Long-term Effects of Vegetation Management on Soil and Plant Derived Nutrient Budgets for Plantations of Four Western Conifer Species

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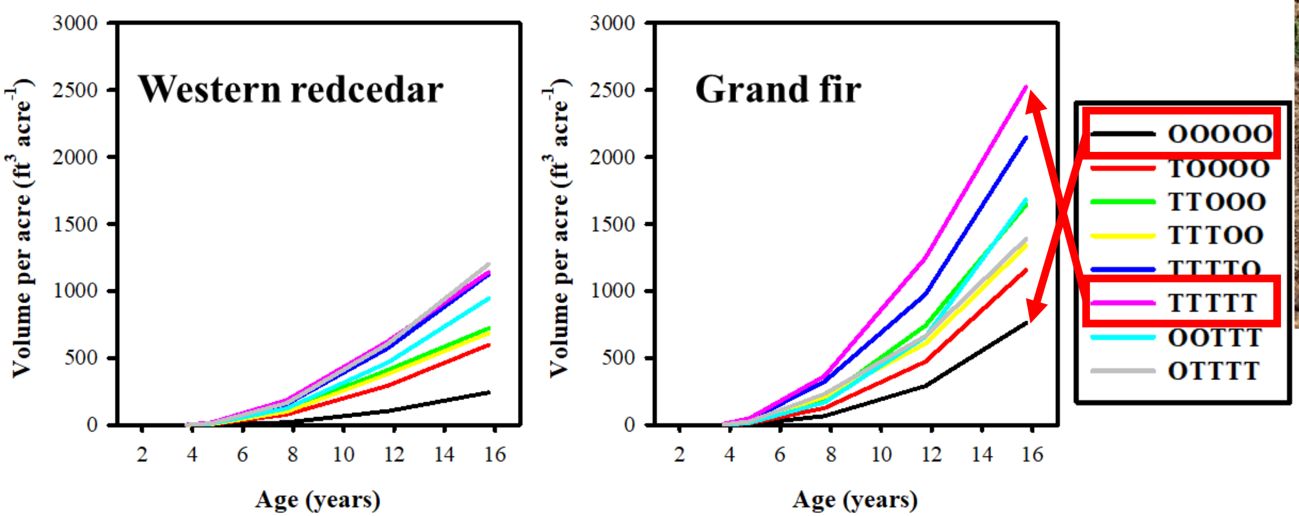
Introduction

- Vegetation management (VM) is used to control competing vegetation during seedling establishment to improve seedling survival and growth
- This study aims to understand how altering plant community structure by intensive control of competing vegetation changes the way nutrients are stored in the ecosystem



The big picture

- Wood products are in important resource
- Need to understand the long term implications of management
- Is the way we are managing forests detrimental to natural processes e.g. soil fertility
    - Do species and site factors play a role?

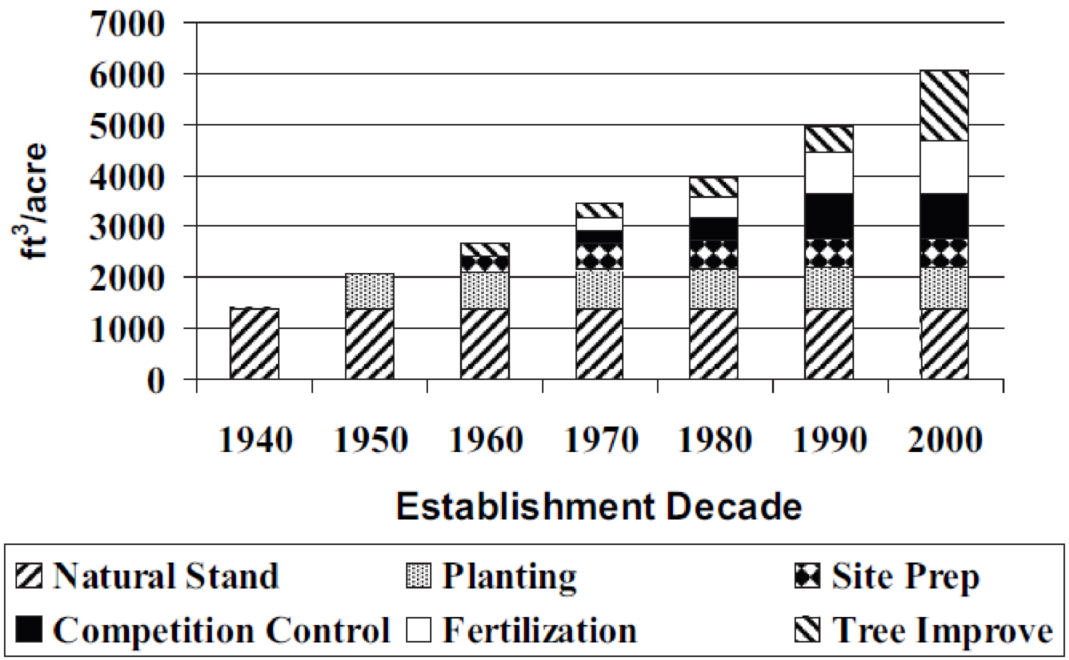


Figure 2. Estimated total yield and contributions of individual silvicultural practices to productivity of pine plantations in the southern United States from 1940 to 2000.

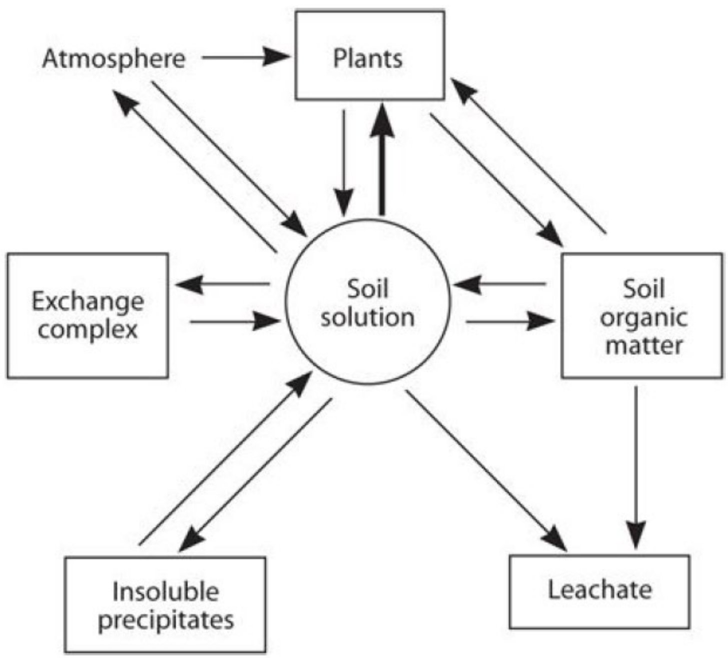
Fox (2007)

Background- Forest Nutrition

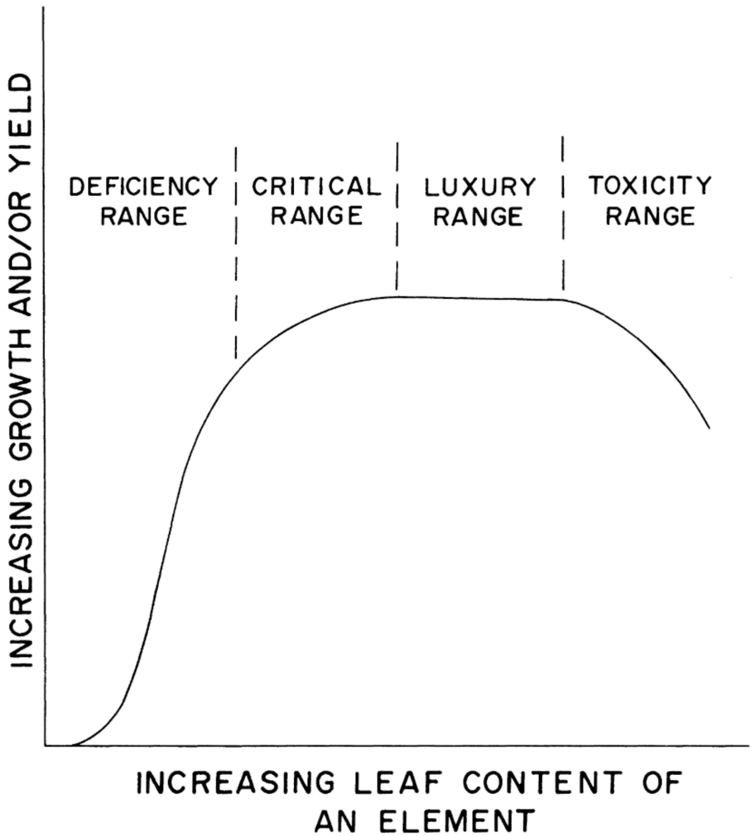
- Plants uptake nutrients to satisfy physiological needs
- These needs are different for each tissue and vary by species
- Macronutrients required in large amounts:
  - Carbon (C), nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)
- Micronutrients are required in small amounts:
  - Boron (B), copper (Cu), iron (Fe), manganese (Mn), sodium (Na), and zinc (Zn)
- Plants acquire all of these (except C) from soil solution

Background- Plant Uptake

- Available soil nutrients are a (sometimes) small subset of total soil nutrients
- Many factors play into how and when nutrients become available

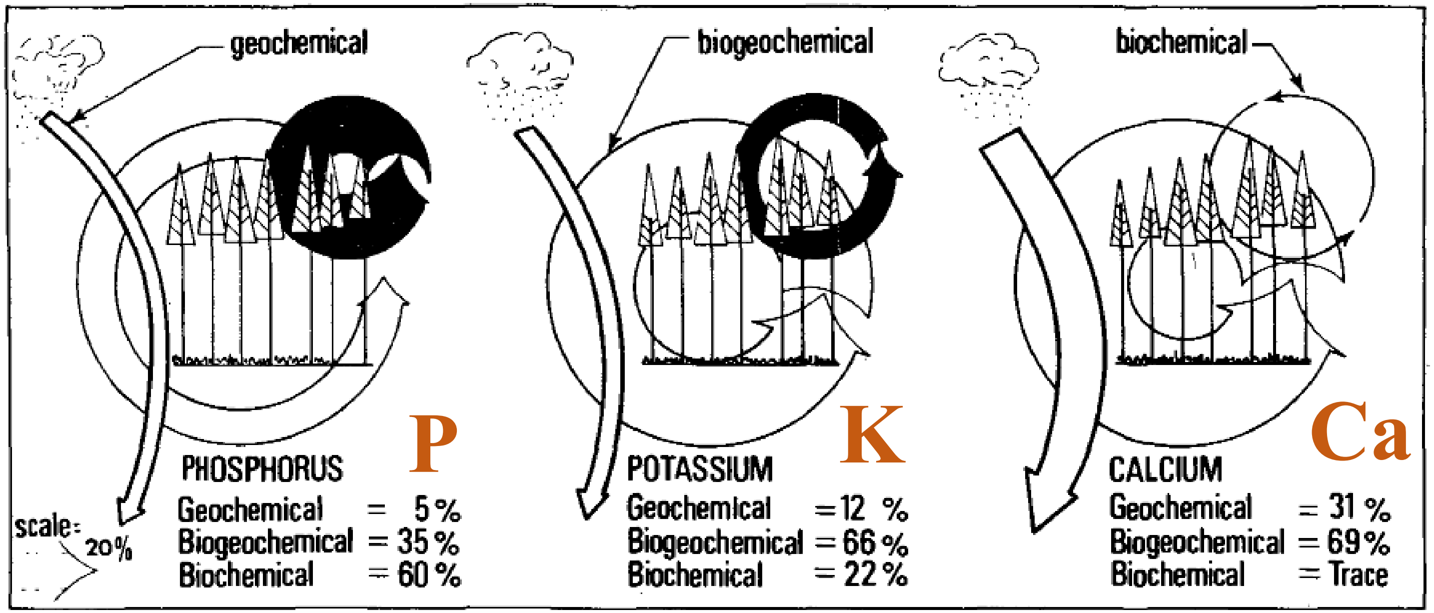


Perry (2008) adapted from Swift et al. (1979)



van den Dreische (1974)

Background- Nutrient Cycling

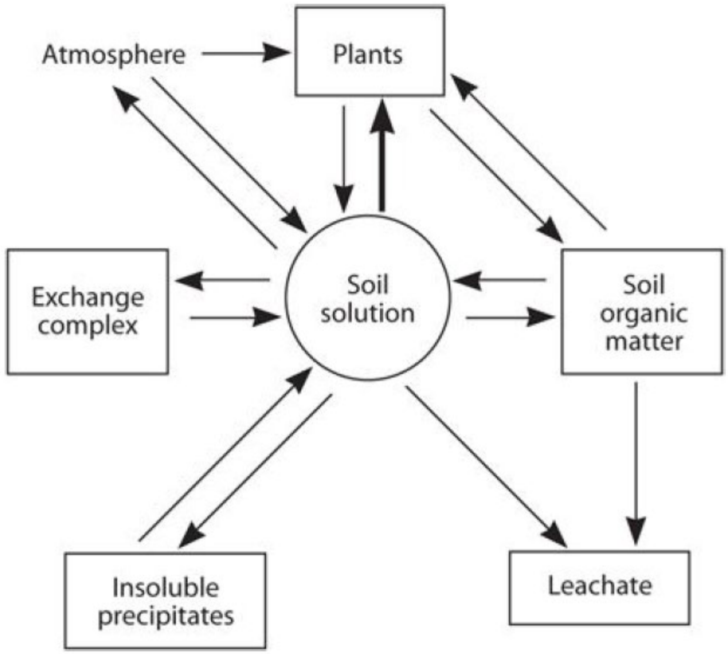


Switzer and Nelson (1972)

- Geochemical in: weathering, wet and dry deposition
  out: leaching, precipitation, erosion
- Biogeochemical: nutrients taken from soil by plants, returned via litter
- Biochemical: nutrient resorption before tissue senescence

Background- Where do plants fit?

- Plants uptake nutrients and fix them in tissue, retaining them on site
  - Different in
- Plant litter is th   nutrients (biogeochemic
  - Litter nutrie   and site
- Plants can fix N   ınge mineralization   hing



Perry (2008) adapted from Swift et al. (1979)

Background- VM and Trees

- VM alters plant community structure, species composition, and successional trajectory
- In the short term (first five to ten years) VM:
  - Increases crop tree biomass and nutrient content
  - Increase certain foliar concentrations
    - Effects vary by site, often short lived (1-10 years)
      (Powers and Reynolds, 1999; Rose and Ketchum, 2002)

Background- VM and Soil

- In the short term (first five to ten years) VM:
  - Reduces recovery rate of soil nutrient availability (Slesak et al., 2016)
    - Ca, Mg, K, and total N (near surface)
  - Potential increase in deep soil C (Knight et al. 2014)
  - Potential to deplete soil nutrients
    - in loblolly plantations (Miller et al., 2006)
    - in eastern white pine and black spruce forests (Hoepting et al. 2011)

Methods

Treatment design:

Treatment	Pre-planting	Post-planting (years)
Control	1	0
VM	1	5

Study sites in OR:

- Coastal Range (CR) – planted 2000
  - DF WH WRC GF
  - Mean Temperature — 52.0 °F
  - Annual rainfall — 1,707 mm
  - Andic Dystrudept
  - Sandstone/siltstone bedrock

- Cascade Foothills (CF) - 2001
  - DF WRC
  - Mean Temperature — 54.3 °F
  - Annual rainfall — 1,179 mm
  - Xeric Haplohumult
  - Sedimentary bedrock with tuff and mafic intrusions

Objectives

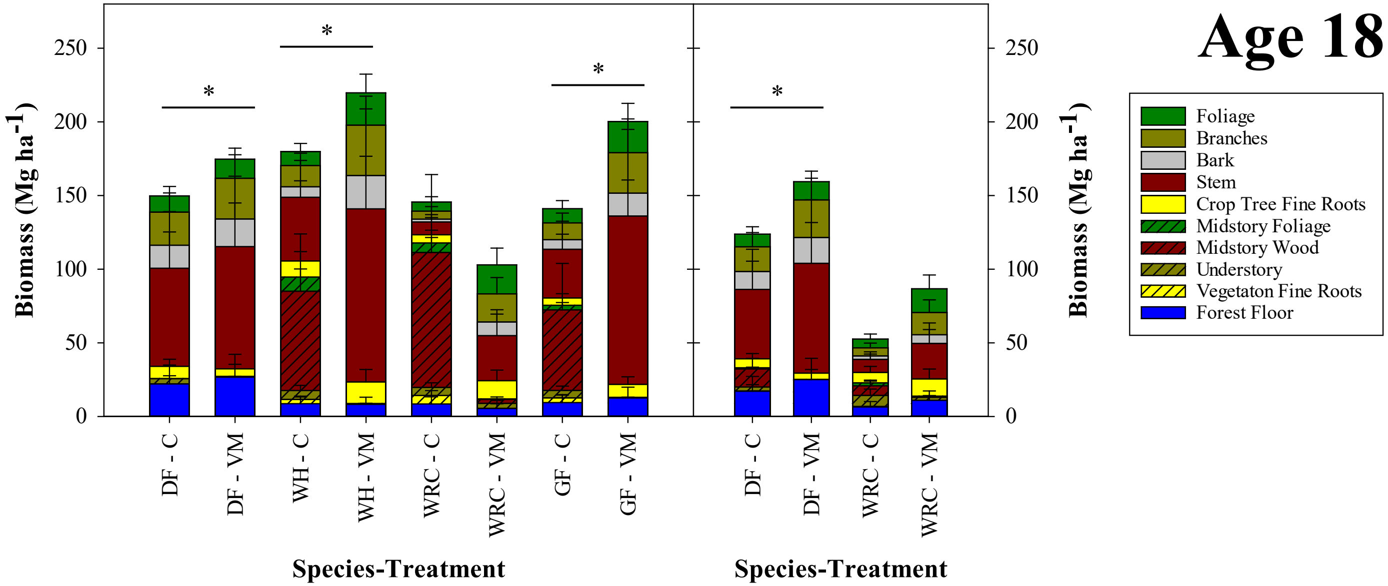
- Quantify nutrient concentrations of each biomass pool
- Construct nutrient budgets for each nutrient, conifer species, treatment and site
- Calculate carbon:nutrient ratios as a proxy for measuring nutrient use efficiency
- Analyze total plant nutrient ratios

Control

VM

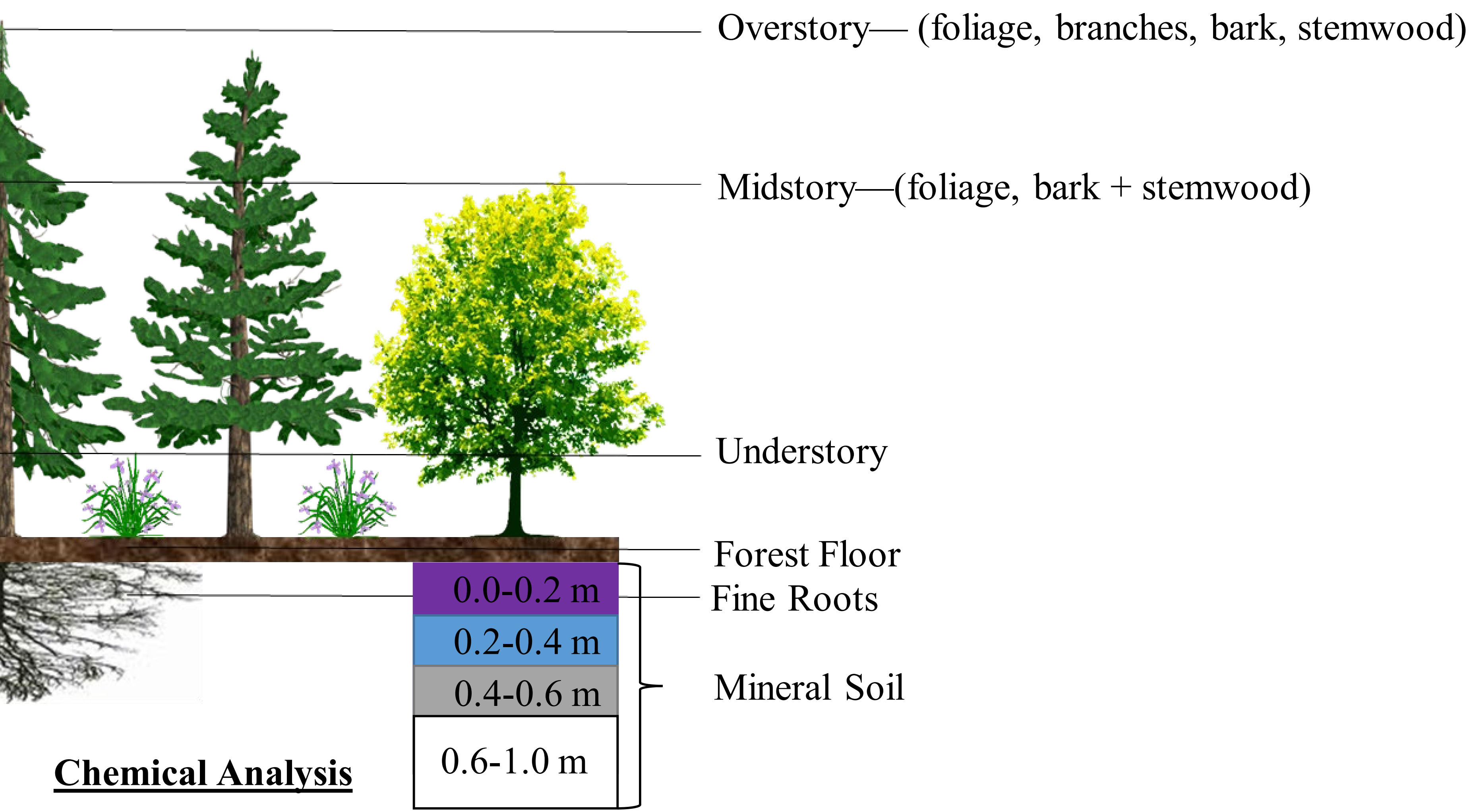
Stand level differences

Site	Species	Treatment	TPHA (ac^{-1})	QMD (in)	Crop tree BA (ft^2 ac^{-1})	Midstory BA (ft^2 ac^{-1})
CR	DF	C	276	3.3	109.6	0.0
		VM	293	3.6	135.3	0.0
	WH	C	351	2.6	84.7	70.3
		VM	418	3.5	185.9	0.0
	WRC	C	303	1.6	30.6	127.9
		VM	391	2.8	104.8	3.1
	GF	C	367	2.3	72.0	77.3
		VM	399	3.6	185.5	0.0
CF	DF	C	282	2.8	80.3	19.6
		VM	291	3.5	124.4	0.0
	WRC	C	142	2.5	30.6	11.8
		VM	378	2.5	83.4	0.0



Age 18 years

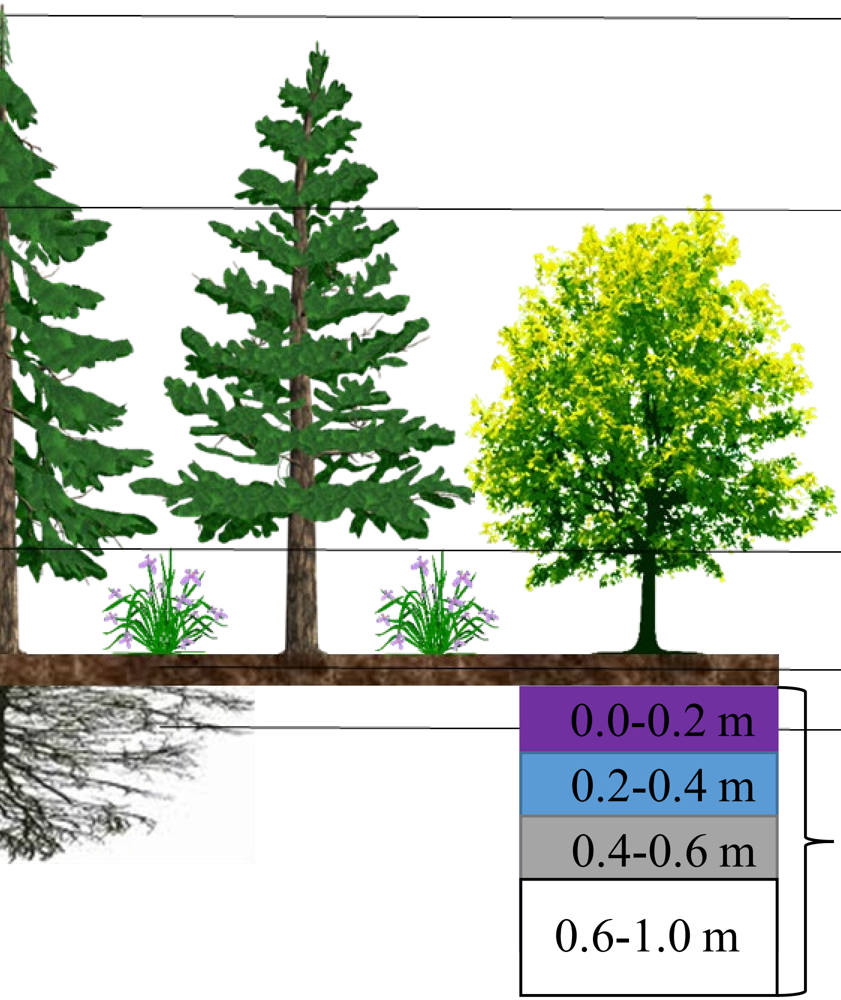
Methods – Sample Analysis



Chemical Analysis

- C, N, and S determined by dry combustion
- P, K, Ca, Mg, B, Mn, Fe, Zn, Cu, and Mo determined by ICP-OES
  - Soil extracted by microwave digestion in HNO_3 (180 samples)
  - Plant material extracted by dry ash (350 samples)

Methods – Sample Collection



Overstory— (foliage, branches, bark, stemwood)
4 trees sampled per treatment (not one per plot)

Midstory—(foliage, bark + stemwood)
4 trees sampled from CR site

Understory
6 clip plots per plot

Forest Floor — **6 subsamples per plot**

Fine Roots — **6 subsamples per plot**
(only 0-0.2 m sample used for chemical analysis)

Mineral Soil
0-0.2 m - 6 subsamples per plot
Deeper – 1 sample per plot

- Most samples collected at 16 years (Flamenco et al. 2019)
    - All crop tree tissues, understory, forest floor, and 0-0.2 m
- Soil below 0.2 m and midstory samples collected at 18 years

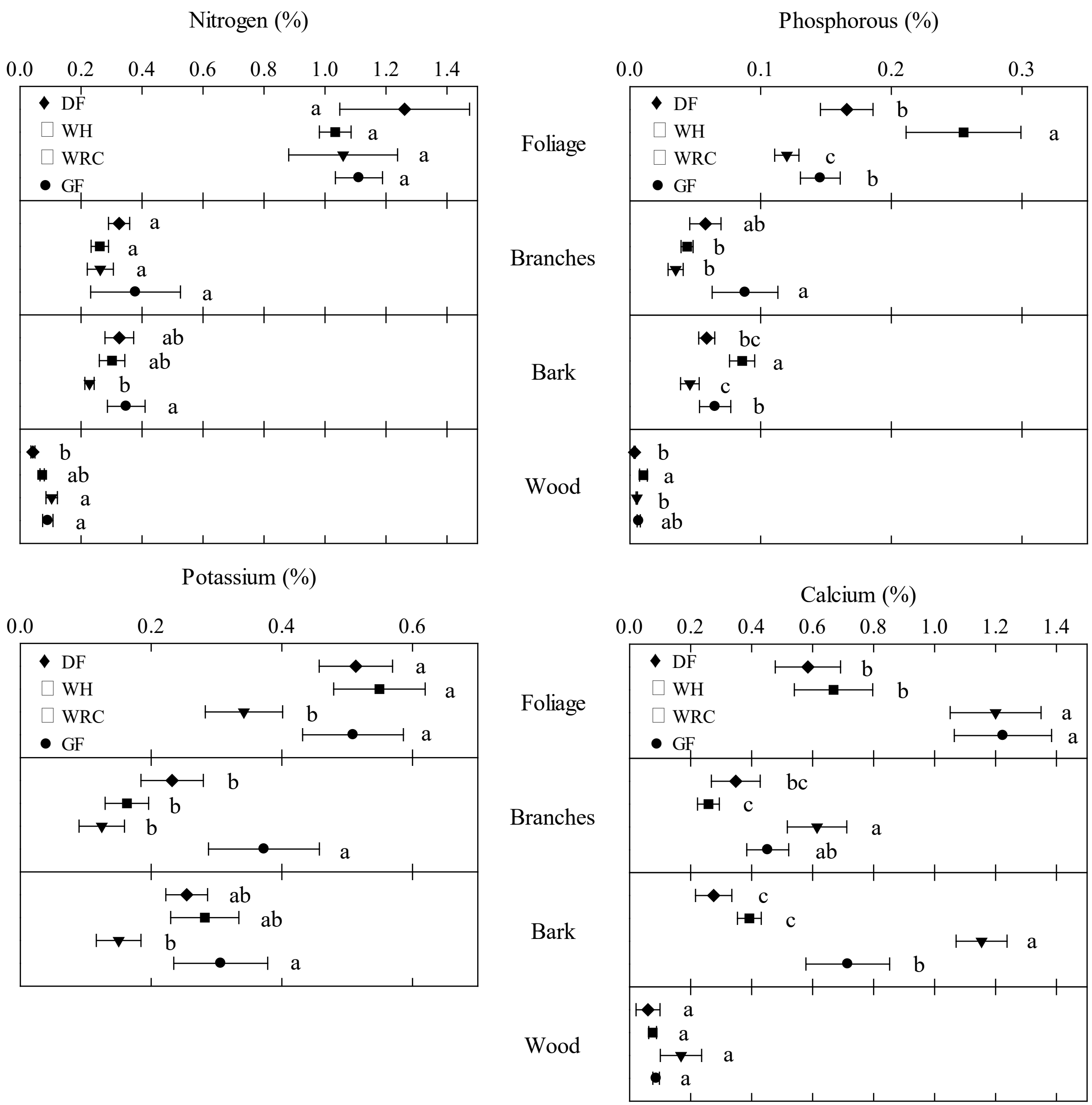
Results - Nutrient Concentrations

		Carbon		Nitrogen		Phosphorous		Potassium		Magnesium		Calcium		Sulfur	
		%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
DF	Foliage	49.460	0.171	1.252	0.064	0.184	0.009	0.607	0.037	0.097	0.005	0.600	0.038	0.125	0.010
	Branch	47.234	0.100	0.274	0.019	0.060	0.005	0.236	0.020	0.040	0.004	0.319	0.030	0.057	0.002
	Wood	47.781	0.086	0.077	0.013	0.005	0.001	BLD	-	0.009	0.001	0.051	0.012	0.032	0.001
	Bark	49.225	0.361	0.294	0.018	0.056	0.002 [1]	0.222 [1]	0.015	0.036 [1]	0.002	0.300 [1]	0.027	0.053	0.003
	Root	28.253	1.244	0.591	0.024	0.077	0.004	0.143	0.020	0.068	0.003	0.477 [1]	0.040	0.076	0.002
	Forest Floor	37.392	1.738	0.986	0.053	0.091	0.003	0.175 [1]	0.016	0.116 [1]	0.006	0.860 [1]	0.042	0.111	0.004
	Soil 0-20 cm	4.198	0.275	0.250	0.014	7.633	0.627	1.293	0.110	2.194	0.182	2.583	0.341	-	-
	Soil 20-40 cm	2.811	0.242	0.165	0.013	6.743	0.669	1.139	0.120	2.293 [1]	0.179	2.340	0.370	-	-
	Soil 40-60 cm	1.410	0.175	0.101	0.010	5.503	0.433	1.124	0.140	2.262	0.209	1.542 [1]	0.246	-	-
	Soil 60-100 cm	0.705	0.072	0.055 [2]	0.004	4.976	0.682	1.140	0.148	2.271	0.229	1.031	0.228	-	-
WH	Foliage	49.315	0.264	1.033	0.032	0.255	0.027	0.549	0.043	0.114	0.009	0.669	0.078	0.101	0.013
	Branch	46.505	0.117	0.261	0.017	0.044	0.003	0.163	0.020	0.033	0.003	0.259	0.022	0.051	0.002
	Wood	47.740	0.205	0.072	0.004	0.022	0.012	BLD	-	0.015	0.001	0.076	0.008	0.032	0.001
	Bark	46.131	0.644	0.301	0.025	0.086	0.006 [1]	0.282 [1]	0.032	0.043 [1]	0.004	0.393 [1]	0.024	0.056	0.003
	Root	33.904	1.737	0.522	0.026	0.084	0.006	0.159	0.019	0.094	0.005	0.409 [1]	0.029	0.071	0.002
	Forest Floor	40.966	1.314	0.903	0.086	0.107	0.003	0.179 [1]	0.028	0.146 [1]	0.015	0.754 [1]	0.039	0.105	0.004
	Soil 0-20 cm	4.960	0.306	0.206	0.012	6.911	0.793	1.444	0.083	2.573	0.041	1.111	0.132	-	-
	Soil 20-40 cm	2.693	3.755	0.351	0.204	6.268	0.937	1.416	0.068	2.707 [1]	0.060	0.782	0.166	-	-
	Soil 40-60 cm	1.513 [2]	0.308	0.106 [2]	0.017	5.230	0.479	1.391	0.073	2.751	0.087	0.700 [1]	0.157	-	-
	Soil 60-100 cm	0.658	0.100	0.056 [2]	0.004	3.470	0.378	1.352	0.094	2.605	0.178	0.370	0.020	-	-
WRC	Foliage	48.675	0.209	0.978	0.080	0.116	0.005	0.381	0.027	0.105	0.008	1.300	0.069	0.074	0.004
	Branch	45.646	0.965	0.216	0.021	0.039	0.003	0.146	0.015	0.035	0.003	0.624	0.048	0.045	0.002
	Wood	47.748	0.352	0.238	0.042	0.008	0.003	BLD	-	0.017	0.001	0.142	0.021	0.036	0.001
	Bark	47.871	0.300	0.262	0.015	0.049	0.003 [1]	0.154 [1]	0.013	0.052 [1]	0.003	1.009 [1]	0.051	0.053	0.003
	Root	27.354	1.664	0.552	0.021	0.076	0.004	0.119	0.011	0.079	0.006	0.577 [1]	0.047	0.077	0.002
	Forest Floor	39.943	1.826	0.774	0.085	0.077	0.009	0.222 [1]	0.050	0.126 [1,2]	0.019	1.123 [1]	0.100	0.090	0.006
	Soil 0-20 cm	4.867	0.266	0.250	0.012	9.785	0.794	1.396	0.119	2.146	0.206	2.778	0.365	-	-
	Soil 20-40 cm	3.079	0.318	0.178	0.014	7.450	0.585	1.204	0.125	2.227 [1]	0.206	2.186	0.326	-	-
	Soil 40-60 cm	1.464	0.201	0.108	0.011	5.829	0.439	1.153	0.138	2.263	0.212	1.782 [1]	0.263	-	-
	Soil 60-100 cm	0.608	0.049	0.062	0.005	4.735	0.498	1.218	0.200	2.202	0.232	1.438	0.377	-	-
GF	Foliage	48.667	0.122	1.111	0.047	0.146	0.009	0.509	0.047	0.130	0.012	1.205	0.097	0.096	0.009
	Branch	46.347	0.240	0.379	0.090	0.088	0.015	0.373	0.052	0.054	0.010	0.453	0.042	0.061	0.005
	Wood	47.360	0.096	0.091	0.010	0.007	0.001	BLD	-	0.016	0.001	0.087	0.007	0.034	0.001
	Bark	46.708	0.376	0.348	0.038	0.065	0.007 [1]	0.305 [1]	0.044	0.0550 [1]	0.005	0.715 [1]	0.083	0.058	0.002
	Root	27.373	1.733	0.597	0.059	0.104	0.010	0.136	0.011	0.105	0.005	0.468 [1]	0.045	0.079	0.003
	Forest Floor	35.490	1.831	1.005	0.114	0.105	0.008	0.132 [1]	0.015	0.122 [1]	0.004	1.600 [1]	0.176	0.100	0.006
	Soil 0-20 cm	6.119	0.705	0.292	0.032	8.275	1.157	1.760	0.121	2.840	0.129	1.867	0.126	-	-
	Soil 20-40 cm	2.541	0.226	0.162	0.015	5.566	0.854	1.498	0.073	2.999 [1]	0.048	1.089	0.183	-	-
	Soil 40-60 cm	1.625	0.243	0.106	0.013	4.897	0.781	1.538	0.115	3.033	0.111	0.850 [1]	0.172	-	-
	Soil 60-100 cm	0.648	0.144	0.059	0.008	3.735	0.721	1.768	0.202	3.082	0.133	0.711	0.161	-	-

Results - Nutrient Concentrations

N

P



K

Ca

Results – Nutrient Concentration

Plant derived :

- Forest floor, bark, and fine roots displayed the most treatment (Trt) effects across species
  - Bark concentrations higher in Control plots for P, Mg, and Ca
  - No consistent treatment effect **across species** for foliar concentrations (individual species showed various Trt effects)

Soil:

- Few soil treatment effects detected
  - C higher in Control for the 0.4-0.6 m of WRC
  - Some differences in soil N observed
    - Higher in VM DF (0.6-1.0 m)
    - Lower in VM WRC (0.2-0.4 m and 0.4-0.6 m)
  - Ca higher in Control for 0.4-0.6 m depth
  - Mg higher in VM for 0.6-1.0 m depth

Results – Nutrient Concentration

- **Plant derived** tissue concentrations:
  - More variance among species and sites than among treatments
  - Plant foliar nutrient responses vary by nutrient, species, site

- **Soil** concentrations:
  - Differ greatly by site
  - Generally, few treatment differences
  - Potential for VM to decrease total soil N for WRC

Methods – Nutrient Content

- Crop tree biomass updated with inventory at 18 years
  - Species specific functions from Flamenco et al. (2019)

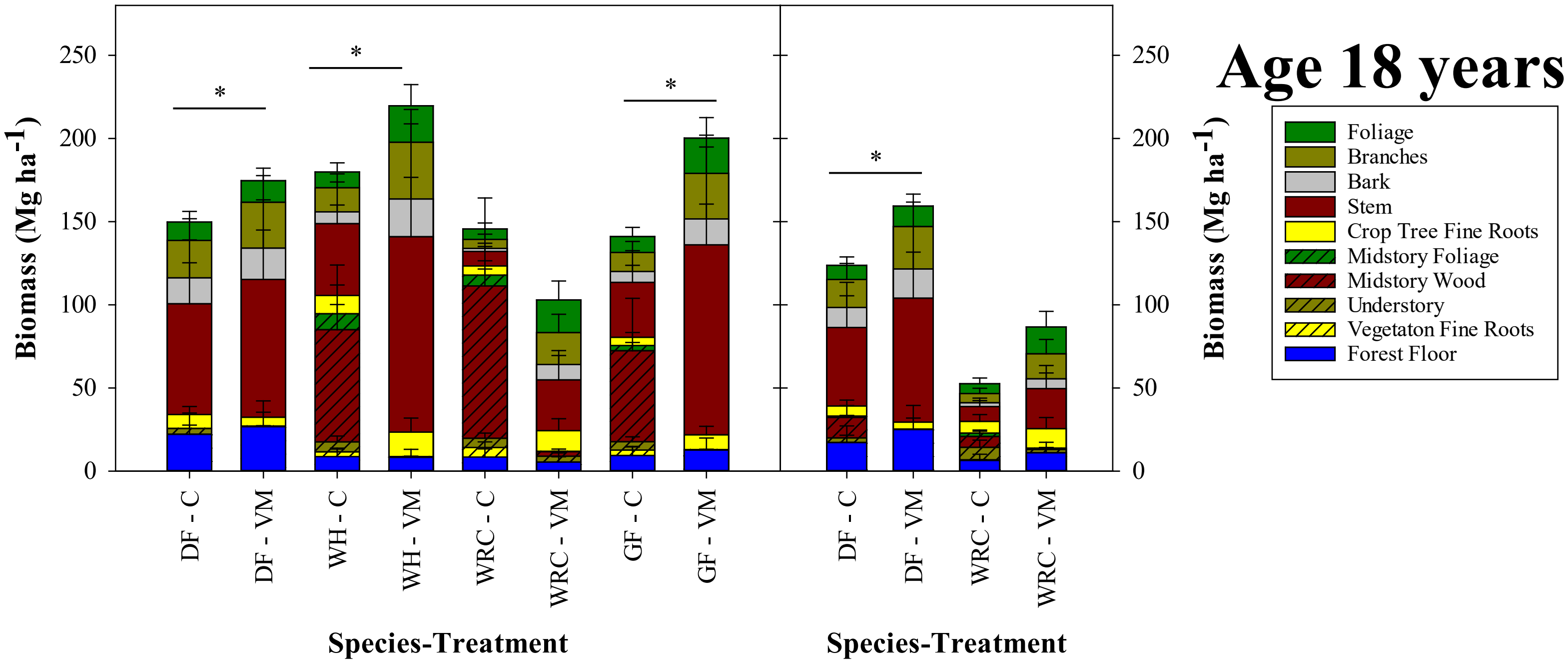
- Midstory biomass calculated from 2 m^2 subplot inventory at 18 years
  - 6 subplots per plot
  - Species specific functions from Flamenco et al. (2019)
  - Foliage mass calculated using literature derived equations

- Soil mass calculated using bulk density

- Nutrient mass calculated by multiplying tissue biomass by tissue nutrient concentration

Stand level differences

Age 18 years



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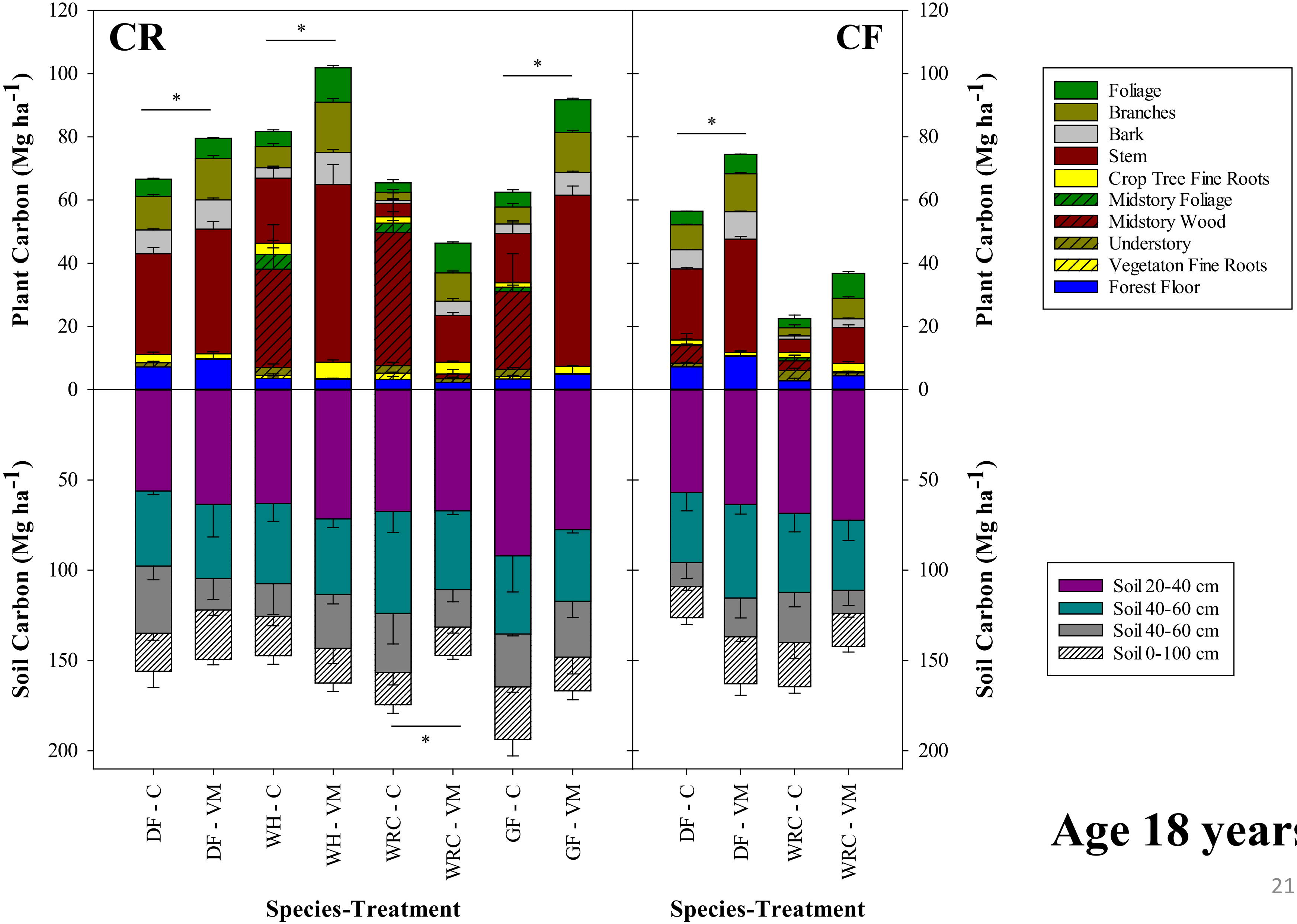
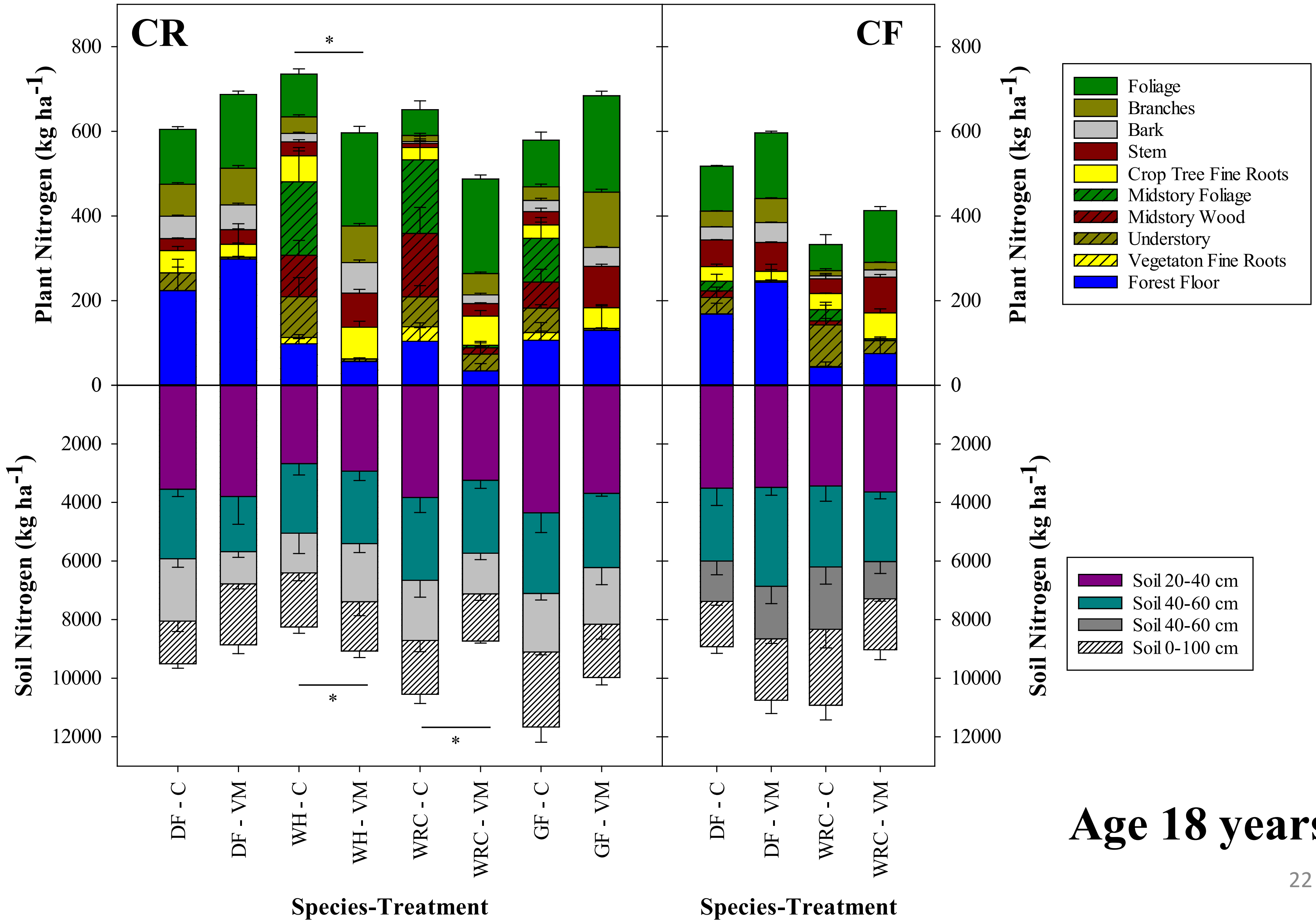
		VM	291	3.5	124.4	0.0
	WRC	C	142	2.5	30.6	11.8
		VM	378	2.5	83.4	0.0

Results – Carbon Content



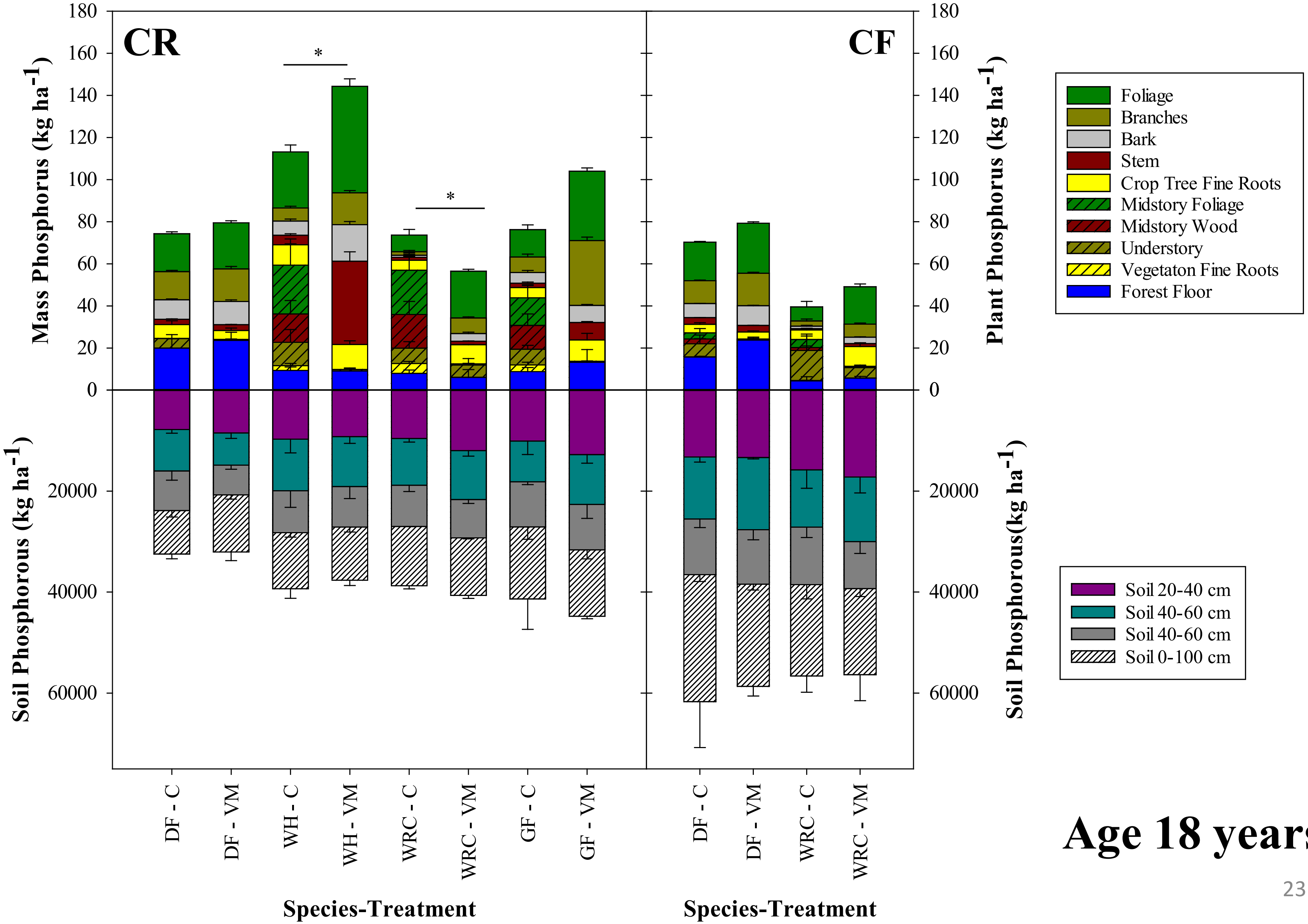
Age 18 years

Results – Nitrogen Content



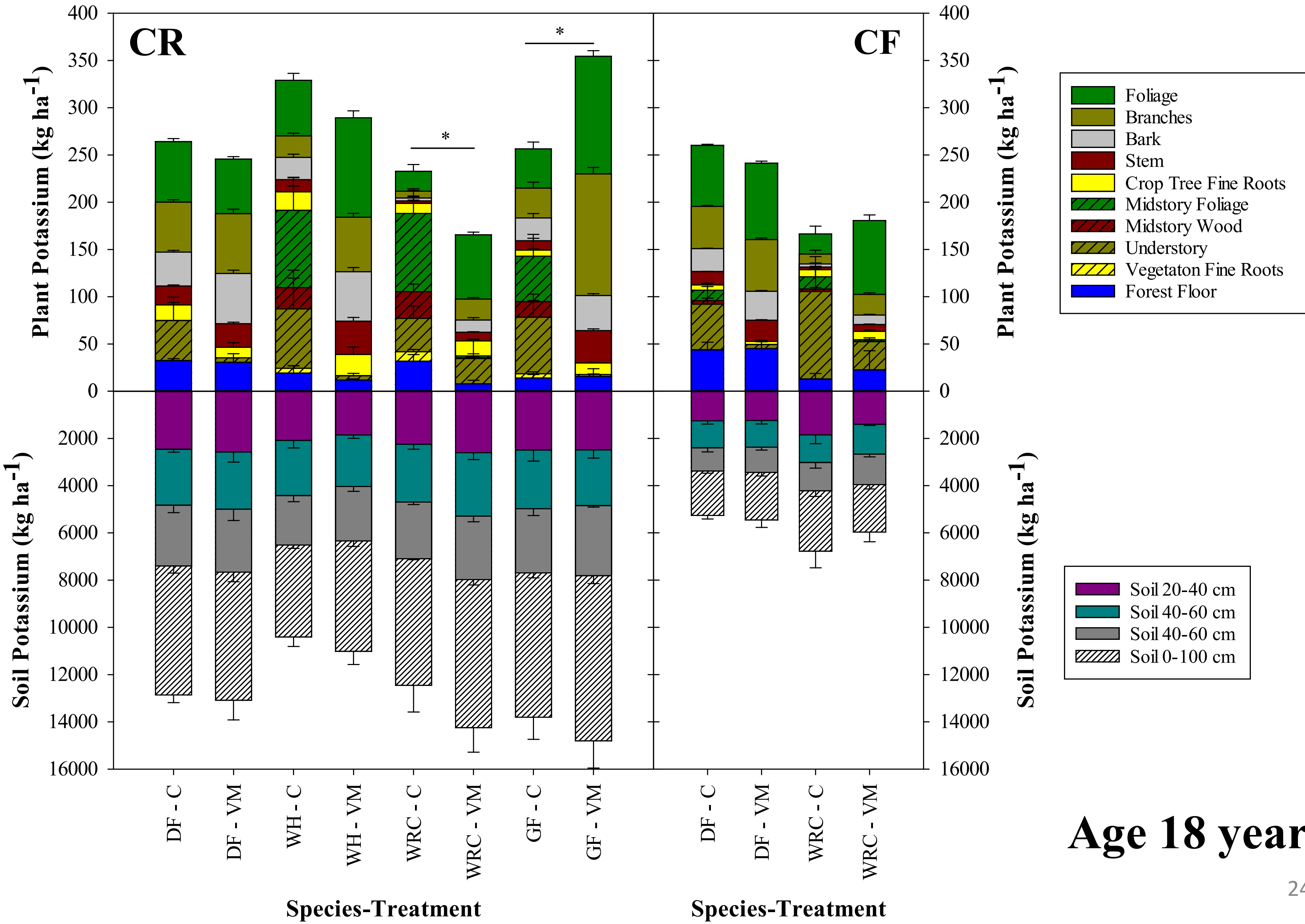
Age 18 years

Results- Phosphorous Content



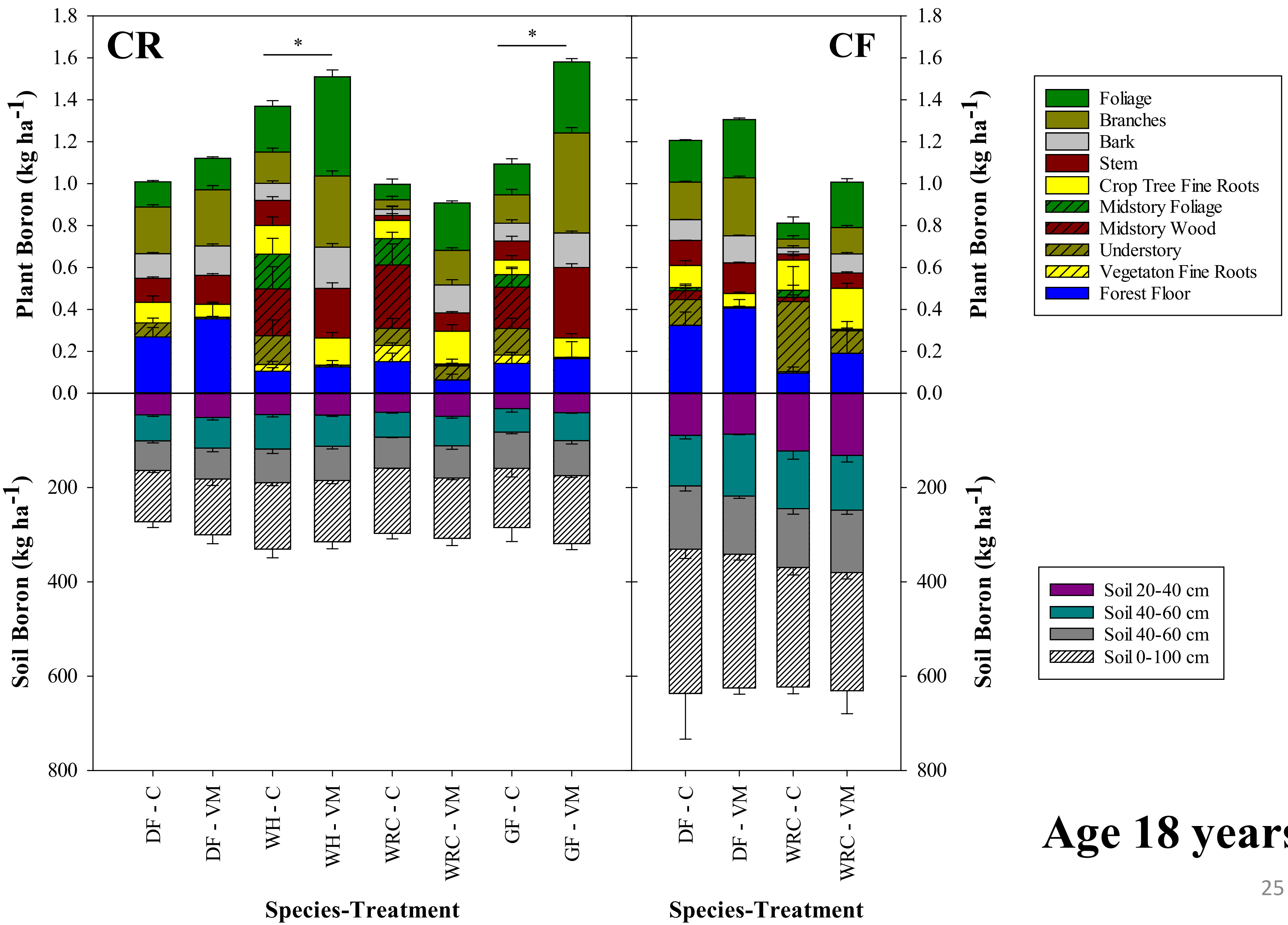
Age 18 years

Results- Potassium Content



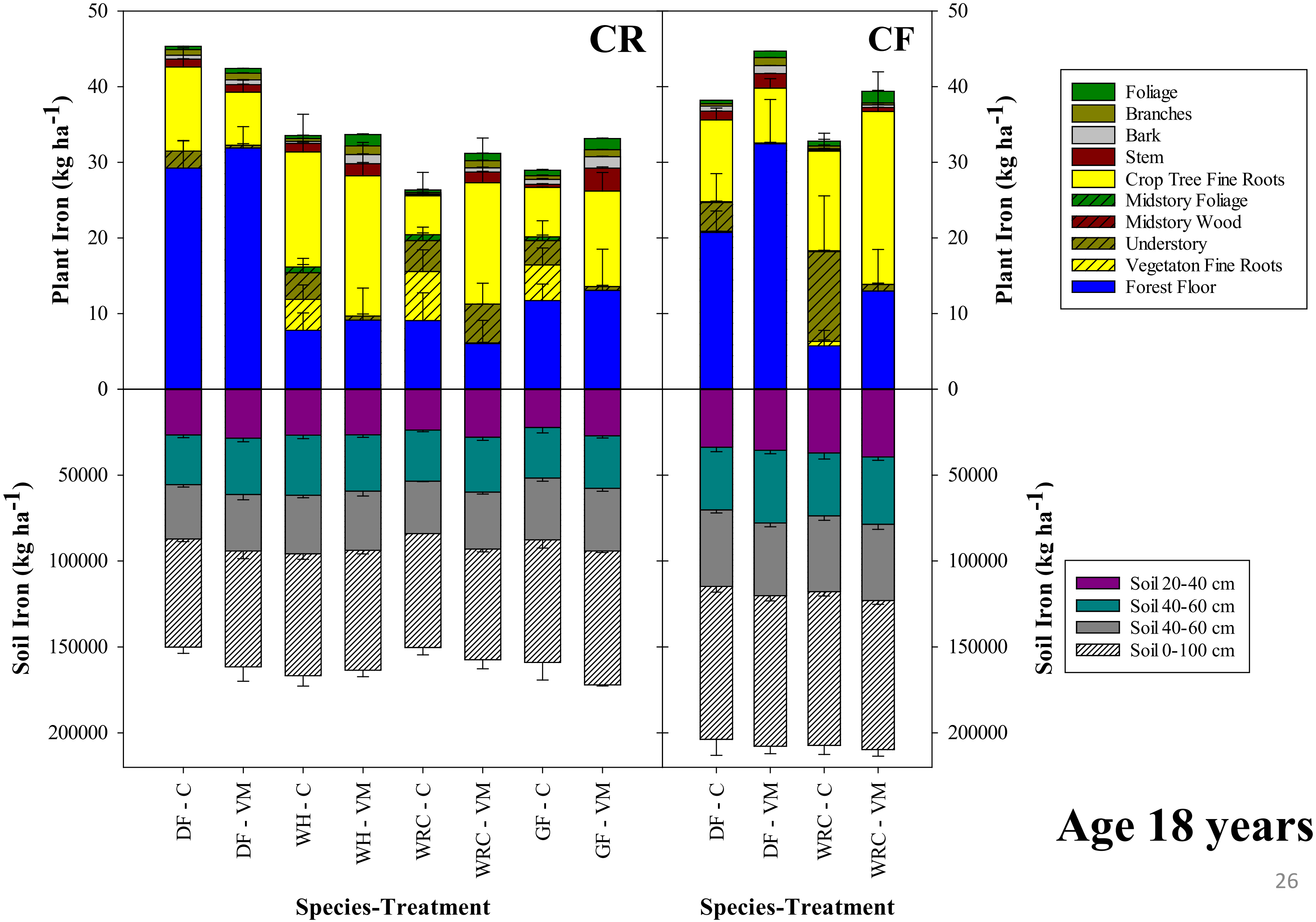
Age 18 years

Results- Boron Content



Age 18 years

Results- Iron Content



Age 18 years

Conclusions – Nutrient Content

- **Plant nutrient content response varied greatly by site and species**
  - All crop tree tissues had higher content in VM plots

- **Ca is the only nutrient that responded to treatment similarly across all sites and species**
  - WRC at the CR site was a common outlier due to the unique midstory response to the Control treatment
  - C, Cu, P, and B all tend to have greater plant derived masses in VM plots (excluding WRC at the CR site)

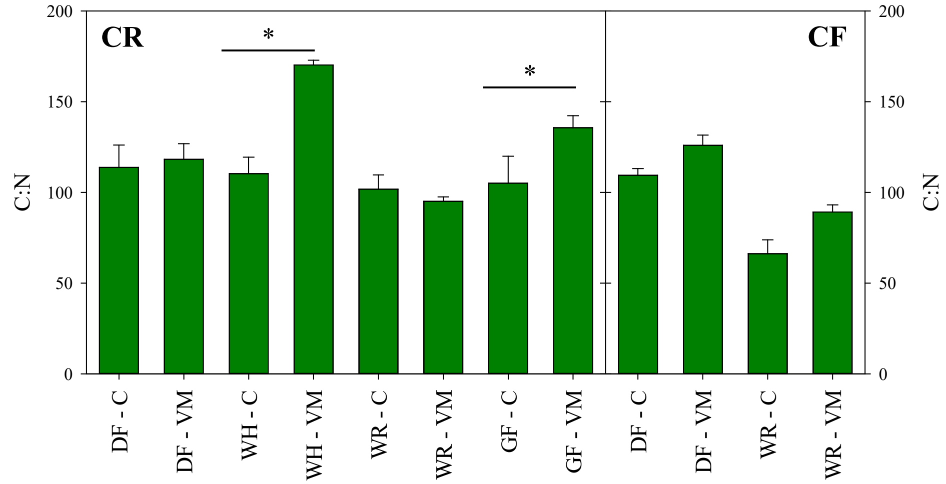
- **Total soil content was generally unaffected by treatment**
  - Soil N content – WRC at CR
  - Soil Cu content – Site x Species x Treatment
  - Treatment effects by depth similar to concentration

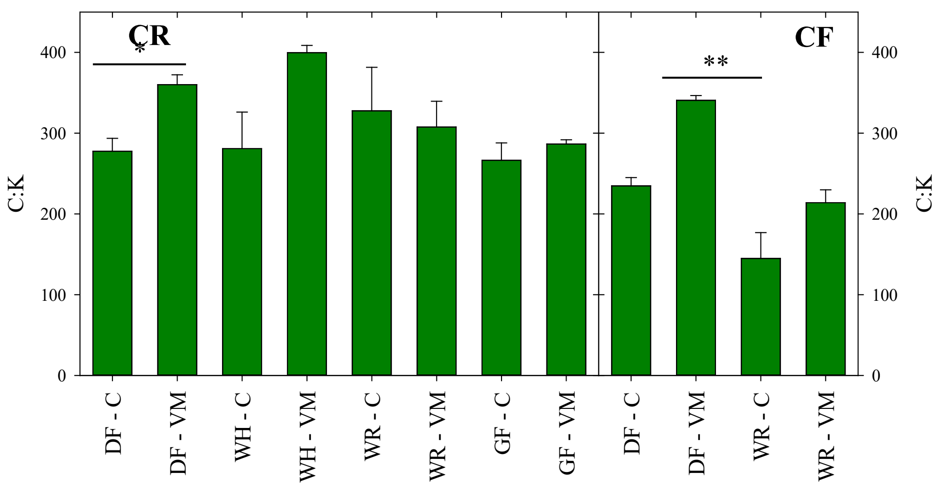
Results- Nutrient Use Efficiency

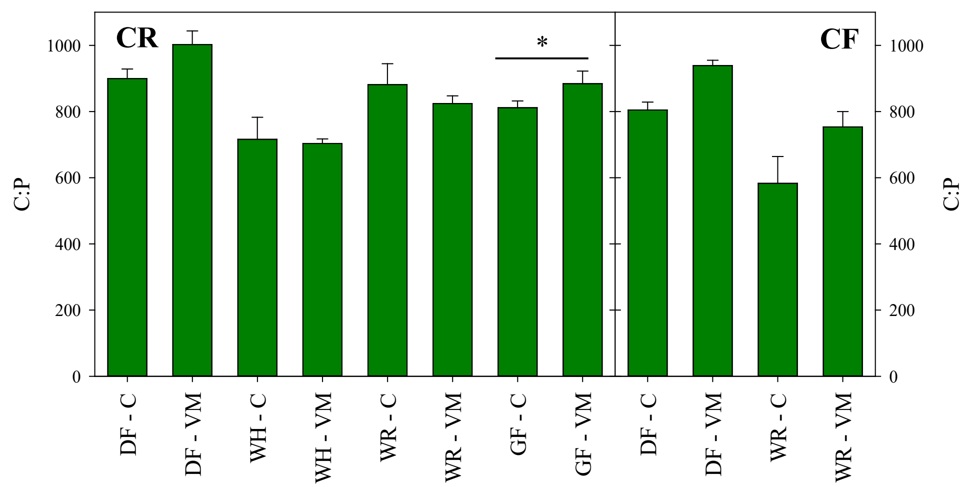
NUE: kg C / kg Nutrient

Nutrient	Site	Spp	Trt	Site* Spp	Site*Trt	Spp*Trt	Site*Spp*Trt
C:N	0.123	**<0.001**	**<0.001**	0.074	0.057	**0.010**	0.388
C:P	**0.002**	**0.002**	0.074	0.135	0.072	0.540	0.160
C:K	**<0.001**	**0.038**	**0.001**	**0.009**	0.121	0.140	0.348
C:Mg	0.745	**<0.001**	**<0.001**	0.209	0.075	**0.033**	0.324
C:Ca	**0.001**	**<0.001**	0.493	0.136	0.057	0.104	**0.015**
C:S	0.098	**0.007**	**<0.001**	0.879	0.477	**<0.001**	0.053

Nitrogen NUE







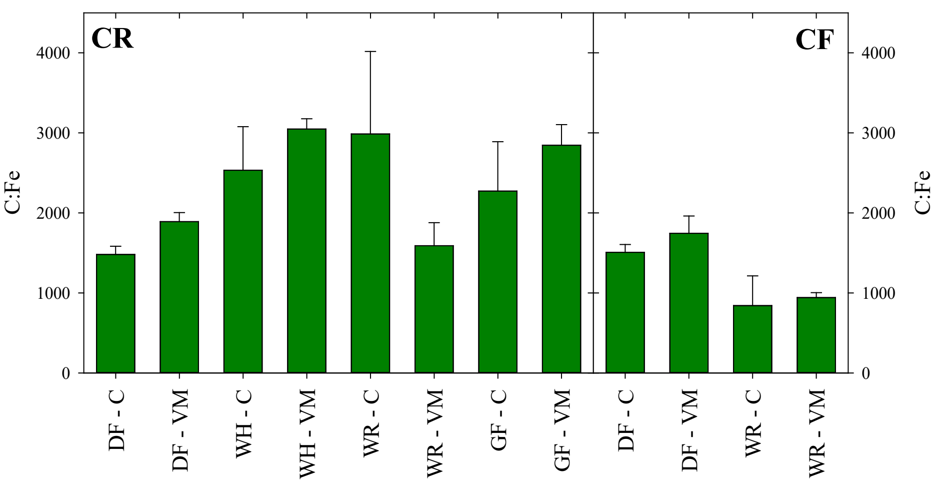
Potassium NUE

Phosphorus NUE

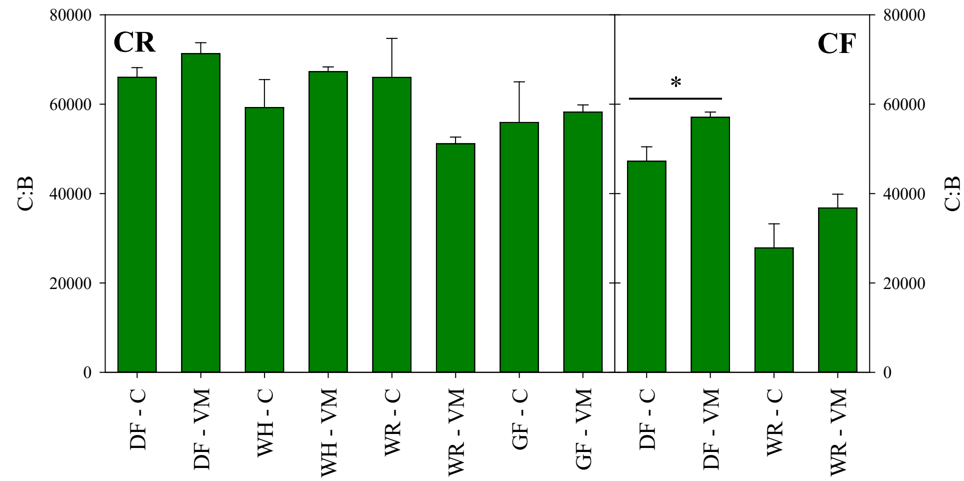
Results- Bole Nutrient Use Efficiency

NUE: kg C / kg Nutrient

Nutrient	Site	Spp	Trt	Site*Spp	Site*Trt	Spp*Trt	Site*Spp*Trt
C:B	**<0.001**	**0.033**	0.165	0.146	**0.009**	0.518	0.056
C:Mn	**0.001**	0.632	0.141	**0.026**	0.074	0.601	0.074
C:Fe	**0.024**	**0.013**	0.360	**0.035**	0.124	0.240	0.060
C:Cu	**<0.001**	**0.017**	**0.004**	0.575	0.880	0.068	**0.002**
C:Na	**0.020**	0.212	0.138	**0.001**	**0.035**	0.932	**0.033**
C:Zn	**<0.001**	**0.001**	0.218	**0.001**	**0.016**	0.194	**0.005**



Iron NUE



Boron NUE

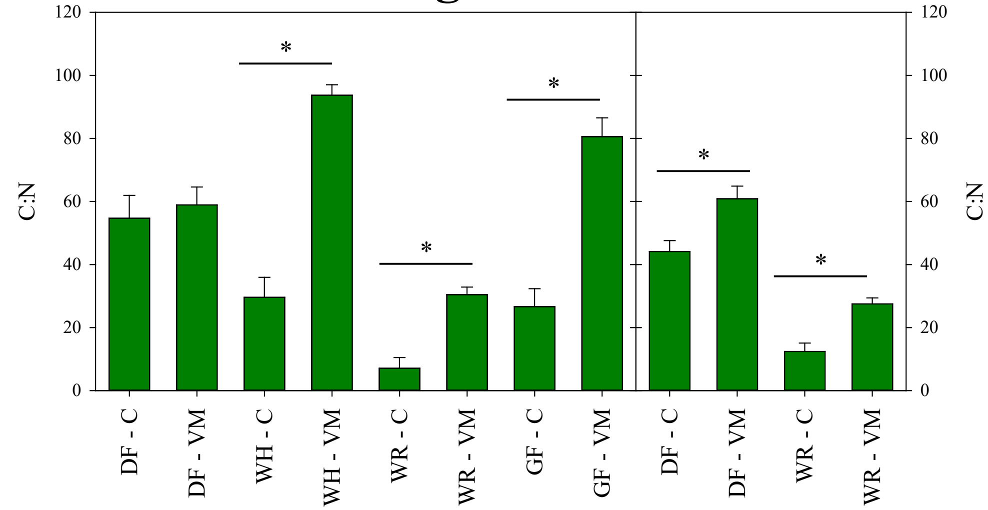
Results- Nutrient Use Efficiency

- If NUE is defined as ratio of stemwood C:total plant derived nutrients

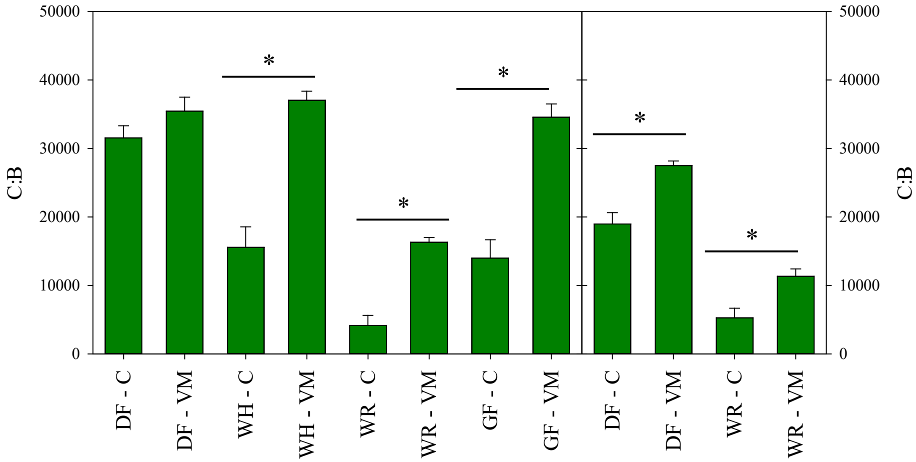
Nutrient	Site	Spp	Trt	Site*Spp	Site*Trt	Spp*Trt	Site*Spp*Trt
C:N	**0.001**	**<0.001**	**<0.001**	**0.011**	0.153	**0.002**	0.409
C:P	0.652	**<0.001**	**<0.001**	0.324	0.825	**<0.001**	**0.008**
C:K	0.592	**<0.001**	**<0.001**	0.678	0.544	**<0.001**	0.096
C:Mg	**<0.001**	**<0.001**	**<0.001**	0.356	0.130	**<0.001**	0.052
C:Ca	**0.003**	**<0.001**	**<0.001**	**0.004**	**0.011**	0.078	0.132
C:S	**0.049**	**<0.001**	**<0.001**	0.370	0.058	**<0.001**	**0.003**
C:B	**0.014**	**<0.001**	**<0.001**	**0.020**	0.757	**0.004**	0.375
C:Mn	0.651	**<0.001**	**<0.001**	0.429	0.724	**<0.001**	0.100
C:Fe	**0.022**	**<0.001**	**<0.001**	0.294	0.289	**0.001**	**0.001**
C:Cu	0.089	**<0.001**	**<0.001**	0.878	0.220	**0.001**	0.212
C:Na	**0.037**	**<0.001**	**<0.001**	**0.012**	0.723	**0.006**	**0.031**
C:Zn	0.652	**<0.001**	**<0.001**	0.324	0.825	**<0.001**	**0.008**

Results- Bole Nutrient Use Efficiency

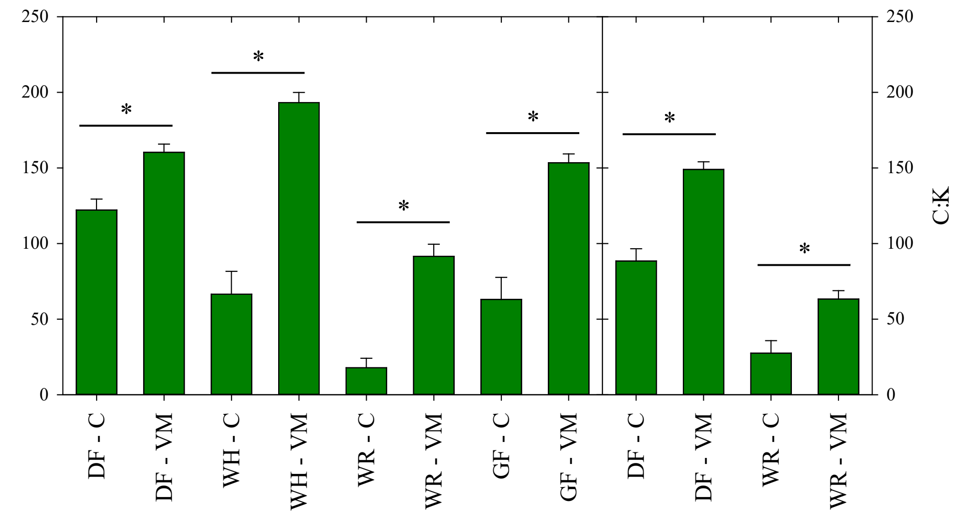
Nitrogen NUE



Boron NUE



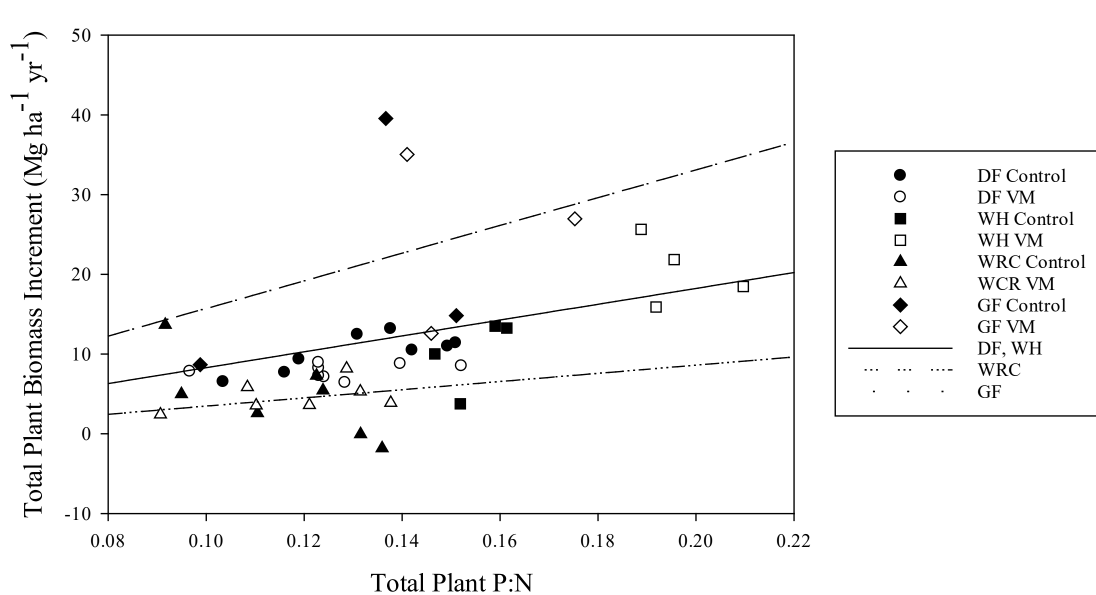
Potassium NUE

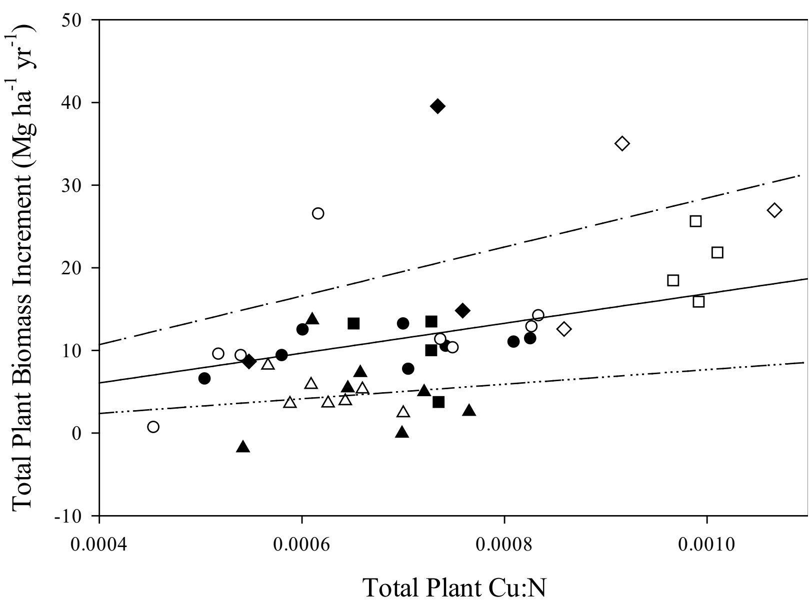


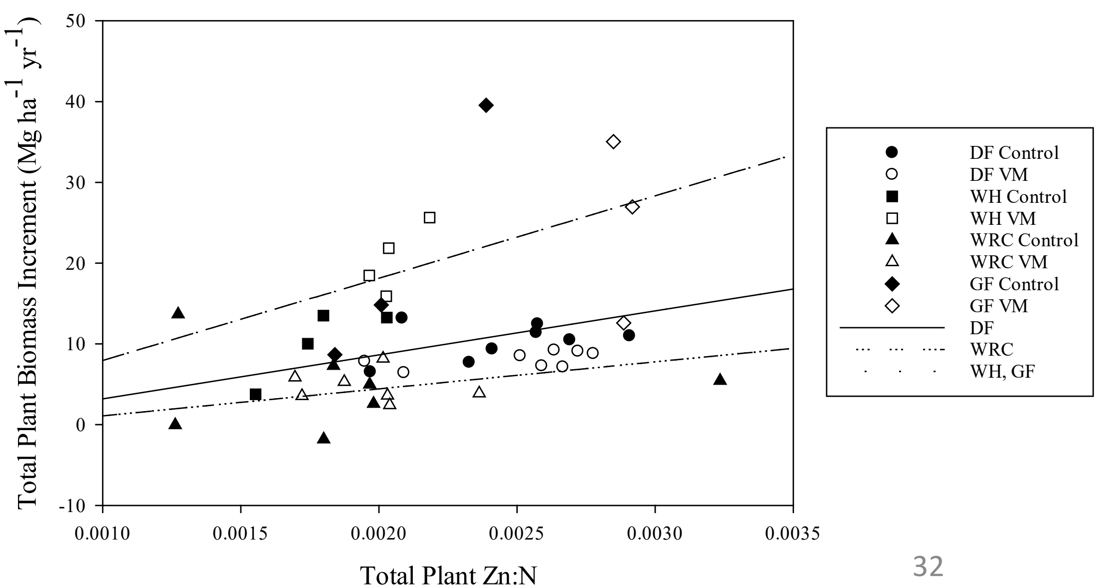
Results- Total Plant Nutrient Ratios

Ecosystem increment increases with ratio

Slope varies by species, not treatment



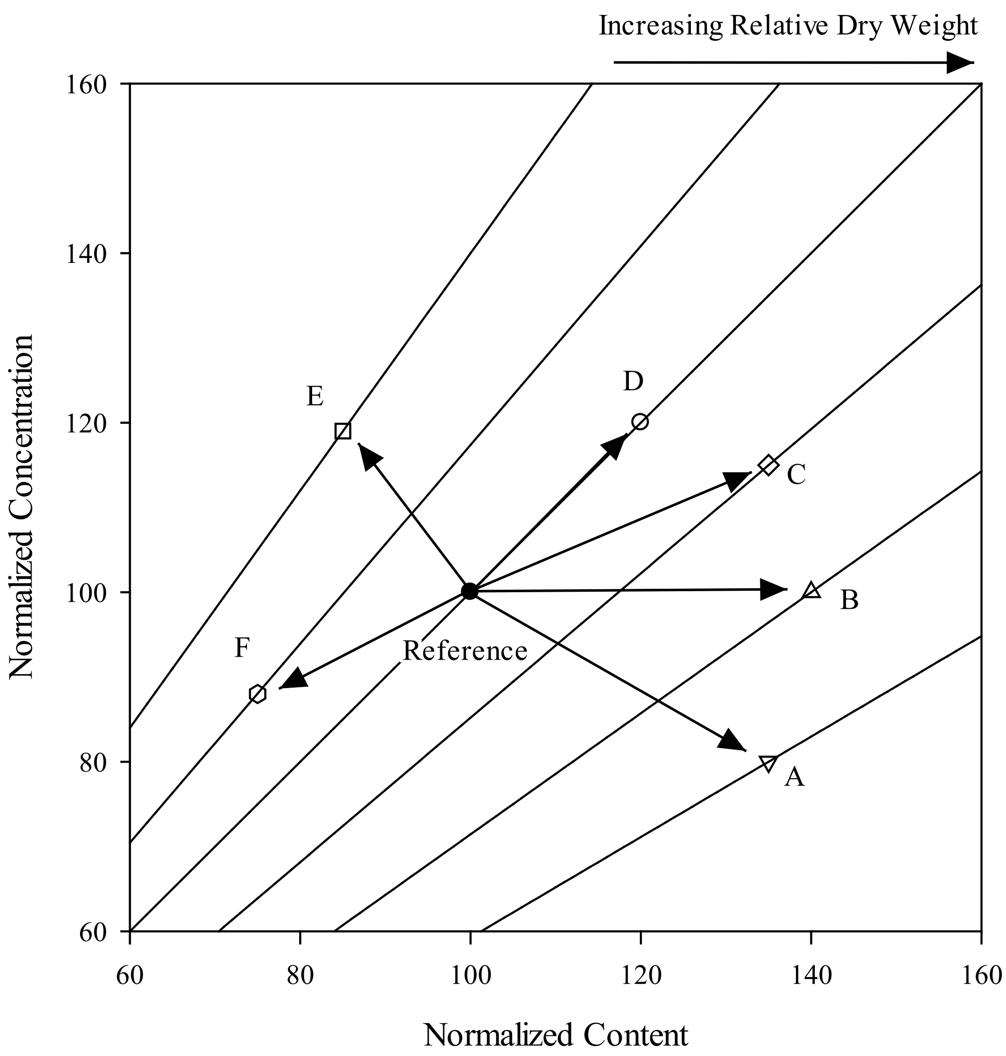




Results- Total Plant Nutrient Ratios

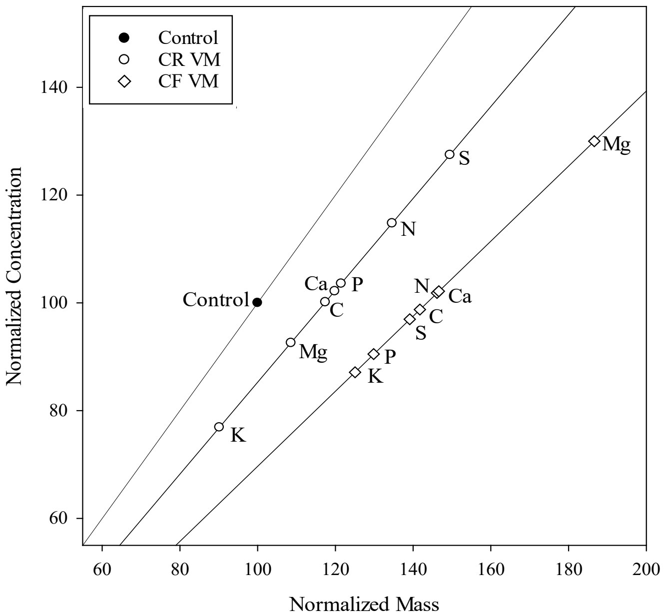
Ratio	Site	Spp	Trt	Site*Spp	Site*Trt	Spp*Trt	Site*Spp*Trt
P:N	0.231	**<0.001**	**0.006**	0.368	0.718	**0.016**	0.935
K:N	**0.011**	0.327	0.860	0.245	0.665	0.090	0.878
Mg:N	0.065	**0.001**	**<0.001**	0.704	0.803	0.925	0.611
Ca:N	**0.021**	**<0.001**	**<0.001**	0.449	0.357	**<0.001**	**0.045**
S:N	**0.002**	**0.003**	0.131	**0.007**	**0.010**	0.384	**0.009**
B:N	**<0.001**	0.629	**0.024**	0.400	0.364	0.086	0.556
Mn:N	**<0.001**	**0.002**	**0.001**	0.192	0.681	**0.001**	0.295
Fe:N	0.217	0.570	0.484	0.217	0.216	0.572	0.216
Cu:N	**0.001**	**<0.001**	**0.001**	**0.018**	0.100	**0.001**	0.480
Na:N	**<0.001**	0.074	0.968	**0.002**	0.854	0.429	**0.029**
Zn:N	**0.022**	**0.001**	**0.016**	0.192	0.789	0.141	0.095

Results- Vector Analysis



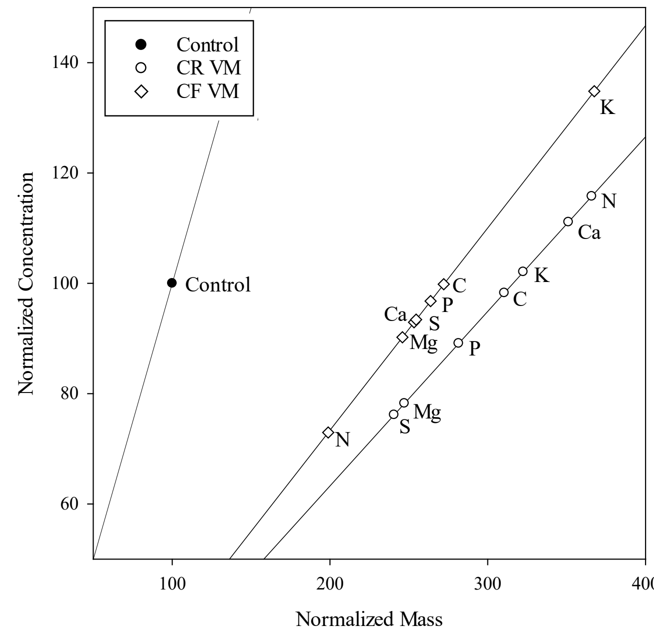
Adapted from Timmer and Stone (1978)

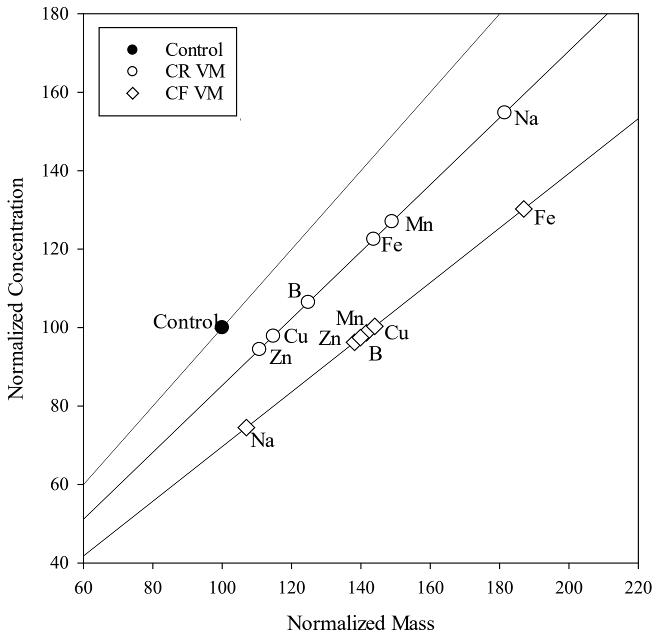
Results- Vector Analysis



DF

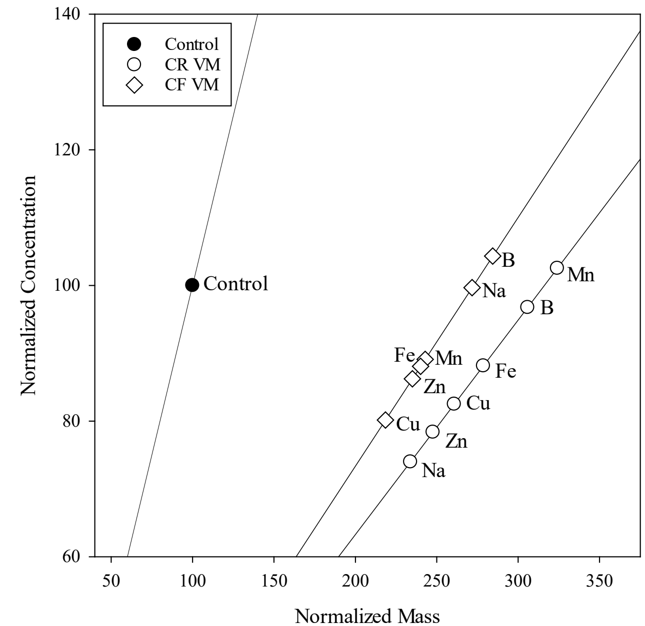
WRC



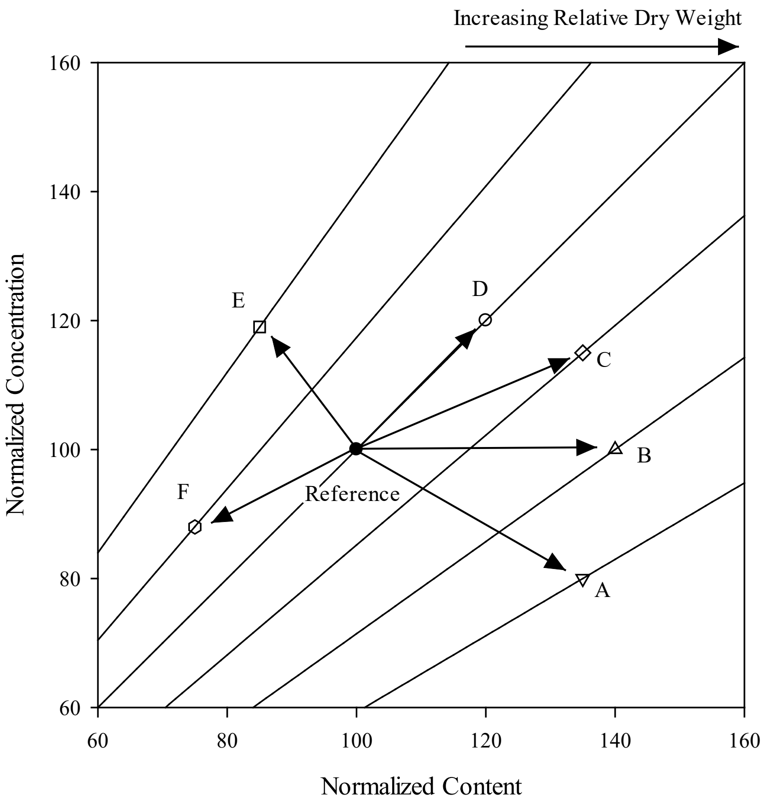


DF

WRC



Results- Vector Analysis



Adapted from Timmer and Stone (1978)

DF CR
A: K *Mg* *Zn*
B: ***C*** P Ca *B* **Cu**
C: ***N*** S Mn Fe Na

DF CF
A: P K Zn
B: ***C*** S **B** Mn **Cu**
C: **N** **Ca** *Mg* S *Fe* Na

Same by site

WRC CR
A: **P** *Mg* S Cu *Zn* Fe Na
B: ***C*** K Mn *B*
C: *N* **Ca**

WRC CF
A: N **P** K S Mn Na
B: ***C***
C: ***Ca*** *Mg* B Cu Zn *Fe*

Same by species

A: Dilution
B: Sufficiency
C: Potential deficiency

Conclusions

- Treatment effects on plant derived nutrient pools and foliar nutrient status varied between nutrients, sites, and species

- Total soil nutrients pools were largely unaffected by VM treatment and were 10 to 1000 times greater than total plant derived pools
  - WRC at the CR site had less soil N mass in VM plots

- VM decreased the amount of N, K, Mg, S, and Cu used per unit mass of C stored in plant derived tissues
  - Higher NUE

- Nutritional requirements of a stand depend on site, species, and treatment

Management Implications

- Harvest practices that only remove crop tree stems likely to have little impact on total soil nutrient reserves

- VM results in larger crop trees and higher NUE of total plant biomass and stemwood production

- VM unlikely to accelerate soil nutrient depletion
    - Possibility of reducing soil N reserves for WRC stands

Thank you!

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