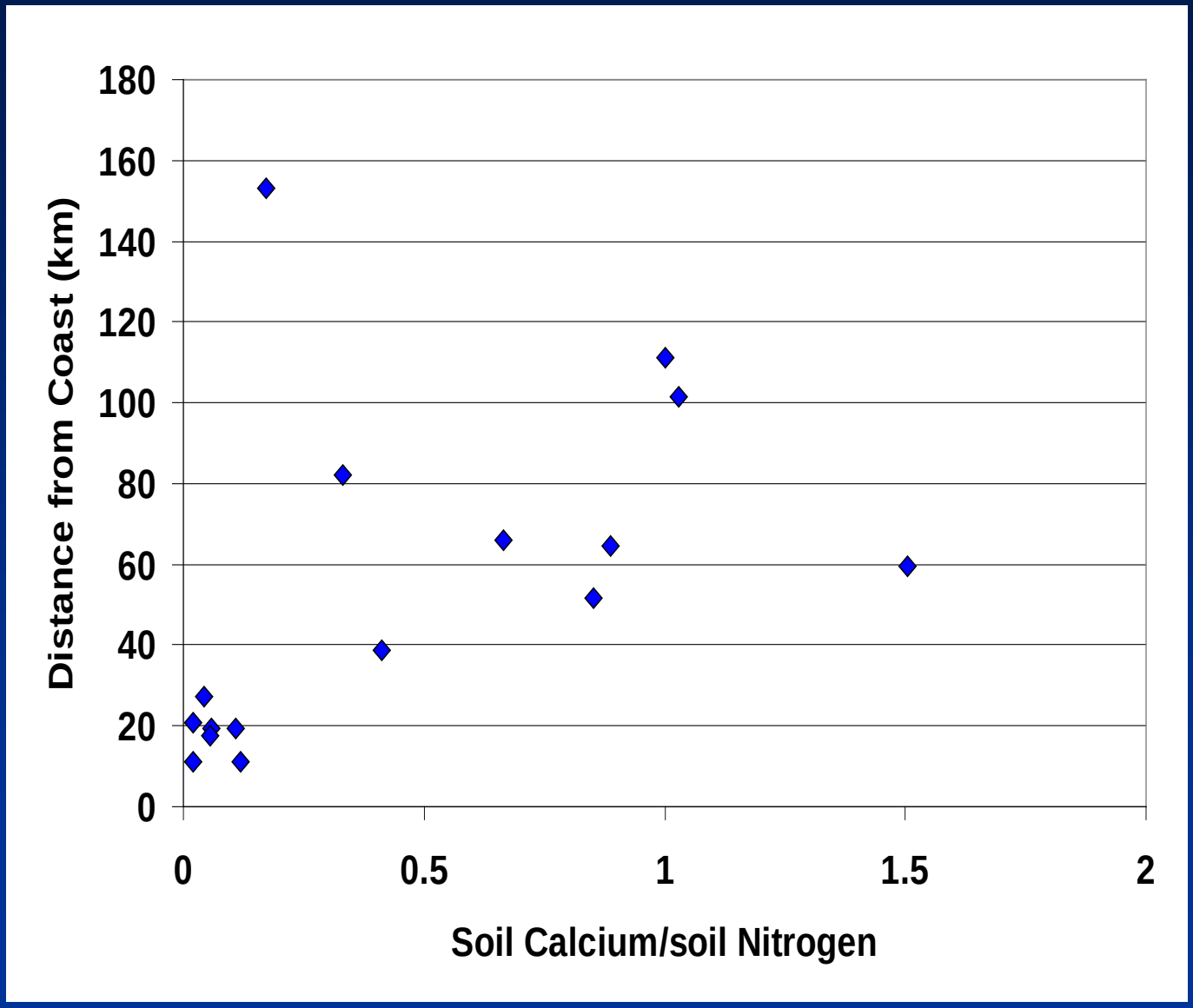
- **Response dependent on soil Ca/N**

$$\ln(VOLGR) = 1.36321 + 0.4957*\ln(D^2H) + 1.2724*\ln(SI) + -0.191*(pH) + 0.4866*\ln(fCa) + -0.0844*\ln(sCaN) + 0.1383*(I_U) + 0.04652*I_U*\ln(sCaN)$$

where	VOLGR	=	Predicted periodic annual volume increment for individual tree (dm^3yr^{-1})
	D^2H	=	Initial volume index
	SI	=	Site index
	pH	=	Initial soil pH
	fCa	=	Initial foliar calcium concentration (%)
	sCaN	=	Initial ratio of soil calcium % to soil nitrogen %
	I_U	=	(1 if urea fertilized; 0 otherwise)

3-yr Volume Growth, N treatment

- Line represents multiplicative response to N fertilization
- Points represent site-level response vs. Ca/N combinations within dataset
- Response dependent on soil Ca/N



3-yr Volume Growth, Lime treatment

- **Response dependent on initial soil pH, foliar Ca conc.**

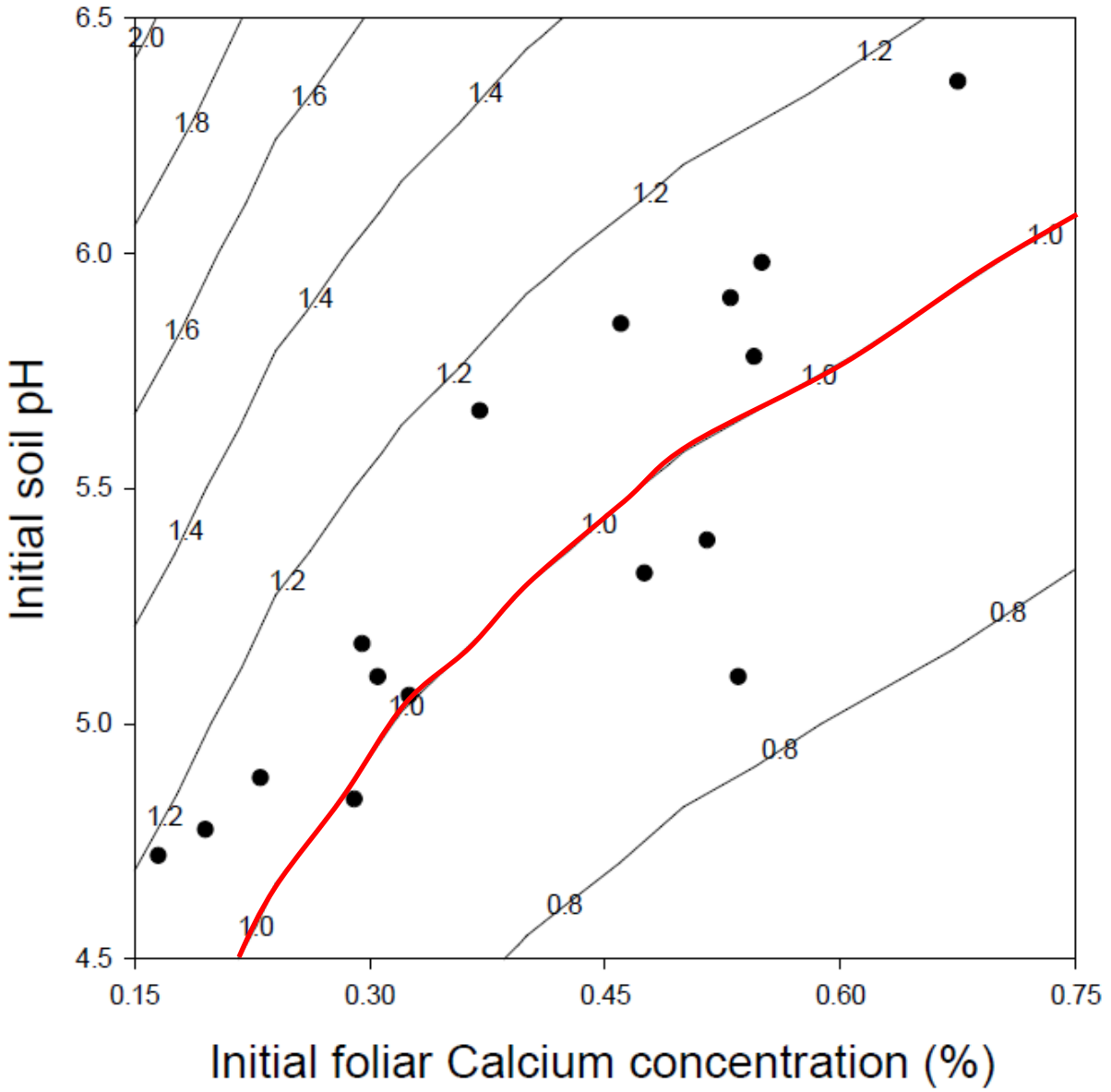
- $VOLGR = \exp(2.674)*D^2H^{0.474} *SI^{1.06} *fCa^{0.597} * sCaN^{-0.0822} * \exp((-0.2609*pH)+ (I_C *(-1.1914 + -0.37*\ln(fCa) + 0.2969*pH)))$

where

VOLGR	=	Predicted periodic annual volume increment for individual tree (dm^3yr^{-1})
D^2H	=	Initial volume index
SI	=	Site index
pH	=	Initial soil pH
fCa	=	Initial foliar calcium concentration (%)
sCaN	=	Initial ratio of soil calcium % to soil nitrogen %
I_C	=	(1 if lime fertilized; 0 otherwise)

3-yr Volume Growth, Lime treatment

- Lines represent multiplicative response to lime fertilization
- Points represent combinations of pH, fol_Ca present within dataset
- Response dependent on initial soil pH, foliar Ca conc.



3-yr Volume Growth, $CaCl_2$ treatment

- **Response dependent on initial soil pH, foliar Ca conc.**

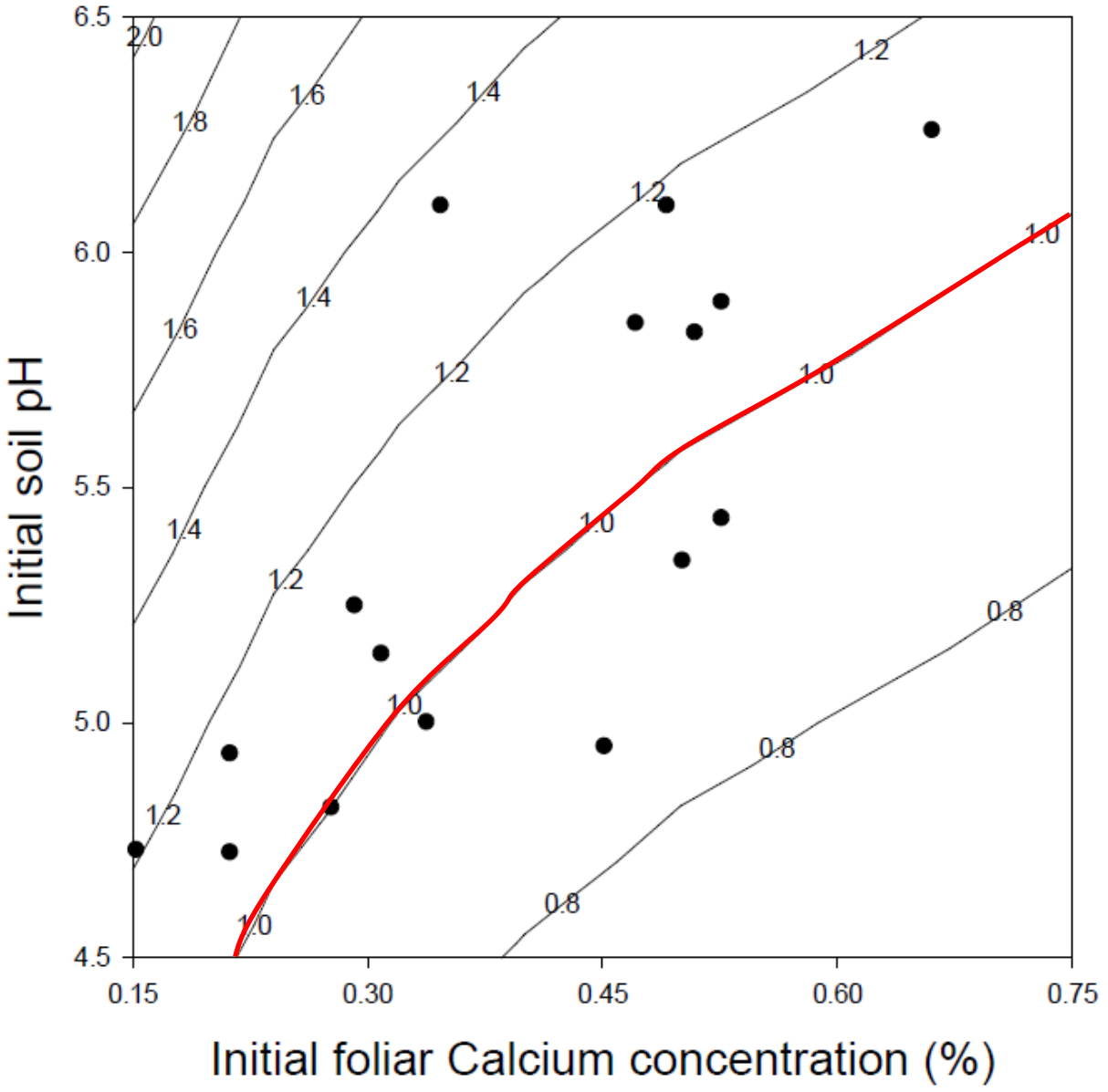
- $VOLGR = \exp(3.2763)*D^2H^{0.8535} *SI^{1.06} *fCa^{0.714}* sCaN^{-0.135} * \exp((-0.2211*pH)+ (I_C *(-1.7936 + -0.3312*\ln(fCa) + 0.22829*pH)))$

where

$VOLGR$	=	Predicted periodic annual volume increment for individual tree (dm^3yr^{-1})
D^2H	=	Initial volume index
SI	=	Site index
pH	=	Initial soil pH
fCa	=	Initial foliar calcium concentration (%)
$sCaN$	=	Initial ratio of soil calcium % to soil nitrogen %
I_C	=	(1 if $CaCl_2$ fertilized; 0 otherwise)

3-yr Volume Growth, $CaCl_2$ treatment

- Lines represent multiplicative response to $CaCl_2$ fertilization
- Points represent combinations of pH, fol_Ca present within dataset
- Response dependent on initial soil pH, foliar Ca conc.



3-yr Volume Growth, Phosphorus treatment

- **Response dependent on initial soil pH, foliar P conc.**

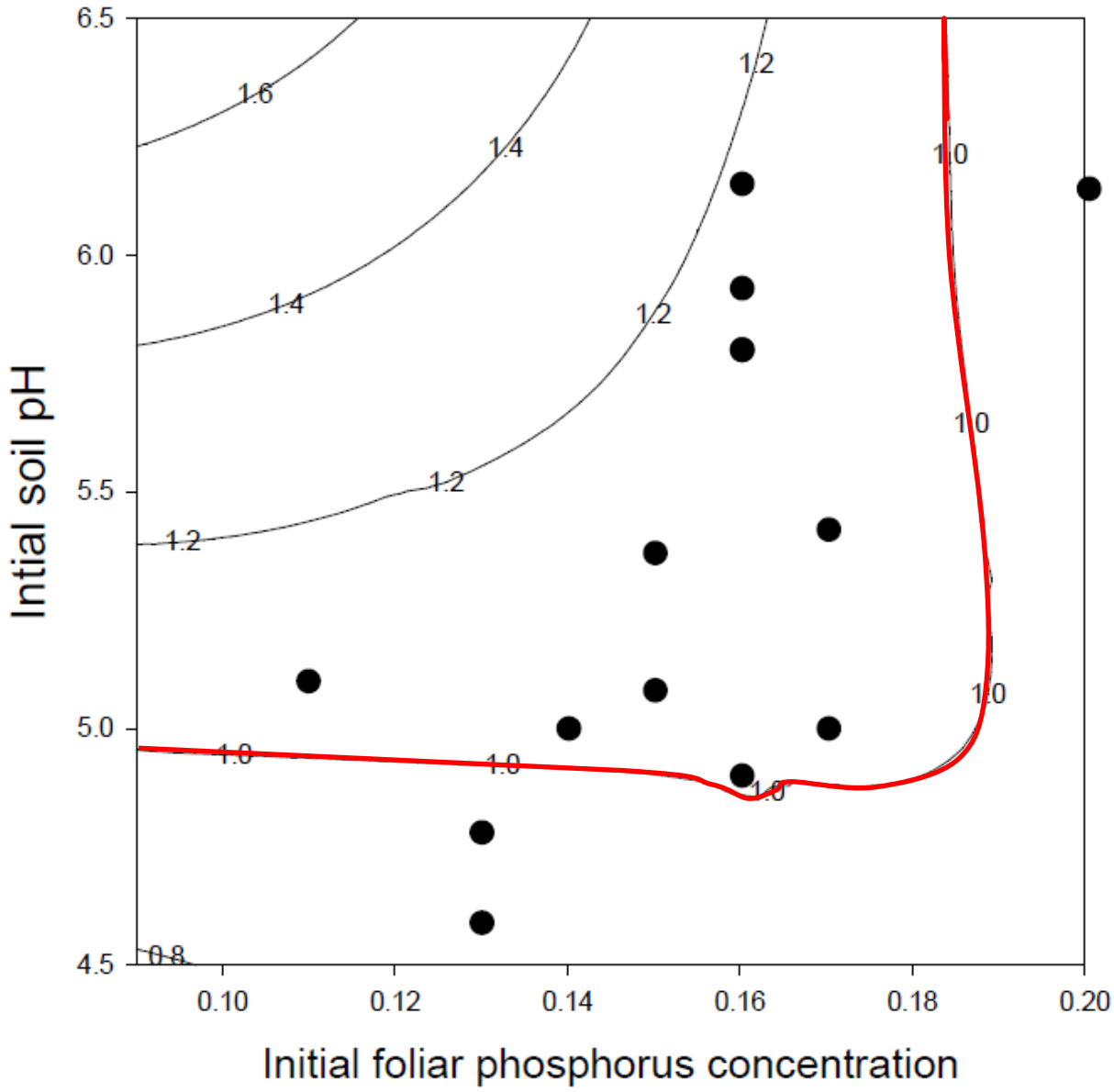
$$VOLGR = 0.0444(D^2H)^{0.4375} * SI^{1.9562} * \exp[(10.9373 + -1.3531pH) * fP] * \exp[I_P * (-5.2574 + 1.0577 * pH + 29.0023 * fP + -5.8157 * pH * fP)]$$

where

VOLGR	=	Predicted periodic annual volume increment for individual tree ($dm^3 yr^{-1}$)
D^2H	=	Initial volume index
SI	=	Site index
pH	=	initial soil pH
fP	=	initial foliar Phosphorus
Ip	=	1 if P fertilized; 0 otherwise

3-yr Volume Growth, Phosphorus treatment

- Lines represent multiplicative response to P fertilization
- Points represent combinations of pH, fol_P present within dataset
- Equation implies no response to P below pH=5, above P=0.19%



Conclusions

- There is evidence of a marginal regional response to N, lime, and P, but there is lots of site to site variation
- Response to N is positively correlated with soil Ca/N ratio. Given relation between this ratio and geography, SNC stands don't appear a good bet for N fertilization
- Calcium may be an effective fertilizer at certain combinations of soil pH and foliar Ca. Short term response can be more efficiently obtained using $CaCl_2$
- Phosphorus may be an effective fertilizer at certain combinations of soil pH and foliar P. Phosphorus does not appear to be effective at soil pH<5 or foliar P>0.19%
- Because these results are based on individual trees, stand level response can't be inferred

Questions?