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# Evaluating Chemical Indices of Growing Media for Nursery Production of *Quercus rubra* Seedlings

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*Additional index words.* antagonistic interactions, container culture, fertilization, nitrogen, northern red oak, seedling development

*Abstract*. **We evaluated suitability of chemical indices of three media formulations or substrates (A, B, and C) consisting of composted pine bark, coconut coir pith, sphagnum peatmoss, processed bark ash, and perlite in varied proportions for growing northern red oak (*Quercus rubra* L.) seedlings. These substrates were ranked according to their ability to promote seedling growth. The low-yielding substrate (A) was devoid of pine bark and perlite and the medium-yielding substrate (B) contained no peatmoss or processed bark ash. The high-yielding substrate (C) contained all components. Additionally, we tested plant response to high nitrogen (N) fertilization on each substrate. Media EC, pH, and total dissolved solids measured at transplanting explained 68%, 43%, and 66%, respectively, of the variation in plant dry weight and 39%, 54%, and 46%, respectively, of the variation in shoot height. Vector diagnosis effectively ranked nutritional limitations on seedling growth as N > P > K. High N fertilization highlighted element deficiency in seedlings grown on substrate A, but resulted in element toxicity and antagonistic interactions in plants established on substrates B and C, respectively.**

Although chemical properties of formulated growing substrates may affect plant growth and nutritional response in varied ways (Folk et al., 1992), the nutritional mechanisms are poorly understood in forest tree seedling culture. Additionally, environmental concerns (Barkham, 1993; Buckland, 1993; Robertson, 1993) and rising peat prices have generated interest in the development of alternatives for use in container culture (Evans and Stamps, 1994, 1996). Partial substitution of peat with coconut (*Cocos nucifera* L.) coir-based products in media formulations could help conserve fragile and diminishing peat ecosystems (Handreck, 1993; Knight, 1991; Offord et al., 1998). The physical stability, ease in rewetting, ability to withstand compression, and low shrinkage rate over time (Cresswell, 1992) make coir a suitable alternative to peat. Another alternative is pine bark. Like coir, the use of pine bark in media formulations serves as a means of recycling waste materials (Hernández-Apaolaza et al., 2005). Pine bark can reduce phosphorus leaching (Tucker, 1995) and has better air porosity than peat or coir, which can facilitate water movement to the roots of plants (Landis, 1990). Pine bark does not exhibit hysteresis (i.e., inability of a dried solid to return to its full size on rehydration), a problem often encountered with peat (Naasz et al., 2005).

Thus far, studies conducted to evaluate substrate characteristics for growing horticultural species often relate plant performance to the varied physical or chemical properties of the medium (Bilderback et al., 1982; Brown and Emino, 1981; Hochmuth and Davis, 2004). For example, northern red oak (*Quercus rubra* L.), hereafter referred to as red oak, has been grown in a wide variety of substrates such as sewage sludge and (or) pine bark (Struve, 1996), soil–peat–sand–vermiculite (Crunkilton et al., 1994), compost (Percival and Henderson, 2003), silt loam (Maupin and Struve, 1997), topsoil–sand mixture (Bassman et al., 2003), and loam–peat–pine bark mixture (Kubiske and Abrams, 1992). However, none of these studies examined suitability of chemical indices of each substrate relative to others for optimal performance of the crop, especially under high N fertilization scenarios.

The objectives of this study were to 1) evaluate suitability of chemical indices of three substrates in relation to growth of container red oak seedlings, 2) examine nutritional interactions in plants exposed to high N fertilization on each substrate, and 3) confirm N as the primary nutrient limiting red oak seedling growth and nutrition on peat-based substrates (Folk et al., 1992; Imo and Timmer, 1992; Landis et al., 1989) using vector diagnosis. Vector analysis offers accurate diagnostic information (Timmer and Armstrong, 1987) and facilitates detection of nutritional interactions that may complicate conventional diagnostic techniques (Timmer and Armstrong, 1987).

## Materials and Methods

*Growth conditions.* Red oak seeds were collected the fall before sowing from a single mother tree (i.e., open pollinated, half-sib) on the campus of Purdue University, West Lafayette, Ind. (40°25′N, 86°55′W). Seedlings were germinated from seed and grown for 2 weeks in 2.83 l Treepots (Stuewe and Sons, Corvallis, Ore.) in three different growing substrates denoted A, B, and C (Table 1). These substrates were comprised of composted pine bark, coconut coir pith, sphagnum peatmoss, processed bark ash, and perlite in varied proportions. Seedlings were transplanted into 5.66 l pots on 23 April 2004 3 weeks after germination. Four pots were fitted into milk crates and arranged onto a greenhouse bench (mean day/night temperature of 24/20 °C) under ambient light conditions in the Department of Horticulture and Landscape Architecture Plant Growth Facility at Purdue University. Each pot was irrigated to container capacity determined gravimetrically at planting (Timmer and Armstrong, 1989). Plants were irrigated twice a week to return pots to container capacity (Royo et al., 2001; White and Marstalerz, 1966).

*Nitrogen treatments and experimental design.* Each of the three growing substrates (Table 1) was tested at two fertility levels (0 and 100 mg N plant$^{-1}$). The experimental design was a 3 × 2 factorial design with three replications. Each experimental unit consisted of four plants held within one milk crate. The fertilizer (Miracle Gro Excel 15N-5$P_2O_5$-15$K_2O$-Cal-Mag; Scotts Co., Marysville, Ohio) was supplied with the irrigation. Three split applications of 30, 30, and 40 mg N plant$^{-1}$ were conducted at transplanting and 2 and 4 weeks thereafter, respectively, to improve nutrient uptake efficiency.

*Sampling, chemical and statistical data analyses.* Plants were destructively sampled on 23 July at 90 days after transplanting. Root collar diameter and shoot height were measured. Plants were then partitioned into roots, leaves, and stems. These were composited by treatment replication, oven-dried at 68 °C for 72 hours, and weighed for dry weight. Subsequently, plant samples were milled for chemical analysis. Plant N was determined according to Association of Official Analytical Chemist (AOAC) methods. Total N was determined by combustion ("Dumas") procedure (AOAC 968.06) using a LECO nitrogen analyzer (LECO Corp., St. Joseph, Mich.).

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Table 1. Characteristics of growing substrates (provided by The Scotts Company) evaluated in this study for growing red oak seedlings.

| | Composition (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| Media Type | Composted pine bark | Coconut coir pith | Sphagnum peatmoss | Processed bark ash | Perlite | pH | Bulk density (g/cm$^3$) |
| A | 0–0 | 35–45 | 20–30 | 15–25 | 0–0 | 5.5–6.8 | 0.26–0.32 |
| B | 20–30 | 30–40 | 0–0 | 0–0 | 10–20 | 5.2–6.4 | 0.26–0.29 |
| C | 35–45 | 20–30 | 10–20 | 5–15 | 5–15 | 5.2–6.6 | 0.26–0.34 |

Additionally, plant samples were digested in nitric + perchloric acids (AOAC 935.13) and P and K determined using inductively coupled argon plasma (ICAP) analysis (AOAC 985.01). Electrical conductivity (EC) and total dissolved solids (TDS) of growing media sampled at day zero (or at transplanting) and at harvest (90 days after transplanting) were determined from saturated aqueous extracts of growing media as described in detail by Timmer and Parton (1984). TDS, a reflection of ions in solution and potential native fertility of substrate, was measured using a S30 SevenEasy Conductivity meter (Mettler Toledo, Leicester, U.K.). Water-extractable $NO_3$-N, P, K, and Ca (Table 2) were based on the saturated paste method (Jacobs and Timmer, 2005; Timmer and Parton, 1984) and chemical analysis followed procedures in Brown (1997). Three replicate samples were conducted on each substrate at transplanting.

Growth and nutritional data were evaluated by analysis of variance (ANOVA) based on Anderson and McLean's (1974) linear model using SAS (SAS, 2001). Fertility and fertility × media interaction effects were nonsignificant. Hence, one-way ANOVA was conducted to compare responses on unfertilized substrates. Significant treatment means were ranked according to Tukey's HSD tests at $\alpha = 0.05$. Linear regression models were developed using chemical indices of unfertilized substrates measured at transplanting as predictors of seedling dry weight and shoot height (Table 3). Dry weight and shoot height data were obtained from seedlings established on unfertilized substrates at day 90. Statistical modeling of the relationships between response variables (dry weight and shoot height) and the predictor variables (Table 3) was conducted using SPSS version 13.0 (SPSS Inc., 2001). Significant regression models ($P = 0.05$) were evaluated for goodness of fit by graphic analysis of residuals, which were assumed to be normally distributed and, hence, showed constant variance. Graphic analysis was adequate for residual evaluation (Neter et al., 1996). No transformation was required for independent variables because the assumptions of normality and homoschedasticity were met. Computed coefficient of determination ($R^2$) determines the percentage variation in the response that is explained statistically by the predictor variables (Table 3).

*Vector analysis.* Vector diagnosis allows for simultaneous comparison of dry weight, nutrient concentration, and content of plants or plant components in an integrated graphic format (Haase and Rose, 1995; Timmer, 1991). The technique was used here to facilitate interpretation of nutritional interactions on red oak seedling growth in the different substrates. Nutrient deficiency was demonstrated using data from unfertilized red oak plants grown on the low-yielding substrate A as reference, which was compared with data obtained from unfertilized plants established on the high-yielding substrate C as discussed under vector analysis. Additionally, antagonistic interactions and nutrient toxicity induced by high N fertilization were demonstrated using data from the fertilized medium-yielding (B) and fertilized high-yielding (C) substrates, respectively. Unfertilized substrates of the respective media served as controls for relative comparisons.

## Results and Discussion

*Growing media characteristics.* Growing media characteristics were not significantly influenced by fertility treatments (data not shown). High N fertilization induced antagonistic interaction and element toxicity, and these nutritional mechanisms could explain the lack of significant plant growth response to fertilization as discussed in detail under vector diagnosis. However, unfertilized substrates contrasted markedly in composition (Table 1) and chemical characteristics (Fig. 1, Table 2). For example, EC and TDS differed among the 3 media formulations at day zero (at transplanting) and at 90 days after transplanting (Fig. 1). TDS decreased 35%, 160%, and 149% in substrates C, B, and A, respectively, from transplanting to day 90, suggesting severe depletion in the latter two formulations (Fig. 1). Similarly, EC declined by 51%, 156%, and 143% over time in respective substrates C, B, and A.

Diminished EC and TDS levels by day 90 may suggest plant uptake. The EC range in the unfertilized substrates at time of transplant (0.7–1.0 dS $m^{-1}$, Table 3) is lower than recommended (2.0–2.5 dS $m^{-1}$) for optimum growth of conifer container stock (Jacobs and Timmer 2005; Phillion and Bunting, 1983; Timmer and Parton, 1984). Black spruce and white spruce (*Picea glauca* [Moench] Voss) seedlings displayed optimal growth at 2.5 dS $m^{-1}$, but mortality occurred above 4.0 dS $m^{-1}$ (Phillion and Bunting, 1983; Timmer and Teng, 2004). Similarly, maximum plant growth occurred at 1.8–2.2 dS $m^{-1}$ for container-grown red pine (*Pinus resinosa* Ait.), whereas toxicity was noted at 2.5 dS $m^{-1}$ (Timmer and Parton, 1984). For red oak seedlings, damage was noted at solution EC <1.0 dS $m^{-1}$ when grown in hydroponic systems (Thornton et al., 1988). Foliar symptoms appeared at 0.6 dS $m^{-1}$ and leaf dry weight was reduced at 0.75 dS $m^{-1}$ in red oak seedlings resulting from toxicity induced by excess $Na^+$ concentration (Thornton et al., 1988).

*Seedling growth and nutrition.* Although fertilization can be used to promote seedling growth in the nursery (e.g., Salifu and Jacobs, 2006; Salifu and Timmer, 2003), we were unable to detect significant fertilizer effects on dry weight and shoot height in this study (data not shown). However, dry weight production (Fig. 2), shoot height, and RCD (Fig. 3) were significantly greater ($P < 0.05$) in unfertilized substrate C relative to the others. This suggests that the fertility, physical, and chemical characteristics of substrate

Table 2. Mean and standard error (SE) of initial chemical characteristics of growing substrates measured at transplanting in this study for growing red oak seedlings.

| | Water-extractable | | | | |
|---|---|---|---|---|---|
| Media type | $NO_3$-N (mg/kg) | P (mg/kg) | K (cmol [+]/kg) | Ca (cmol [+]/kg) | pH |
| A | 3.33 (0.33)b | 4.17 (0.03)c | 10.10 (1.33) | 6.38 (0.60)a | 6.50 (0.15) |
| B | 13.13 (1.20)a | 7.40 (0.20)b | 10.99 (0.85) | 5.03 (0.44)ab | 5.63 (0.54) |
| C | 3.25 (0.50)b | 9.90 (0.24)a | 10.88 (0.45) | 5.06 (0.72)b | 5.42 (0.12) |

Column means followed by similar letters are not statistically different according to Tukey's HSD test at $\alpha = 0.05$.

Table 3. Mean and standard error (SE) of initial chemical indices of growing substrates (measured from unfertilized substrates) measured at transplanting and their coefficient of determination ($r^2$) with total height and dry weight production of red oak seedlings grown on unfertilized substrates for 90 d in a controlled greenhouse environment.

| | | Coefficient of determination | |
|---|---|---|---|
| Property | Mean (SE) | Height | Dry weight |
| pH | 6.49 (0.05) | 0.54 | 0.43 |
| EC (dS/m) | 0.79 (0.04) | 0.39 | 0.68 |
| Total Dissolved solids | 92.56 (3.94) | 0.46 | 0.66 |
| Water-extractable $NO_3$-N (mg/kg) | 6.56 (1.73) | 0.02 | 0.01 |
| Water-extractable P (mg/kg) | 7.16 (0.83) | 0.68 | 0.73 |
| Water-extractable K (cmol [+]/kg) | 10.66 (0.50) | 0.08 | 0.05 |
| Water-extractable Ca (cmol [+]/kg) | 4.93 (0.50) | 0.37 | 0.43 |

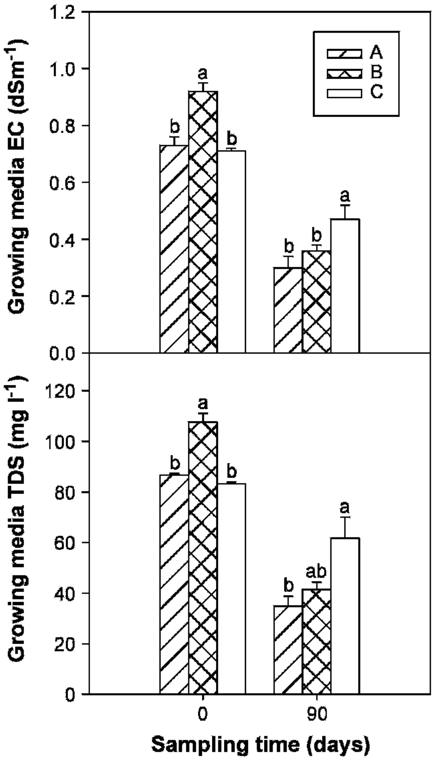

Fig. 1. Chemical properties of unfertilized (A) low-yielding, (B) medium-yielding, and (C) high-yielding substrates measured at day 0 (at transplanting) and at 90 d after transplanting. Bars marked with similar letters at each sampling event are not statistically different according to Tukey's HSD test at α = 0.05. Error bars represent the standard error of the mean.

C were more favorable for plant growth (Fig. 1). The greater growth (Figs. 2 and 3) in the coir-based substrate (B) without peatmoss and bark ash (Table 1) compared with the mixed substrate (A) suggests coir could serve as a viable substitute for peat in media formulations (Evans and Stamps, 1994, 1996; Guérin et al., 2001; Rose and Haase, 2000). This finding is significant given that substitution of coir, a byproduct for peat (a resource), could help preserve fragile peat ecosystems that are being depleted faster than replacements (Evans and Stamps, 1996; Offord et al., 1998). Benefits associated with coir may come from the release of phenolic compounds, which promoted root growth and proliferation in bougainvillea (*Bougainvillea* spp.) (Lokesha et al., 1988). Additionally, phenolic compounds exhibit significant antipathogenic properties that protect roots from disease-causing agents (Mansfield, 1982). For example, phenolics in coir promoted better root development than peat (Offord et al., 1998) or inhibited loss of roots to disease-causing pathogens (Evans and Stamps, 1996).

The presence of composted pine bark in substrate C may also explain the greater growth response in red oak seedlings. Substrate C contained the highest proportion of pine bark (40%). Pine bark can reduce phosphorus leaching (Tucker, 1995) and has better air porosity than peat or coir, which facilitates water transport to the roots of plants (Landis, 1990). Perhaps, the potential lack of hysteresis associated with pine bark compared with peat could be another reason to favor higher productivity with increased pine bark in substrates (Naasz et al., 2005). Thus, pine bark could serve as another useful alternative to peat in media formulations.

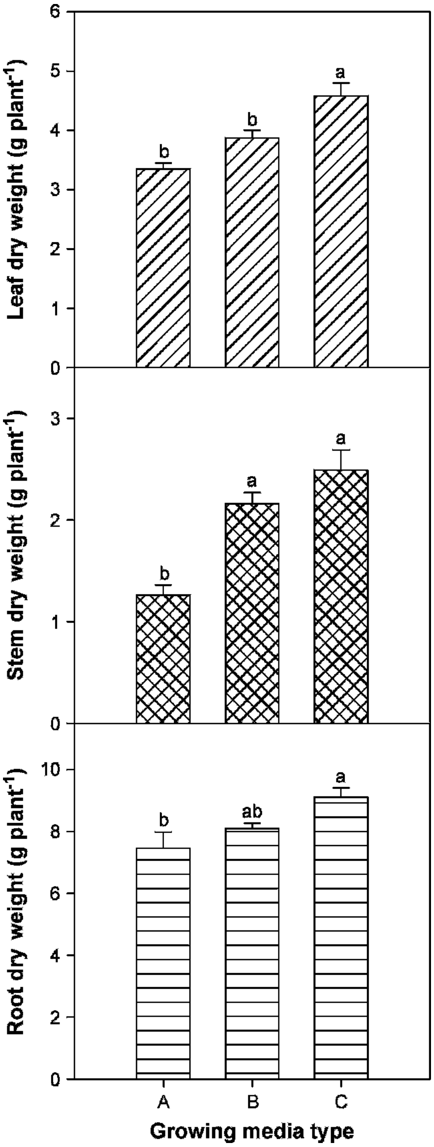

Fig. 2. Component dry weight production of red oak seedlings measured on unfertilized (A) low-yielding, (B) medium-yielding, and (C) high-yielding substrates at 90 d after transplanting. Bars marked with similar letters are not statistically different according to Tukey's HSD test at α = 0.05. Error bars represent the standard error of the mean.

*Correlations between growing media characteristics and plant growth.* Chemical characteristics of unfertilized substrates differed at transplanting (Fig. 1 and Table 2). Seedling dry weight and shoot height measured 90 d after transplanting on unfertilized substrates are shown in Table 3. The linear regression relationships indicate that a high percentage of the variation in seedling height was explained by chemical indices of substrates measured at transplanting (Table 3). Similarly, initial EC, pH, and TDS explained 68%, 43%, and 66%, respectively, of the variation in seedling dry weight. The poor correlation between growth and $NO_3$-N reflects low native N fertility of substrates (Table 2) as noted previously by Folk et al. (1992). Such response was attributed to the inability of conventional chemical tests to detect interactions between substrate components and added N fertilizer. By contrast, the strong correlation found between initial substrate characteristics with seedling growth in this study suggests that substrate chemical indices measured at transplanting can be used to evaluate substrate suitability for the production of container red oak seedlings.

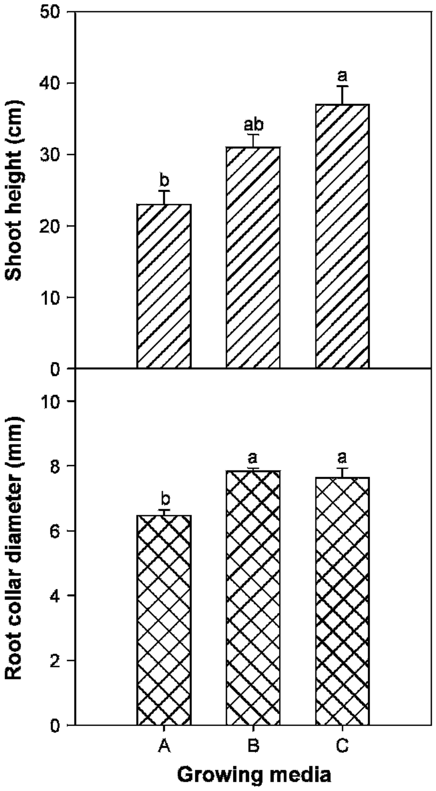

Fig. 3. Shoot height and root collar diameter of red oak seedlings measured from unfertilized (A) low-yielding, (B) medium-yielding, and (C) high-yielding substrates at 90 d after transplanting. Bars marked with similar letters are not statistically different according to Tukey's HSD test at α = 0.05. Error bars represent the standard error of the mean.

*Vector diagnosis.* Plant dry weight and nutrient data were plotted in a vector nomogram to examine whole plant response between substrates A and C (Fig. 4). The major vector orientation in Figure 4 signifies a deficiency response associated with improved growth and nutrient uptake (Salifu and Timmer, 2003). The magnitude of response indicated by vector length confirms N as the most limiting nutrient for plant growth (Folk et al., 1992; Imo and Timmer, 1992). Thus, nutrient limitation on the growth of red oak seedlings can be ranked as N > P > K (Fig. 4).

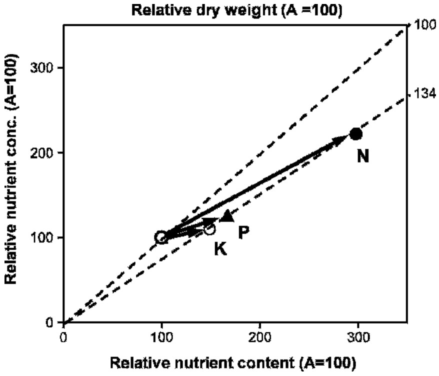

Fig. 4. Vector nomogram of relative change in plant dry weight, nutrient content and concentration of red oak seedlings grown on unfertilized high-yielding (C—complete formulation; see Table 1) and on unfertilized low-yielding (A—devoid of pine bark and perlite) substrates. Status of the low-yielding substrate was normalized to 100 to facilitate relative comparisons. Consult Salifu and Timmer (2003), and Imo and Timmer (1992) for interpretations.

Plant N, P, and K content increased by 198%, 67%, and 49%, respectively, in substrate C relative to A, confirming highest N uptake in seedlings grown in the high-yielding substrate.

An antagonistic effect (Fig. 5A) occurred in seedlings established on fertilized substrate C, whereas plants grown on the fertilized substrate B exhibited nutrient toxicity (Fig. 5B). An antagonistic effect occurs when a decline in nutrient concentration is associated with reduced growth and nutrient uptake (Imo and Timmer, 1997; Teng and Timmer, 1990a, b). For example, N, P, and K uptake and growth were 11%, 8%, 16%, and 7% lower, respectively, for substrate A compared with C (Fig. 5A). By contrast, nutrient toxicity or excess accumulation is associated with reduced growth but elevated tissue nutrient concentration (Fig. 5B). In this study, nutrient toxicity occurred when growth of seedlings on fertilized substrate A was 6% lower than those on fertilized substrate B but increased N, P, and K concentration by 3%, 10%, and 5%, respectively. These nutritional mechanisms could explain the lack of significant plant growth and nutritional response to fertilization observed in this study. High N supply and (or) $NH_4^+$ uptake may be antagonistic to $K^+$ nutrition and result in large reduction in $K^+$ uptake (Flaig and Mohr, 1992; Imo and Timmer, 1992). Depressed $K^+$ uptake (Fig. 5A) may be partly explained by the high N input, which induced antagonistic $K^+$ interaction (Boivin et al., 2002; Imo and Timmer, 1992).

## Conclusions

Chemical properties of substrates at transplanting were strongly correlated with growth, suggesting these indices can be used to characterize substrate suitability for production of high-quality container red oak seedlings. Nitrogen, P, and K content was

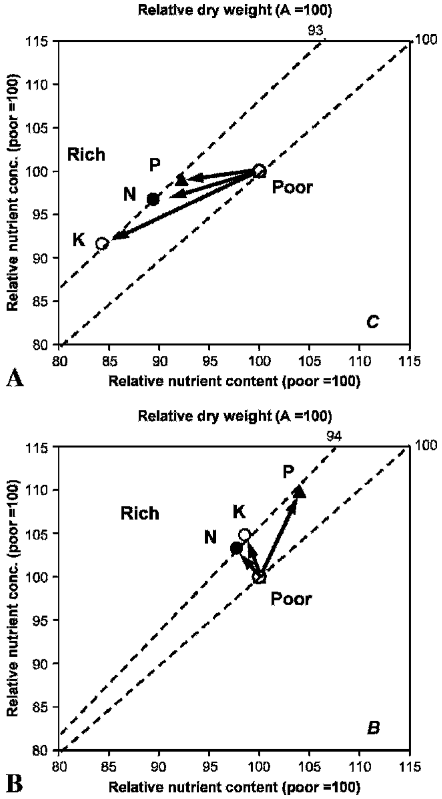

Fig. 5. Vector nomogram of relative change to fertilization in plant dry weight, nutrient content, and concentration of red oak seedlings grown on the fertilized high-yielding (C—complete formulation; see Table 1) or on the fertilized medium-yielding (B—devoid of peatmoss and bark ash) substrates (**A** and **B**, respectively). Seedling status on unfertilized (poor) was normalized to 100 to facilitate relative comparisons with responses on fertilized (rich) substrates. Consult Salifu and Timmer (2003), and Imo and Timmer (1992) for interpretations.

198%, 67%, and 49% higher, respectively, in substrate C relative to A. Plant growth was greater on substrate C compared with that on A and B. Thus, substrate C appears to be the most suitable among the tested media formulations for the production of red oak container stock under the current cultural conditions. Red oak seedling growth was better promoted in pine bark and coir-based substrates than in those containing peat, suggesting pine bark and (or) coir could serve as viable alternatives for use in media formulations. Vector diagnosis identified N as the primary element limiting red oak seedling growth on the tested substrates. High N fertilization induced antagonistic interaction in plants established on the high-yielding (C) substrate and element toxicity in plants grown on the medium-yielding (B) substrate. These nutritional interactions reflected the marked contrasts in media chemistry. Additional studies with other hardwood species as well as examination of physical indices of substrates may further improve our understanding of how substrate composition, chemistry, and fertilization can interact to promote seedling growth and nutrition.

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