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VECTOR DIAGNOSIS OF CONTAINER-GROWN PONDEROSA PINE NUTRIENT STATUS WITH CONTROLLED-RELEASE FERTILIZER INCORPORATED IN THE ROOT PLUG

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Vector diagnosis of container-grown ponderosa pine nutrient status with controlled-release fertilizer incorporated in the root plug

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Abstract

Prior to sowing seeds, three controlled-release fertilizers (fast release (FR), moderate release (MR) and slow release (SR)) were incorporated in the growing media at rates of 0.8, 1.6 or 3.2 grams per seedling as supplements to nursery supplied soluble fertilizer. Effects on seedling foliar and root nutrient status of "160/90" container ponderosa pine *(Pinus ponderosa Doug. ex Laws*) in the greenhouse were evaluated using graphical vector analysis. Treatment FR-0.8 produced the largest increase in foliage mass (238%) and root mass (169%) of all treatments while maintaining a nearly "steady-state" condition. The "steady-state" vectors resulting from treatment FR-0.8 indicate that nutrients were supplied in sufficient amounts to support the higher growth rates and increased biomass accumulation compared to the controls since nutrient contents increased in proportion to biomass. Some slow release fertilizers applied at higher rates, when combined with the existing nursery fertilization schedules, produced seedlings with poor nutritional balance in both foliage and roots. These treatments were readily detected with nutrient vector analysis and the technique proved to be effective in assisting the development of nursery fertilization regimes.

Key words: *Pinus ponderosa Doug. Ex Laws,* foliage, root, nutrient content, nutrient concentration.

Introduction

Nutrient status of containerized tree seedlings plays a critical role in tree establishment and growth after planting, especially on nutrient-deficient sites (Timmer and Miller 1991). Fertilization has been an important practice used to improve nutrient status and production of containerized tree seedlings. Some nursery fertilization practices call for application of fertilizers in a single dose at the start of the tree growing cycle or in equal amounts as top dressing through the growth regime. Such fertilization regimes can result in leaching and cause negative effects on seedling growth due to initial toxicity from over-fertilization, followed by deficiency because nutrient supply does not match the absorption rates of the rapidly growing seedlings. Based on a series of plant nutrition experiments using solution culture techniques, Ingestad (1974) proposed the concept of steady-state nutrition wherein plants are free of nutrient stress and are thus able to maintain a stable internal nutrient concentration by matching nutrient supply to the nutrient uptake required to support seedling growth and biomass accumulation. Implementation of this concept has proved successful in enhancing growth and improving early outplanting performance of conifer seedlings (Timmer and Miller 1991).

As suggested by Imo and Timmer (1992), "steady-state" nutrition can be achieved, and a tree's nutrient status improved, using exponentially based fertilization schedules. A potentially efficient method for achieving steady-state nutrition would be to incorporate slow-release fertilizer in the root plug at the time of sowing. Carefully controlling release rate, nutrient composition, and application rate of slow-release fertilizers could improve the nutrient status of container-grown tree seedlings. Furthermore, this practice could also avoid additional fertilization at planting.

Thus, the major objective of our study was to quantify the nutrient status of ponderosa pine seedlings at the end of one growing season in the nursery using nutrient vector analysis of seedling foliage and root tissue samples. Graphical vector analyses allow comprehensive evaluation of potential effects of fertilizer release rates, nutrient composition and application rates on seedling nutrient status. This information would be useful for fertilizer manufacturers to formulate and nursery managers to use products with desirable release rates and nutrient composition that produce balanced tree nutrition.

Materials and Methods

Experimental design

Three controlled-release fertilizer products characterized by different release rates and nutrient compositions (Table 1) were incorporated in the growth medium at rates of 0.8, 1.6 and 3.2 grams per seedling prior to sowing the seeds. Ponderosa pine seedlings were grown in 160/90 styroblocks (160 cavities per block, 90 cm^3 per cavity) at the University of Idaho (UI) Forest Research Nursery during the 1996-growing season. The growing medium was a 50/50 percent peat-vermiculite mix (pH 4.2). A specific amount of controlled-release fertilizer was first fully mixed into the 50/50 percent peat-vermiculite growing medium, and then container cells were hand filled with the mixture of growing medium and fertilizer. For the control treatment, no slow-release fertilizer was applied. Ponderosa pine seeds were sown with a vacuum seeder and covered with about 0.6 cm of Target Forestry Sand®. A completely randomized design with four replicates was used in this experiment since the environment where the seedlings were grown was homogeneous. Seedlings were grown in the regular nursery regime, in which seedlings also received regular nursery-based irrigation and fertilization in addition to the controlled-release fertilizers. Thus, our control treatment is the regular nursery culture condition, which serves as the reference point in the vector analysis. Wenny and Dumroese (1987) delineated the growing environment for ponderosa pine in detail. They feel that seedlings grown in such an environment, i.e. the controls in our experiment, suffer no nutrient stress.

Biomass harvest and tissue analysis

A random sample of thirty-two seedlings for each treatment was harvested for biomass measurement and tissue analysis at lifting (December 1, 1996). Each seedling was cut at the root collar, and the root was extracted from the cells and hand washed. The shoot was separated into foliage and stem. The foliage, stem and root samples were weighed after oven drying at 70 °C for 48 hours. Foliage and root samples were then ground and sent to the Scotts Company Laboratories in Allentown, PA for nutrient concentration analysis. The nutrients analyzed were N, P, K, Ca, Mg, B, Cu, Zn, Fe, Mn and Mo. Foliar nitrogen was determined using a standard mico-Kjeldahl procedure. Phosphorus, K, Ca, Mg, Mn, Fe, Cu and Zn were determined by inductively coupled plasma (ICP) emission with digested plant tissue. Biomass and tissue concentration data were used in the graphical vector analysis.

Vector analysis

Graphical vector analysis has successfully been used to interpret plant nutrient status and nutrient shifts (dilution, deficiency, excess, etc) in response to silvicultural treatments (Weetman and Fournier 1982, Timmer and Miller 1991, Imo and Timmer 1992, 1996, Weetman et al.1993, Yobterick et al.1994, Binkley et al.1995). Timmer and Miller (1991) and Haase and Rose (1995) reviewed vector analysis comprehensively. Unlike other approaches such as critical value approach (CVA), diagnosis and recommendation integrated system (DRIS) and compositional nutrient diagnosis (CND), vector analysis considers the change in both nutrient concentration and biomass, as well as nutrient content, the three parameters of plant response to nutrient supply simultaneously through the formula: $c=a/m$, where c, a, and m are nutrient concentration, content and dry mass, respectively (Timmer and Miller 1991). Based on the relative change (direction and magnitude) of the three parameters, plant nutrient status can be diagnosed as growth dilution, steady state, deficiency, accumulation, toxic accumulation or antagonism (Figure 1). A control treatment or some early state of the same treatment can serve as the reference point for calculating and comparing the relative change of the three parameters for treatments of interest. In our study, the control treatment, theoretically free of nutrient stress, is the reference point for comparing the controlled release fertilizer effects on growth and nutrient status of ponderosa pine seedlings.

In the vector diagram, determination of the direction and magnitude (length) of each resultant vector depends on its component horizontal and vertical vector lengths (the means of the relative nutrient concentrations and contents) but does not consider potential variation in relative nutrient contents and concentrations. Conclusions may be incorrect if the amount of variation in the vector is not considered. To address this issue, we expanded the vector interpretation of Figure 1 by considering the statistical significance of the component horizontal and vertical vectors. Dunnett's multiple-range tests were conducted for detecting the significance of nutrient concentrations and contents between the nine fertilization treatments and the control (Table 2). Two-way classification analysis of variance was performed to further test the fertilizer type and dosage effects on both foliar and root nutrient concentrations. The statistical computations were conducted using the General Linear Model (GLM) procedure of SAS (SAS® Institute Inc. 1995).

The following results and discussion are based on interpretations described in Table 2. For simplicity and convenience, we use CTR to represent the control (no controlled release fertilizer added), and FR-0.8, FR-1.6, and FR-3.2 to represent the 0.8, 1.6 and 3.2 grams per seedling of the FR fertilizer treatments. The moderate (MR) and slow (SR) treatments are similarly designated. We used an α level of 0.1 for all comparisons.

Results

No treatment produced a decrease in either foliage or root mass compared to the control (Table 3 and Figures 2 and 3), thus diagnoses of toxic accumulation or antagonism did not occur in our study based on interpretations in Figure 1 and Table 2. Relative foliage mass increases ranged from 148% to 238%, while relative root mass increases ranged from 113% to 169% compared to the control (reference point). Treatment FR-0.8 produced the greatest relative increase for both foliage and root mass, 238% and 169% respectively, among all treatments tested in our study. Content (concentration × mass) increased for most nutrients and treatments, although many contents were not statistically different from the controls, indicating increased nutrient uptake for the fertilized seedlings (Table 3).

All three rates of FR fertilizer produced relatively few statistically significant changes in either foliage or root nutrient concentrations (Table 4 and Figure 2a and 2b; and Figure 3a and 3b) indicating "steady-state" nutrition. Such a vector occurs when mass (foliage or root) and nutrient content increase (mass and content are provided in Table 3) while nutrient concentration remains unchanged (a 'B' vector in Figure 1). In contrast, treatments MR-3.2 and SR-3.2 produced a number of significant changes in nutrient concentrations (Table 4 and Figure 2c through 2f; and Figure 3c through 3f) indicating either deficiency or dilution vectors.

Discussion

Since the control treatment is theoretically free of nutrient stress (Wenny and Dumroese 1987), controlled release fertilizer treatments that maintain "steady-state" nutrition while increasing seedling mass are highly desirable in our study. Treatment FR-0.8 produced the largest increase in foliage mass (238%) and root mass (169%) of all treatments while maintaining all nutrients, except foliage Mo, at "steady-state" (Figure 2a and 2b and Figure 3a and 3b). The "steady-state" vectors resulting from treatment FR-0.8 indicate that nutrients were supplied in sufficient amounts to support the higher growth rates and increased biomass accumulation compared to the controls since nutrient contents increased in proportion to biomass. Perhaps formulation of the controlled-release fertilizer could be modified to include more Mo in the blend. Alternatively, Mo amounts could be increased in the nursery-based "fertilization" regime. The much larger seedlings produced by the FR-0.8 treatment also had an acceptable shoot/root ratio of about 3 (Fan 1999).

The MR-3.2 treatment produced the second largest increase in both foliage and root mass, 214% and 149% respectively (Figure 2c and 2d; and Figure 3c and 3d). However, most of the nutrients did not show "steady-state" behavior; rather, many deficiency vectors were produced by the MR-3.2 treatment. Finally, the application rate of the MR-3.2 treatment is four times higher than for FR-0.8, yet the seedlings were somewhat smaller. Clearly FR-0.8 is a superior treatment, likely because the fast nutrient release early in the growth cycle closely matches seedling nutrient requirements to support rapid growth and increased biomass accumulation. Additionally, the low (0.8 gm) dosage allows sufficient room for root expansion. With the higher application rates tested in our study, fertilizer granules occupied substantial volume in these small "160/90" containers during a large part of the growing season, particularly for the slow release products.

We did not include economic or nursery operational considerations in our study. Our intent was to demonstrate the use of graphical vector analysis, modified with statistical comparisons of the vector components, to design nutrition regimes combining irrigation water fertilizers with controlled-release fertilizers in the root plug to obtain a desirable biological outcome. Nursery mangers can conduct tests similar to ours with controlled – release fertilizers combined with their existing nutrient regime. Then, using the vector analysis approach employed in our study, they could select the best regime for their particular nursery economic and operational conditions.

Conclusions

Compared to the control, treatment FR-0.8 produced the largest increase in foliage mass (238%) and root mass (169%) of all treatments while maintaining all nutrients, except foliage Mo, at a desirable "steady-state" condition. Some slow release fertilizers applied at higher rates, when combined with the existing nursery fertilization schedules, produced seedlings with poor nutritional balance in both foliage and roots. These treatments were readily detected with nutrient vector analysis. Our study demonstrates the use of graphical vector analysis to design container nursery nutrient regimes.

Acknowledgments: The authors thank the Scott's Company and other members of the Intermountain Forest Tree Nutrition Cooperative for their support. We also thank Terry Shaw, Mariann Garrison and Mary Moore for their technical assistance.

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Table 1. Percent by weight of macronutrients and micronutrients provided by three controlled-release fertilizers used in the ponderosa pine experiment.

	Product		
Nutrient	Fast release (9 months)	Moderate release (12-14 months)	Slow release (16-20 months)
N	16	18	18
P (P_2O_5)	9	6	5
K (K_2O)	12	12	12
Ca	1.5	1.5	1.5
Mg	1	1	1
B	0.02	0.02	0.02
Cu	0.05	0.05	0.05
Zn	0.05	0.05	0.05
Fe	0.4	0.4	0.4
Mn	0.1	0.1	0.1
Mo	0.001	0.001	0.001

Table 2. Expanded interpretation of the vector diagram in Figure 1 based on the potential significance of relative nutrient concentration (c) and content (a) given the indicated change in mass (m)*.

Change and significance in			Interpretation	Diagnosis
M	c	a		
+	- s	+ s/n	Dilution	growth dilution
0	0 n	0 n	No change	uncertain
+	0 s/n	+ s/n	Sufficiency	steady state
+	+ s	+ s	Deficiency	deficient
0	+ s/n	+ s/n	Luxury	accumulation
-	+ s	± s/n	Excess	toxic accumulation
-	- s	- s/n	Excess	antagonism

* s----significant; n---- non-significant

Table 3. Average foliage and root nutrient contents of ponderosa pine seedlings in December (lifting) for various fertilization treatments.*

Treatment		CTR	FR-0.8	FR-1.6	FR-3.2	MR-0.8	MR-1.6	MR-3.2	SR-0.8	SR-1.6	SR-3.2
Nutrient											
N	Foliage	20.94	51.12 +	35.70	41.95	45.82 +	40.95	59.86 +	32.93	29.87	35.73
	Root	20.07	40.22	24.92	27.43	40.35	35.99	48.78 +	21.78	13.99	14.65
	Total	41.01	91.34 +	60.62	69.38	86.17	76.94	108.64 +	54.71	43.86	50.38
P	Foliage	2.58	5.98 +	4.49	5.10	4.96	4.84	7.19 +	3.87	4.21	5.11
	Root	2.75	5.56	3.55	4.46	4.39	4.45	5.52	4.18	3.95	4.00
	Total	5.32	11.54 +	8.04	9.56	9.34	9.29	12.71 +	8.05	8.16	9.11
K	Foliage	9.93	23.22	16.95	18.56	19.81	18.55	26.33	13.58	15.09	17.51
	Root	4.50	6.82	4.70	6.28	5.68	4.94	6.80	6.32	7.62	7.17
	Total	14.43	30.03 +	21.65	24.84	25.48	23.49	33.13 +	19.90	22.72	24.69
Ca	Foliage	1.58	3.59	2.85	3.09	3.35	3.13	3.94 +	2.48	3.14	3.56
	Root	2.04	3.45	2.37	2.29	3.03	2.79	2.38	2.13	2.47	2.96
	Total	3.62	7.04 +	5.21	5.38	6.38	5.92	6.32	4.61	5.61	6.53
Mg	Foliage	1.32	2.90	2.51	2.52	2.62	2.54	3.40 +	2.25	2.57	3.12 +
	Root	1.23	2.16	1.51	1.52	1.68	1.71	1.58	1.59	1.81	1.76
	Total	2.55	5.06	4.02	4.05	4.30	4.25	4.98	3.83	4.38	4.88
B	Foliage	30	82 +	56	71	65	62	107 +	85 +	56	85 +
	Root	10	23	12	17	15	13	28 +	14	14	14
	Total	40	105 +	68	88	80	75	135 +	99 +	70	99 +
Cu	Foliage	8	19	16	17	21 +	19	29 +	8	13	9
	Root	124	261	185	174	263	255	437 +	64	124	69
	Total	132	280	201	191	284	274	466 +	72	137	78
Zn	Foliage	45	99	82	136	159	112	232 +	115	105	154
	Root	169	414	218	313	199	248	271	93	361	202
	Total	214	513	299	450	357	360	503	208	466	356
Fe	Foliage	192	461 +	344	389	341	358	510 +	299	383	484 +
	Root	219	372	238	281	289	302	289	228	250	317
	Total	410	833 +	583	671	631	660	800	527	634	800
Mn	Foliage	133	298	238	242	345	350	445 +	316	295	311
	Root	232	521 +	216	290	165	149	308	370	399	282
	Total	364	819	454	532	509	582	753	686	694	593
Mo	Foliage	0.50	0.70	0.92	0.81	0.71	0.67	1.00	0.65	0.76	1.02
	Root	3.96	6.36	3.22	9.06	4.57	4.02	14.58 +	6.82	4.35	4.69
	Total	4.46	7.06	4.14	9.87	5.29	4.69	15.58 +	7.48	5.12	5.71
Wt	Foliage	0.94	2.24 +	1.79 +	1.59 +	1.78 +	2.01 +	1.68 +	1.39	1.77 +	1.50 +
	Root	0.72	1.22 +	0.92	0.82	1.01	1.07	0.96	0.85	0.92	0.81
	Total	1.66	3.46 +	2.71 +	2.41 +	2.79 +	3.08 +	2.64 +	2.24	2.69 +	2.31

N, P, K, Ca and Mg in units of mg; B, Cu, Zn, Fe, Mn and Mo in units of μg; Wt in gm.

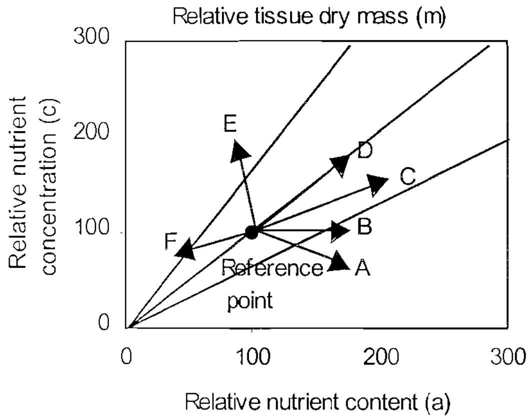
'+' and '-' indicate treatments that are significantly higher and lower than the control respectively (p=0.10).

Table 4. Average foliage and root nutrient concentrations of ponderosa pine seedlings in December (lifting) for various fertilization treatments. *

Treatment		CTR	FR-0.8	FR-1.6	FR-3.2	MR-0.8	MR-1.6	MR-3.2	SR-0.8	SR-1.6	SR-3.2
Nutrient											
N	Foliage	2.25	2.31	2.24	2.37	2.64	2.42	2.73 +	2.47	2.00	2.06
	Root	2.81	3.29	3.10	2.97	4.03 +	3.78 +	4.08 +	2.59	1.68 -	1.63 -
P	Foliage	0.27	0.27	0.28	0.29	0.28	0.29	0.32	0.29	0.28	0.29
	Root	0.39	0.46	0.43	0.48	0.45	0.47	0.47	0.51 +	0.47	0.44
K	Foliage	1.07	1.05	1.07	1.05	1.14	1.10	1.19	0.99	1.00	1.00
	Root	0.64	0.55	0.57	0.69	0.57	0.53	0.59	0.76	0.91 +	0.78
Ca	Foliage	0.17	0.16	0.18	0.17	0.20	0.18	0.18	0.18	0.21	0.20
	Root	0.29	0.28	0.28	0.26	0.31	0.30	0.21 -	0.26	0.29	0.32
Mg	Foliage	0.14	0.13	0.16	0.14	0.15	0.15	0.15	0.17	0.17	0.18 +
	Root	0.17	0.18	0.18	0.17	0.17	0.18	0.14	0.19	0.21 +	0.19
B	Foliage	32	37	35	41	38	37	50 +	62 +	37	49 +
	Root	14	19 +	15	18 +	15	14	23 +	16	17	15
Cu	Foliage	9	9	10	9	12	11	13 +	6 -	9	5 -
	Root	176	213	232	192	272	266	335 +	77	148	72
Zn	Foliage	48	45	50	76	88	67	104	90	70	90
	Root	238	332	270	317	198	244	246	109	464	213
Fe	Foliage	211	209	215	214	195	210	235	223	257 +	271 +
	Root	308	305	290	308	294	320	252	279	301	340
Mn	Foliage	147	135	149	135	194	207	193	246	197	183
	Root	339	424	258	327	166	148 -	274	453	476	310
Mo	Foliage	0.55	0.32 -	0.55	0.45	0.41	0.40	0.45	0.49	0.51	0.61
	Root	5.56	5.25	3.92	9.52	4.51	4.58	11.63 +	8.23	5.16	5.04

* N, P, K, Ca and Mg in units of %, and B, Cu, Zn, Fe, Mn and Mo in units of ppm

'+' and '-' indicate treatments that are significantly higher and lower than the control respectively (p=0.10).



Vector Direction	Change in			Interpretation	D(c)/dt	Possible Diagnosis
	m	C	a			
A	+	-	+	Dilution	<0	Growth Dilution
B	+	0	+	Sufficiency	=0	Steady State
C	+	+	+	Deficiency	<1, >0	Deficiency
D	0	+	+	Luxury	=1	Accumulation
E	-	++	±	Excess	>1	Toxic Accumulation
F	-	-	-	Excess	<0	Antagonism

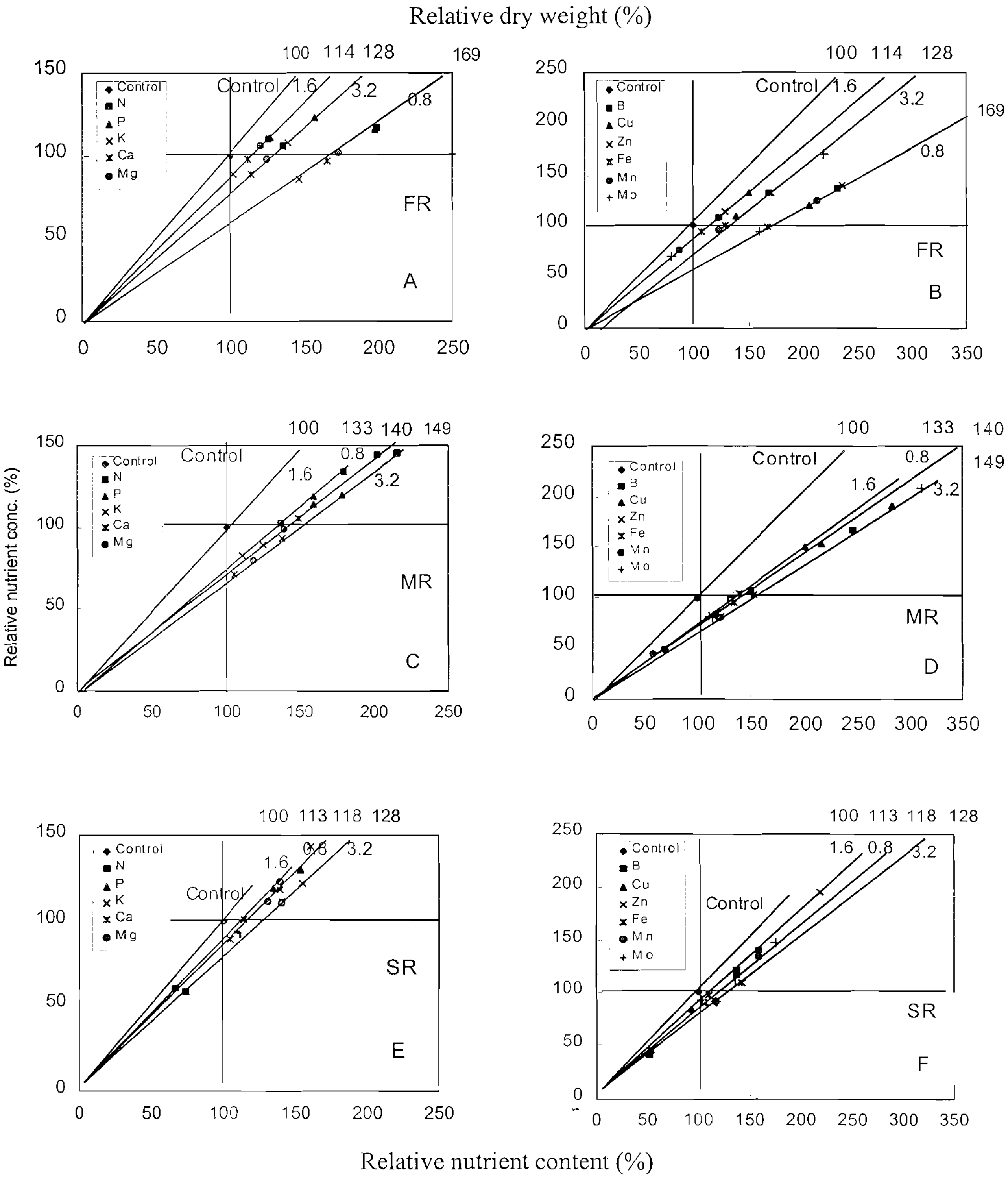

Relative dry weight (%)
Relative nutrient conc. (%)
Relative nutrient content (%)
A
FR
100 114 128 169
Control 1.6 3.2 0.8
Control
N
P
K
Ca
Mg
B
FR
100 114 128 169
Control 1.6 3.2 0.8
Control
B
Cu
Zn
Fe
Mn
Mo
C
MR
100 133 140 149
Control 1.6 0.8 3.2
Control
N
P
K
Ca
Mg
D
MR
100 133 140 149
Control 1.6 0.8 3.2
Control
B
Cu
Zn
Fe
Mn
Mo
E
SR
100 113 118 128
Control 1.6 0.8 3.2
Control
N
P
K
Ca
Mg
F
SR
100 113 118 128
Control 1.6 0.8 3.2
Control
B
Cu
Zn
Fe
Mn
Mo
0
50
100
150
200
250
300
350

Figure 1. Interpretation of changes in nutrient concentration, content and tissue dry mass (adapted from Imo and Timmer 1996)

Figure 2. Vector diagrams of relative changes in foliage dry mass, nutrient contents, and nutrient concentration of ponderosa pine seedlings under various fertilization treatments in the greenhouse at lifting. Vertical axes are relative concentration, horizontal axes are relative content, and isolines are treatment specific relative needle weights.

Figure 3. Vector diagrams of relative changes in root dry mass, nutrient contents, and nutrient concentration of ponderosa pine seedlings under various fertilization treatments in the greenhouse at lifting. Vertical axes are relative concentration, horizontal axes are relative content, and isolines are treatment specific relative root weights.