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RESEARCH ARTICLE

Evaluating Soil and Foliar Fertilization of *Abies nordmanniana* Under Container and Field Production

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Abstract
Considerable debates exist about the efficacy of foliar application of nutrients to Christmas trees, but little research has been conducted to determine whether this method of fertilization is beneficial. In this study, standard foliar and soil-applied fertilization products were applied to Nordmann fir Christmas trees under greenhouse and field-grown management regimes. On both sites, foliar nitrogen (N) and boron (B) concentrations, color, and normalized difference vegetation index (NDVI) were evaluated. Plant growth and needle chlorophyll/carotenoids were also monitored at the greenhouse site and sulfur (S) at the field site. At all sites, the soil-applied fertilizers were effective in increasing foliar N% compared to untreated and foliar applications. The foliar-applied products did not improve foliar N% compared to untreated trees. Foliar B concentrations were correlated with foliar fertilizer applications, indicating that B can be absorbed via foliar application. A second part of this study investigated alternate or complementary methods of assessing foliar N%. We addressed whether plant color, spectral reflectance, chlorophyll measures, or NDVI measurements could serve as surrogates for foliar N%. Color, chlorophyll/carotenoid, and foliar N% were closely correlated. However, NDVI evaluations showed no relationship with foliar N%, color, or chlorophyll/carotenoid levels.

Keywords: *Abies nordmanniana (Stev.) Spach, chlorophyll, Christmas trees, color, foliar fertilization, NDVI, nutrient management.*

Introduction

Nordmann fir [*Abies nordmanniana* (Stev.) Spach] is the dominant Christmas tree throughout Europe (Nielsen et al. 2011). The annual European harvest of Nordmann fir exceeds 30 million trees (Ostergaard 2009). This species occupies approximately 5% of the forested land in Denmark (Pedersen et al. 2006). It is also an emerging Christmas tree species in the USA and is now the third most commonly planted Christmas tree species in the US Pacific Northwest after Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco.] and noble fir [*Abies procera* Rehd.] (PNW) (NASS 2011).

Field plantings of Christmas trees are typically nonirrigated and intensively managed. They complete a production cycle roughly every 10 years. Nordmann fir is also grown under irrigated conditions in containers, using soilless media. The resulting plants are used as seedlings for field plantings, containerized Christmas trees, or landscape plants.

Nitrogen (N) is the most important nutrient required to obtain desired tree color and growth (Christensen et al. 2000). The form of N applied, as well as application methods and rates, varies by country, region, soil type, legal restrictions and other factors (McEvoy 1992). In the PNW, N is typically applied as urea or ureasul (urea and ammonium sulfate blend). It is usually broadcast on the soil following recommendations in the *Christmas tree nutrient management guide for western Oregon and Washington* (Hart et al. 2009). In Denmark, multi-element fertilizers (such as NPK 23-3-7) are used, and soil-applied rates of N may not exceed 75 kg ha^{-1} on clayey soil or 100 kg ha^{-1} on sandy soil (Pedersen et al. 2006).

Despite the wide range of N application rates, forms, and mixtures, general agreement exists in

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Europe and the USA that the critical foliar N levels for adequate growth and color for Nordmann fir grown in Christmas tree plantations are around 1.28–1.4% (Matschke 2005; Hart et al. 2009).

For container-grown conifers with irrigation, fertilization typically consists of annually applied controlled-release fertilizers (CRF) (Yeager et al. 2007; Klooster et al. 2010).

The use of foliar-applied fertilizers alone, or in conjunction with soil-applied nutrients, is actively debated by producers and promoted by suppliers. Grower opinion varies widely, as does the variety of foliar fertilization products and application techniques. Few studies have been conducted to determine whether foliar-applied nutrients are beneficial, either applied alone or as a supplement to soil-applied products. In addition, plant/fertilizer interactions – e.g. cuticle structure, needle wax penetration, and plant age – make generalizations difficult and extension of results from one crop or species to another unwise (Fernandez & Eichert 2009).

Although this study focused primarily on foliar fertilization, we also began a complementary investigation into the use of plant color, spectral reflectance, and chlorophyll measures as surrogate measures for tissue N. The current system of collecting needles, delivering them to a laboratory, and waiting for results is slow and costly; each sample costs $10–50 with a 7–21 day turnaround time (Landis et al. 2005). Producers would welcome ways to speed up the process and reduce costs.

Tissue N has been correlated to Normalized Difference Vegetation Index (NDVI) levels in grass seed, maize crops, and geraniums (Flowers et al. 2010; Shaver et al. 2011; Wang et al. 2012). The relationship between NDVI and foliar N is unknown in Nordmann fir and could offer producers an inexpensive and quick option to determine foliar N.

The objectives of this study were to (1) determine whether foliar fertilization of Nordmann fir produces any measurable improvement in tissue N or B concentration, color or growth not provided by standard soil fertilization practices in either field or container production systems and (2) assess NDVI, chlorophyll, and color as an economic means of assessing tissue N concentration.

Materials and methods

Plant material

Field- and container-grown Nordmann fir were utilized in this experiment. Plants were grown under management practices appropriate to each system.

For the container study, 50 containerized Nordmann fir (19 L) were selected from a pot-in-pot conifer nursery (Yule Tree Farms, Aurora, OR). Trees of uniform size and color were chosen. Trees were five years of age and grown in Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark. Liners used in these containers were produced from Nordmann fir seed grown in 131 cm^{-3} plug containers. The 50 trees were transported to the Oregon State University North Willamette Research and Extension Center (NWREC) container study site.

On 1 March 2009, trees were re-potted into larger 27-L containers (#7. PT7 Tall, Nursery Suppliers, Inc., Orange, CA). In the potting process, the soilless substrate was removed by gentle shaking, and the root balls were then rinsed in a water bath. Trees were then replanted into a custom-blended soilless substrate consisting of 50% (by volume) coarse Douglas-fir bark (9.6–19 mm), 30% (by volume) fine Douglas-fir bark ($<$9.6 mm), 20% (by volume) screened pumice (1.6–9.6 mm) and 1.8 kg m^{-3} of $CaCO_3$ (calcium carbonate) to maintain an approximate pH of 6.5 for the duration of the study.

In the production field site, the Nordmann fir were planted on 15 February 2004. The planted seedlings were two-year-old bare rootstock of Ambrolauri seed origin grown by Weyerhaeuser Nursery in Aurora, OR.

Fertilizers

Two soil-applied materials were utilized in the experiment. One was an 18.0N-5P_2O_5-9K_2O 13-month controlled-release fertilizer (CRF) with 1.2% Mg and 4.9% S (18-5-9 Osmocote®, The Scotts Co., Marysville, OH). This product was applied as a surface application to the containerized trees in 2009, at the medium label rate of 182 g per container.

The other was a 33N-0P-0K-12S ureasul (33-0-0-12, Kerley Industries, Inc., Phoenix, AZ). It was applied at a rate of 112 kg ha^{-1} to the field-planted trees. In 2010, it was also used to replace the CRF treatment for containerized trees. In this instance, the 112 kg ha^{-1} rate was applied in three treatments of 37 kg ha^{-1} each. Both the field and containerized treatments are designated as Typ.

Foliar fertilizers were all liquids and were applied at label-recommended rates.

A product containing 13N-3.5P-6.6K with 0.34% Ca and 0.17% B (13-8-8 Perfection™ Berry Mix, Wilbur-Ellis, San Francisco, CA) was applied at a rate of 18 L ha^{-1} at all sites and was designated as treatment F-W. A mixture of three liquid products produced by Helena Chemical Company (Collierville, TN) was applied as the second foliar treatment and was designated as F-H. The tank mix included

Table I. Summary of fertilizer treatments, application rates, and product analysis.

Manufacturer	Product	Reference name	Application rate	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B%
Scotts	Osmocote®	Typ. (container)	182 gm./pot	18	5	9		1.2	4.9	
Wilbur Ellis	Perfection™	F-W	18 L ha^{-1}	13	8	8	0.34			0.17
Helena	Kayphol™	F-H	1.2 L ha^{-1}		5	32				
	CoBo™	F-H	2.3 L ha^{-1}	12						5
	PhosCal- Zin	F-H	2.3 L ha^{-1}	4	15		13			
Various	Ureasul	Typ. (field)	112 kg ha^{-1}	33					12	

0.0N-2.2P-26.6K (0-5-32, Kayphol™) at 1.2 L ha^{-1}, 12N-0P-0K (12-0-0, CoBo™), with 5% B at 2.3 L ha^{-1}, and 14.0N-6.6P-0K (4-15-0 PhosCal- Zin) with 13% Ca at 2.3 L ha^{-1} (Table I).

Container-grown trees received foliar application via a hand-held CO_2 backpack sprayer. The sprayer was equipped with a single head boom and a flat fan 8001 nozzle (XR 8001, Spraying Systems Co., Wheaton, IL). Application was at 1.4 kg cm^{-1} and a rate of 30 L ha^{-1}. At the field site, a CP-3 backpack sprayer (Excel Industries, Epernay, France) and a TX-6 solid cone nozzle (Spraying Systems Co., Wheaton, IL) were used at 2.8 kg cm^{-1} and a rate of 30 L ha^{-1}.

Container-grown management regime

The container-grown experiment was conducted at NWREC in Aurora, OR (N45°16.850 W122°45.038), in a retractable roof structure. Container-grown trees were arranged in a completely randomized design (CRD). Plants were placed on a gravel surface covered with a semi-permeable geotextile at a nominal spacing of 1.1 m between containers. Individual drip irrigation stakes (SS-Ag160ORG-100, John Deere, Moline, IL) were placed in each pot to deliver water at a rate of 18.1 L hr^{-1}. All trees were irrigated on a conventional schedule throughout the growing season to ensure that no drought stress occurred.

Each treatment utilized nine trees. Treatments included foliar products applied individually (F-W and F-H), soil-applied fertilizer (Typ.) or a combination of soil and foliar products (Typ.+F-W, Typ.+F-H). The soil-applied CRF product was applied on 2 April 2009. In 2010, ureasul was applied on 10 May, 9 June, and 9 July. All plants were hand irrigated after being fertilized with the CRF or ureasul.

Application timing for all foliar treatments was determined by phenological development of the trees, with the first spray timed to match bud break and the second spray occurring three weeks later. Foliar nutrients were applied on 27 May 2009, 22 June 2009, 2 June 2010, and 30 June 2010. Foliar treatments (F-H and F-W) allowed excess product to drip into the substrate. A treatment designated as F-W (excl.) used a plastic skirt around the container to exclude foliar nutrients from entering the substrate. An unfertilized check (0-Tmt) was included in the study.

Field-grown management regime

The field site was a 3 ha commercial Christmas tree planting in its second rotation. The field had received no fertilizer for the previous five years.

The site location is in Warren, OR (N45°49.245 W122°53.860), and the soils are Aloha Silt Loam (1–2% slope). Trees were planted on 1.5 m centers in rows spaced 1.8 m apart. Weeds were controlled with winter herbicide application, and the site remained fairly weed-free for the duration of the study.

Ureasul was applied on 5 April 2009. The foliar products and rates were identical to those used in the container regime (F-H and F-W). Foliar fertilizer was applied on 31 May 2009 and 20 June 2009. Applications included Typ.+F-W and Typ.+F-H treatments. An unfertilized check (0-Tmt) and conventional ureasul treatment (Typ.) without any foliar products were included. Each fertilizer treatment was replicated four times in a completely randomized block design with approximately 100 trees per replication. Individual treatments were applied on areas three rows wide (4.5 m) with measurement trees in the middle row.

Growth, nutrient, and color data

On 1 May 2009, growth measurements were collected for the container study (leader height, caliper) to establish a baseline for each tree prior to treatment. On 4 August 2009, following the growing season, the same growth measurements were repeated. In the following year, on 1 October 2010, growth measurements included total tree height, leader growth, and needle length. Needle length was based on average values from needles similar to those collected for nutrient analysis (current-season needles from the upper one-third of the tree crown). Growth data were not collected at the field site, as

these trees were all sheared, and heights were regulated by production needs.

For the container study, foliar samples were collected for nutrient analysis on three dates. Composite samples were collected at the beginning of the experiment prior to any treatments (13 March 2009) and at the conclusion of the experiment following two growing seasons (16 December 2010). These composite samples contained equal needle volumes from all trees in the trial. Needles were also collected and processed from individual trees by treatment on 23 February 2010.

For the field site, foliar samples were collected on 26 February 2010 from nine individual trees per treatment. Trees selected were well spaced along tree rows and of generally equal size. Only trees in the middle row were measured, with one buffer row between treatments in all replications. All samples were analyzed for foliar nutrients at Brookside Laboratory (New Knoxville, OH).

The foliar samples for all collections were composed of healthy current-season needles collected from branches on the upper third of the trees. Sampled needles were taken from all sides of the tree, with an equal quantity coming from all whorl positions. Only selected nutrients will be reported and discussed.

On 16 March 2010, each tree in the container study was evaluated for color. For the field site, color evaluations were made on 1 March 2010 using the same nine trees used for tissue sampling. Color was evaluated at around 1100, with the sun angle behind the observer. Color evaluation was based on the Royal Horticulture Color Fan System (The Royal Horticulture Society, London), which captured the color range of green–yellow–blue found on Nordmann fir. Color translation tables between Munsell color chips are available (Kelley, 1965), and both systems allow for color comparison via the international CIE system from the International Commission on Illumination.

NDVI measurements

NDVI measurements were collected using a GreenSeeker (Trimble, Ukiah, CA). Considerable time was devoted to developing protocols that provided consistent, repeated values. Distance to the plant, sensor head, and plant angle, time of day and background color/surface were evaluated to determine the best NDVI measurement regime. At NWREC, the sensor head was mounted on a cart to maintain a consistent height (0.8 m) and angle (parallel to the plant). Plants were moved and set against a standard background for NDVI measurements. Measurements were conducted between 1000 and 1100 on 15 May 2010.

At the field site, NDVI measurements were collected for each tree on 12 May 2010 from 1100 to 1200. Rough terrain did not allow for cart access, so the sensor head was held using a shoulder strap. The sensor head was held 0.8 m above the ground, 60 cm away from the plant and parallel to the cone shape of the tree, approximately at a 60 degree angle. The trees used for color and tissue N were again used for NDVI evaluation.

Chlorophyll and carotenoid analysis

Pigment analysis was conducted only at the container site. Each tree was subsampled three times. Needles were collected on 15 May 2010 and stored at -80°C until analysis. Total chlorophyll was extracted by grinding 150 mg of leaf tissue three times in 3.33 mL of 80% acetone, using a mortar and pestle. After each grind, the extract was transferred to a test tube, for a final volume of 10 mL. After the third grind in acetone, the remaining leaf material was transferred to the test tube containing the extract and maintained in the dark at 4°C for one hour to ensure full extraction. Two milliliters of the extract was centrifuged for 30 s at 6800 g_n. The supernatant was then transferred to a 96-well plate, and absorbance was measured at 646 and 663 nm using a Biotek Synergy II microtitre plate reader (BioTek Instruments, Inc., Winooski, VT). Absorbance for all samples at both wavelengths was between 0.2 and 0.8. Each tree was subsampled three times.

Determination of chlorophyll *a* (C_a), chlorophyll *b* (C_b), and carotenoids (C_{x+c}) was performed using calculations from Lichtenthaler (1987). Chlorophyll *a* content was calculated using the formula: C_a (mg/L) $= (12.25 \times A_{663}) - (2.79 \times A_{646})$. Chlorophyll *b* content was calculated using the formula: C_b (mg/L) $= (22.5 \times A_{646}) - (5.1 \times A_{663})$. Total chlorophyll content was determined by summing C_a and C_b. Water content was determined at each collection time for all taxa and was used to calculate dry weight (DW). Chlorophyll contents were expressed in mg g DW^{-1}.

Statistical analysis, all sites

The containerized experiment was conducted in a completely randomized design with nine individual plant replicates. Field plots were set up in four blocks in a completely randomized block design with approximately 100 trees per replication. All variables were analyzed using general linear model (Proc GLM) in SAS version 9.01 (SAS Institute, Inc.,

Table II. Nordmann fir foliar nutrient levels, pretreatment, and at end of study – container site (bulked samples).

		Tissue nutrient level						
	Sample date	N (%)	P (%)	K (%)	Ca (%)	Mg (ppm)	S (%)	B (ppm)
Pretreatment	3/13/09	1.4	0.1	0.5	0.4	0.15	0.10	6.9
F-H	12/16/10	0.5	0.2	1.2	0.5	0.18	0.07	10.4
F-W	12/16/10	0.5	0.2	0.7	0.3	0.15	0.06	6.4
0-Tmt	12/16/10	0.5	0.2	1.0	0.6	0.16	0.07	6.2
Typ	12/16/10	2.1	0.2	0.8	0.4	0.23	0.14	4.9

Cary, NC). Treatment comparisons were made by Fisher's Protected LSD, $p = 0.05$. Treatment comparisons to the controls were made with a single degree of freedom. Treatment comparisons were conducted using a priori contrasts, $p = 0.05$.

Results

Container-grown management regime

Needle nutrient concentrations were monitored prior to any treatment application and at the conclusion of the trial following two growing seasons (Table II). These samples were composites, so statistical analysis is not possible; however, the evaluation does establish pre- and post-treatment trends. These trends suggest a foliar N decline to 0.5% during these two years for both of the foliar treatments (F-H and F-W) and the control (0-Tmt). The Typ. treatment treaded upward for foliar N and S concentrations during the two-year period.

At the conclusion of the first growing season, tree growth (leader height and caliper), needle nutrient concentration (N and B), needle chlorophyll and NDVI were assessed at the container site.

No statistically significant differences in leader height and caliper among treatments were measured.

The Typ. and Typ.+F-H treatments showed identical foliar N% (171% above that in the other treatments). No statistical difference for N% existed for the other treatments ($p = 0.005$). No differences existed between foliar treatments (F-H and F-W) or between the 0-Tmt (control) and F-H or F-W. Furthermore, N foliar concentration was not affected by preventing the foliar fertilizer from entering the substrate (F-H excl). Importantly, all treatments except those receiving the soil-applied materials had foliar N concentrations below established critical levels.

The F-H treatment showed an increase in foliar boron (B) concentration. The foliar B concentration (ppm) was highest in treatments with the Helena product (F-H, F-H (excl.), and Typ.+F-H). Boron was absent from the Typ. and 0-Tmt and was at a very low concentration in the F-W product (Table III).

Chlorophyll and carotenoid analysis. Treatments that included CRF (Typ. and Typ.+F-H) had higher

Table III. Growth, needle nutrient concentration, chlorophyll, carotenoid, and NDVI – container site.

	Growth		Needle nutrient concentration		Needle pigment concentration (mg g^{-1} DW)		
Treatment	Height (cm)	Caliper (mm)	N (% DW)	B (ppm)	Chlorophyll	Carotenoid	NDVI
0-Tmt	12.38	2.70	0.78b	4.83a	0.85b	0.18b	0.75
Typ	16.13	2.87	1.93a	5.10a	1.85a	0.30a	0.69
F-H	13.13	2.62	0.79b	10.64c	0.70b	0.16b	0.77
F-W	12.17	2.50	0.84b	5.15a	0.79b	0.16b	0.66
Typ + F-H	13.00	3.42	1.93a	12.49c	1.92a	0.33a	0.74
F-H (excl.)	12.63	2.30	0.71b	9.89c	0.84b	0.17b	0.71
Significance	ns	ns	0.0001	0.0001	0.0002	0.0005	ns
Contrasts							
Foliar with vs w/out exclusion	ns	ns	ns	ns	ns	ns	ns
Typ vs Typ + F-H	ns	ns	ns	0.001	ns	ns	ns
F-H vs F-W	ns	ns	ns	0.0026	ns	ns	ns
F-H and F-W vs 0-Tmt	ns	ns	ns	0.0353	ns	ns	ns
F-H and F-W vs Typ	ns	ns	0.0001	ns	0.0001	0.0006	ns
Typ vs 0-Tmt	ns	ns	0.0001	ns	0.0007	0.0033	ns

Note: Numbers followed by the same letter(s) are not significantly different. DW = dry weight.

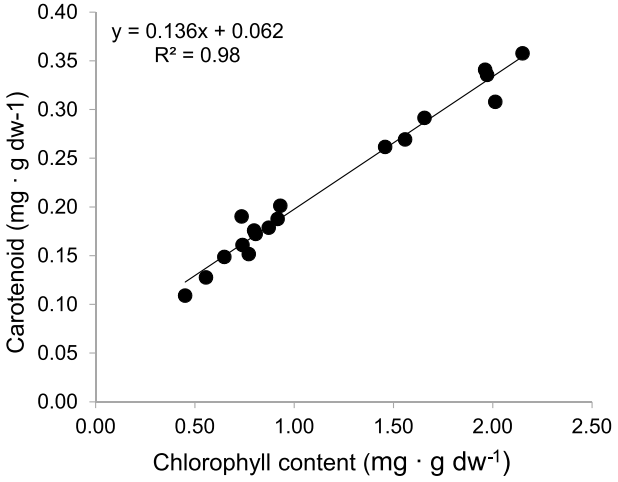

Figure 1. Relationship between carotenoid and chlorophyll extracted from needles of Nordmann fir. Data are pooled over all treatments.

levels of chlorophyll ($p = 0.0002$) and carotenoids ($p = 0.0005$) than both control (0-Tmt) and foliar treatments alone (F-H and F-W). Chlorophyll and carotenoid levels observed with foliar treatments alone were not different from the control (0-Tmt) (Table III).

No correlation existed between chlorophyll or carotenoid concentration and NDVI. There was, however, a strong linear correlation (Figure 1) between chlorophyll and carotenoid concentration ($R^2 = 0.98$). Also, Figure 2 shows a linear relationship between chlorophyll and N ($p < 0.0001$; $R^2 = 0.92$); a similar relationship exists between carotenoid and N ($p < 0.0001$; $R^2 = 0.91$).

NDVI. Evaluations using the GreenSeeker showed no significant differences between or among the six treatments (Table III).

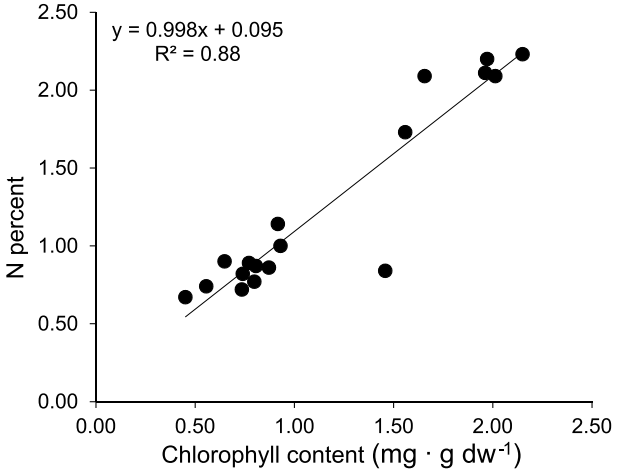

Figure 2. Relationship between chlorophyll and foliar N extracted from needles of Nordmann fir. Data are pooled over all treatments.

Color. Visible color differences were observed between treatments. Perceived color of the trees is summarized for 2009 and 2010 using the Royal Horticulture Color Fan System (Table IV). Statistical differences can be determined between the three CIE coordinates (x,y,Y) associated with each color chip; however, the significance of these differences is difficult to interpret relative to actual plant color. A practical approach involves categorizing the percentage of trees (and number) that fall into three general color groups – green (good), green–yellow (poor), and yellow–brown (very poor). Using this approach, after two growing seasons, only the trees receiving the Typ. treatments remained in the "green" category.

Growth. After two years, treatment differences are evident in tree growth (Table V). The measurements include tree height, the leader height, and needle length in 2010. Leader height and 2010 needle measurements showed that the Typ. treatment differed from the three other treatments ($p = 0.005$). There were no differences between the 0-Tmt and the foliar treatments for these growth measures.

Field-grown results

Results from the field-grown management regime are summarized for foliar nutrient concentrations (N, S, and B) and NDVI (Table VI).

Foliar nutrient concentrations. At this field site, the N% for the Typ. treatment was statistically higher than that of the foliar (F-W and F-H) and 0-Tmt treatments. The foliar treatments were no different than the 0-Tmt. The addition of foliar products (Typ.+F-H and Typ.+F-W) did not change the foliar N levels above the Typ. treatment alone. Nor was there a difference between the two foliar products (F-H and F-W).

The Typ. treatment showed higher sulfur (S) needle concentrations compared to any of the other treatments ($p = 0.005$).

The B nutrient concentration results were similar to those in the container regime. Treatments with the Helena foliar mix (F-H and Typ.+F-H) contained higher B concentrations.

NDVI. The GreenSeeker values were not different between treatments ($p = 0.005$).

Color. At both sites, color was evaluated using the Royal Horticulture Color fan system. Color variation was much lower at the field site than under the

Table IV. Perceived needle color of Nordmann fir trees by treatment (container site, 2009 and 2010).

	Perceived color, 2009 Percent trees (number)			Perceived color, 2010 Percent trees (number)		
Treatment	Green[a]	Green–yellow[b]	Yellow–brown[c]	Green	Green–yellow	Yellow–brown
0-Tmt	25 (2)	63 (5)	13 (1)	0 (0)	25 (2)	75 (6)
Typ	100 (8)	0 (0)	0 (0)	100 (8)	0 (0)	0 (0)
F-W	71 (5)	29 (2)	0 (0)	0 (0)	43 (3)	57 (4)
F-H	25 (2)	50 (4)	25 (2)	0 (0)	57 (4)	43 (3)
Typ + F-H	100 (7)	0 (0)	0 (0)	–	–	–
F-H (excl.)	50 (4)	38 (3)	13 (1)	–	–	–

[a]Green = RHS fan chip #146a,146b,137a,137b,147a,139a.
[b]Green–yellow = RHS fan chip #151a, 144a, 146c, 151c,146d.
[c]Yellow–brown = RHS fan chip #152b, 153a,156a,164b, 152c,153b,153c,153d.

container regime. All the field-grown trees were categorized within a narrow color variance from very dark green (139A) to medium green (137A- B), with no trees in the green–yellow or yellow–brown classifications. The Typ. treatments (Typ., Typ + F-H and Typ.+F-W) had 20% more trees is the very dark green category than the foliar treatments (F-W and F-H) and 0-Tmt., yet all were very acceptable colors for marketing purposes.

Discussion

Studies evaluating Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco.] and Ponderosa pine [*Pinus ponderosa Laws.*] container seedling growth in nursery settings with one-year-old conifers (Ray Leach^{tm} 66 cm. cells) have shown benefits from foliar fertilizer (Montville & Wenny 1990). With a six-year-old Nordmann fir, however, none of the tested foliar products produced any increase in foliar N. In the container-grown management regime, foliar fertilization alone using either of the tested products was ineffective in maintaining foliar N% above the control (0-Tmt). Foliar N concentrations fell below critical levels for Nordmann fir; plant growth and color measures confirmed these deficiencies.

Table V. Growth response of containerized Nordmann fir after the second year of production by treatment, 2010.

Fertilizer	Total height (cm)	Leader height (cm)	Needle length (mm)
0-Tmt	84.63b	2.57b	14.26b
Typ	98.63a	15.88a	31.14a
F-H	89.14ab	4.57b	13.71b
F-W	91.57ab	4.86b	15.83b
Significance	0.0400	0.0001	0.0001

Note: Numbers followed by the same letter(s) are not significantly different.

This discrepancy could be a function of a wide array of variables, including increased needle "wax" and cuticle thickness on older plants, increased plant nutrient needs with age and differences in application techniques. It is also possible that some of the foliar fertilization product applied to seedlings in other settings was leached into the media and was absorbed via root uptake. However, in our container setting, no differences in nutrient levels were noted in the exclusion treatment (F-H excl.).

Boron was absorbed via foliar application with the F-H treatment. This micronutrient was absent from the soil-applied materials and was in very low

Table VI. Foliar nutrient levels and NDVI by treatment, field site.

Needle nutrient concentration				
Treatment	N (%)	S (%)	B (ppm)	NDVI
0-Tmt	1.84b	0.12c	31.55c	0.83
Typ	2.11a	0.14a	29.85c	0.82
F-H	1.90b	0.12bc	43.21a	0.83
F-W	1.85b	0.12bc	35.10bc	0.81
Typ + F-H	2.04a	0.13ab	40.63ab	0.83
Typ + F-W	2.16a	0.13a	29.08c	0.82
Significance	0.00	0.00	0.00	NA
Contrasts				
F-W vs F-H	ns	ns	0.01	
Typ + F-W vs Typ + F-H	ns	ns	0.00	
Typ + F-W vs F-W	0.00	0.01	ns	
Typ + F-H vs F-H	0.02	ns	ns	
Typ + F-W + F-H vs F-H + F-W	0.00	0.00	ns	
Typ vs 0-Tmt	0.00	0.00	ns	
F-H vs 0-Tmt	ns	ns	0.00	
F-W vs 0-Tmt	ns	ns	ns	
F-H and F-W vs 0-Tmt	ns	ns	0.00	
F-H vs Typ	0.00	0.00	0.00	
F-W vs Typ	0.00	0.00	ns	
F-H and F-W vs Typ	0.00	0.00	0.00	

Note: Numbers followed by the same letter(s) are not significantly different.

concentration in the F-W product. Boron is a necessary micronutrient, with adequate levels in the range of 15 ppm for mature Nordmann fir (Hart et al. 2009). This low level can be added to soil-applied fertilizer or provided via foliar applications, if needed.

A strong linear correlation exists between chlorophyll and carotenoid concentrations. Previous studies demonstrated a similar linear relationship between chlorophyll and carotenoid when data were pooled among 36 taxa belonging to Gymnospermae (Ida, 1981). There was also a strong linear relationship between tissue N and chlorophyll content. Other studies have attempted to take advantage of this relationship by using hand-held chlorophyll meters (e.g. SPAD-502) to determine N status (Rodriguez & Miller 2000).

GreenSeeker NDVI evaluations were not useful or sensitive enough to assist in determining tissue N concentration. NDVI values did not differ among treatments, and there was no correlation between NDVI and chlorophyll or carotenoid concentration. Previous studies have observed linear (Yadava 1986; Marquard & Tipton 1987) and quadratic (Netto et al. 2005) relationships between SPAD readings [SPAD-501 (Yadava 1986; Marquard & Tipton 1987); SPAD-502 (Netto et al. 2005)] and total chlorophyll content determined spectrophotometrically. Furthermore, in monocots such as maize and grass seed, tissue N has been correlated to NDVI levels (Flowers et al. 2010; Shaver et al. 2011). In conifers such as Nordmann fir, however, the needle shape and thickness preclude using an instrument such as a SPAD meter that relies on light penetration through the lamina. Likewise, Greenseeker NDVI measurements showed no relationship to tissue N concentration in Nordmann fir. The cause of this discrepancy is unknown, but it may be related to background or branch patterns not encountered with the typically vertical sensor head orientation above these other crops. Other research has noted that systems relying on reflectance, such as NDVI, result in erroneous signals when soil or other background "noise" is within sensor view. A closed canopy or oblique view may minimize this sensor problem (Heege et al. 2008).

Visible color differences were readily observed between treatments and were captured using the RHS color fan. Color measurements based on the RHS color fan showed a strong correlation with tissue N, similar to the relationship between chlorophyll and tissue N. Heiskanen (2005) reported similar results with Norway spruce [*Picea abies* (L.) Karst].

The field-grown regime confirmed the N (%), B (ppm), NDVI and color results found in the container trial. The foliar N levels in the field site were all above the established critical level, and all trees had adequate color. In addition, S is a component of ureasul and was detected at higher levels in the trees receiving the Typ. treatments. The tissue B levels at this site were all well above the critical levels so additional B was not needed.

In conclusion, the field-grown and container management regimes yielded results largely in line with each other. Those are:

1. Soil-applied fertilization alone provided tissue N% levels above those from foliar products.
2. The foliar treatments alone were not different from the 0-Tmt for foliar N%.
3. The addition of these foliar products to the standard soil-applied products did not provide any improvement in tissue N%.
4. GreenSeeker NDVI evaluations were not sensitive enough to provide consistent estimates for N%, color, or chlorophyll/carotenoids.
5. Tissue B concentrations increased with use of the Helena foliar mix, indicating that trees did absorb this micronutrient via foliar application.
6. Tissue N concentrations, color, and chlorophyll/carotenoids were closely correlated.

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References

Christensen CJ, Pedersen LB, Ingerslev M. 2000. Fertilization of Danish Nordmann fir (*Abies nordmanniana)* Christmas trees: impacts on tree quality, needle chemistry, cycling of nutrients and biomass. In Christiansen CJ, editor. Improvements in Christmas tree and greenery quality. Proceedings from the International Christmas Tree and Greenery Research and Extension Conference, Denmark, 2000 Jul 31–Aug 3 (Report No. 7–2000). Horsholm: Danish Center for Forest, Landscape and Planning; p. 36–39.

Fernandez V, Eichert T. 2009 Uptake of hydrophilic solutes through plant leaves: current state of knowledge and perspectives in foliar fertilization. Crit Rev Plant Sci. 28:36–68.

Flowers MD, Hart JM, Young WC. III, Mellbye ME, Garbacik CJ. 2010 Remote sensing assessment of nitrogen status of perennial ryegrass for seed production. Agron J. 102:1441–1447.

Hart J, Landgren C, Fletcher R, Bondi M, Withrow-Robinson B, Chastagner G. 2009. Christmas tree nutrient management guide for western Oregon and Washington (EM 8865-E). Corvallis (OR): Oregon State University Extension Service.

Heege HJ, Reusch S, Thiessen E. 2008. Prospects and results for optical systems for site-specific on-the-go control of nitrogen-top dressing in Germany. Precis Agric. 9:115–131.

Heiskanen J. 2005. Foliar color as an indicator of foliar chlorophyll and nitrogen concentration and growth in Norway spruce seedlings. Scand J For Res. 20:329–336.

Ida K. 1981. Eco-physiological studies on the response of taxodiaceous conifers to shading, with special reference to the behaviour of leaf pigments I. Distribution of carotenoids in green and autumnal reddish brown leaves of gymnosperms. Bot Mag Tokyo. 94:41–54.

Kelly KL. 1965. A universal color language. Color Eng. 3(2):1–7.

Klooster WS, Cregg BM, Fernandez RT, Nzokou P. 2010. Growth and photosynthetic response of pot-in-pot grown conifers to substrate and controlled-release fertilizer. Hortic Sci. 45:36–42.

Landis TD, Hasse D, Dumroese RK. 2005. Plant nutrient testing and analysis in forest and conservation nurseries (USDA Forest Service Proceedings RMRS-P-35). Fort Collins (CO): U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station.

Lichtenthaler HK. 1987. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. Meth Enzymol. 148: 350–382.

Marquard RD, Tipton JL. 1987. Relationship between extractable chlorophyll and an in situ method to estimate leaf greenness. Hortic Sci. 22:1327.

Matschke J. 2005. Weihnachtsbaume. Berlin: Thalacker Medien Berlin (in German).

McEvoy T. 1992. Using fertilizers in the culture of Christmas trees. Richmond (VT): Paragon Books, Inc.

Montville ME, Wenny D. 1990. Applications of foliar fertilizer during bud initiation treatments to container-grown conifer seedlings. In: Rose C, Campbell S, editors. General Technical Report RM-200. Fort Collins (CO): U.S. Department of Agriculture Forest Service, Rocky Mountain Range and Experiment Station p. 233–239.

National Agricultural Statistical Service (NASS). 2011. Oregon Christmas trees. [cited 2012 Jan 1] Available from: www.nass.usda.gov/or

Netto AT, Campostrini E, de Oliveira JG, Bressan-Smith RE. 2005. Photosynthetic pigments, nitrogen, chlorophyll a fluorescence and SPAD-502 readings in coffee leaves. Sci Hortic. 104:199–209.

Nielsen UB, Hansen JK, Kromann HK. 2011. Impact of site and provenance on economic return in Nordmann fir Christmas tree production. Scand J For Res. 26:74–89.

Ostergaard K. 2009. Afsaetninfssituationionen for juletraeer of klippegrount [The present market situation for Christmas trees and greenery products]. Paper from Temadage 2009. [cited 2010 Jan 1] Available from: http://www.christmastree.dk/publikationer/foredrag/temadage-2009.aspx

Pedersen LB, Christensen CJ, Ingerslev M. 2006. Leaching versus input of nitrogen, potassium and magnesium in different fertilizer regimens in Christmas stands in Denmark. Scand J For Res. 21:130–142.

Rodriguez IR, Miller GL. 2000. Using a chlorophyll meter to determine the chlorophyll concentration, nitrogen concentration, and visual quality of St. Augustine grass. Hortic Sci. 35:751–754.

Shaver TM, Khosla R, Westfall DG. 2011. Evaluation of two crop canopy sensors for nitrogen variability determination in irrigated maize. Precis Agric. doi:10.1007/s 111119–011-9229-2.

Wang Y-W, Dunn BL, Arnall DB. 2012. Assessing nitrogen status in potted geranium through discriminant analysis of ground-based spectral reflectance data. Hortic Sci. 47:343–348.

Yadava UL. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. Hortic Sci. 21:1449–1450.

Yeager T, Bilderback T, Fare D, Gilliam C, Lea-Cox J, Niemiera A. et al. 2007. Best management practices: guide for producing nursery crops. 2nd ed. Marietta (GA): Southern Nursery Association.