Growth response and nutrient availability in western redcedar plantations following amendment with fish–wood compost and straw

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Abstract: Fish–wood compost and wheat straw were applied to chlorotic plantations of western redcedar (*Thuja plicata* Donn ex D. Don) on northern Vancouver Island to determine their effectiveness as fertilizers. Two years after application, tree growth was greater in the compost- and straw-amended plots than in control plots. The greatest growth response was in straw-amended plots. The first year after application, foliar concentrations of N, P, K, and S were higher in trees in the straw and compost plots. Two years after treatment, foliar nutrient concentrations returned to pretreatment levels in the compost plots, but remained elevated in the straw plots. Concentrations of KCl-extractable N in forest floors 2 years after treatment were greater in the straw plots than in the control plots prior to and after a 29-day incubation. The rate of CO_2 evolution from the forest floor was also greatest in the straw plots 2 years after treatment. These results suggest that addition of a fresh residue such as straw to these sites may promote a long-term increase in N availability and tree growth.

Résumé : Un compost de poisson ou de bois ainsi que de la paille de blé furent appliqués dans des plantations chlorotiques de thuya géant (*Thuja plicata* Donn ex D. Don) établies dans la partie nord de l'île de Vancouver afin d'évaluer leur efficacité comme fertilisants. Deux ans après l'application, la croissance des arbres était plus forte dans les parcelles amendées avec le compost ou la paille. La plus forte croissance est survenue dans les parcelles amendées avec la paille. La première année après l'application, les concentrations foliaires de N, P, K et S étaient plus élevées dans les parcelles traitées avec le compost ou la paille. Deux ans après le traitement, la concentration foliaire des nutriments est revenue au niveau antérieur au traitement dans les parcelles traitées avec le compost mais elle est demeurée élevée dans les parcelles traitées avec la paille. La concentration de N extractible au KCl dans la couverture morte, 2 ans après le traitement, était plus élevée dans les parcelles traitées avec la paille que dans les parcelles témoins avant et après une période d'incubation de 29 jours. Le taux d'évolution du CO_2 dans la couverture morte était également plus élevé dans les parcelles traitées avec la paille 2 ans après son application. Ces résultats suggèrent que l'addition dans ces sites de résidus non décomposés tels que la paille peut amener une augmentation à long terme de la disponibilité de N et de la croissance des arbres.

[Traduit par la Rédaction]

Introduction

Nutrient deficient plantations of western redcedar (*Thuja plicata* Donn ex D. Don) on cedar–hemlock cutovers on northern Vancouver Island have been shown to be responsive to additions of N + P fertilizers (Weetman et al. 1989) and organic wastes such as sewage sludge (Weetman et al. 1993). Dramatic improvements in growth and nutrition of conifers have also been observed following application of ensiled fish waste (McDonald et al. 1994; Prescott et al. 1995*a*). Silage and offal from fish farms are also composted with wood waste from pulp mills in several facilities on Vancouver Island. The end product is less noxious than silage and easier to apply. Fish–wood compost provided the best growth response of hybrid poplars in a pot bioassay compared with other organic and chemical fertilizers (Zabek 1995), but its efficacy as a fertilizer has not been tested in field trials.

A single application of straw to a nutrient-deficient jack pine (*Pinus banksiana* Lamb.) stand in Quebec smothered the ericaceous vegetation and promoted a long-term increase in tree growth and N availability (Prescott et al. 1995*b*; Weetman et al. 1995). The mechanisms for this response were not clear, but could have been either reduced competition from ericaceous shrubs (*Kalmia angustifolia* L. and *Vaccinium angustifolium* Ait.) or improvement in the quality of the organic matter on the site. Cedar–hemlock cutovers on northern Vancouver Island are ecologically analogous to these sites, being nutrient deficient with poor-quality organic matter and a dense cover of the ericaceous shrub salal (*Gaultheria shallon* Pursh). We applied straw to plantations on these sites to determine if it would result in increased N availability and tree growth. In this case the ericaceous shrubs were not killed, so that the direct nutritional effect of the straw could be ascertained. Here we report effects of compost and straw amendments on growth and foliar nutrition of cedar and N availability in humus.

Methods

Study site

The trial was in an 11-year-old plantation of western redcedar on a cutover of an old-growth forest of cedar and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), north of Port McNeill, on northern Vancouver Island, B.C. (50°35′N, 127°05′W). The site is in the Coastal Western Hemlock very wet maritime (CWHvm) biogeoclimatic subzone. Annual average precipitation is 1700 mm; mean daily

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Table 1. Nutrient concentrations of the fish–wood compost and wheat straw.

	%C	%N	C/N	%P	%K	%Ca	%Mg	NH_4-N	NO_3-N
Compost	46.8	1.69	27.7	1.37	0.35	4.62	0.19	14.2	2420
Straw	47.1	1.19	39.6	0.14	1.37	0.35	0.11	22.6	2.6

Note: Each value is the mean of three samples. Concentrations of NH_4-N and NO_3-N are in µg/g.

temperatures range from 3.0°C in January to 13.7°C in July. Topography is gently undulating, and soils are well to poorly drained Ferro-Humic Podzols on unconsolidated morainal and fluvial outwash materials. The soil is a sandy loam with a thin (4 cm) grey–brown Ae horizon over a yellowish red to yellowish brown Bf horizon. The plantation was established in 1982 after clear-cutting and slashburning an old-growth cedar–hemlock forest.

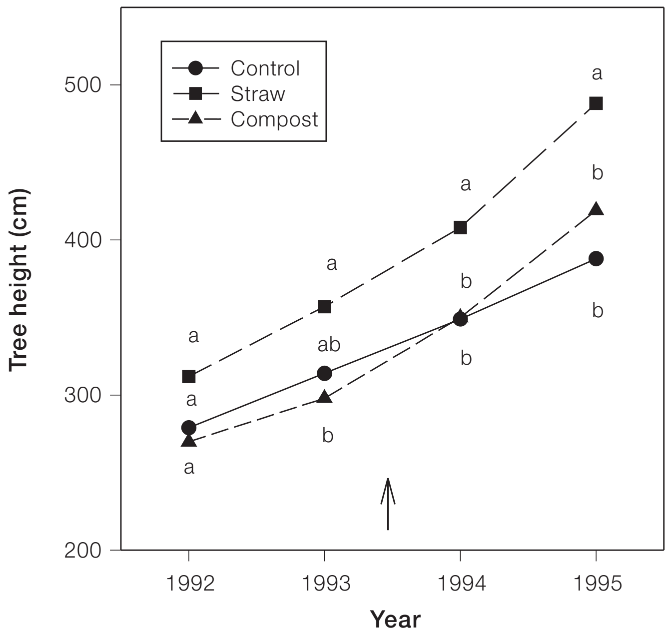
Six 15 × 15 m plots were established in December 1992 adjacent to existing organic fertilization trials. Two plots were randomly assigned to each of three treatments: wheat straw, fish–wood compost, and control (unamended). The height of 25–31 cedar trees in each plot was measured in December of 1992 through 1995. Foliage was collected from five trees in each plot in December 1992, and one composite sample of current-year foliage from each plot was separated as described by Radwan and Harrington (1986). Foliage samples were oven-dried at 70°C and concentrations of N and P were measured on an Alpkem RFA-300 autoanalyzer following digestion in sulphuric acid and hydrogen peroxide (Parkinson and Allen 1975). Concentrations of K, Ca, and Mg were measured on a Varian Spectra 400 atomic absorption instrument. Sulphur concentrations were determined by combustion in a Fisher oven. All analyses were done at the MacMillan Bloedel laboratory in Nanaimo, B.C.

On May 7, 1994, 13 m^3 of fish–wood compost and 178 bales of wheat straw were transported from the University of British Columbia Research Farm near Campbell River to the field site in a chip truck. On May 12, 1994, 64 bales of straw were transported by backpack to each of the two straw plots, and approximately 6 m^3 of compost was transported in buckets to each of the two compost plots. These additions were equivalent to approximately 2000 kg N/ha. Bales were broken up and straw was applied loosely with a pitchfork to the forest floor. The average depth of straw was 25 cm, and the salal was only covered temporarily. The compost was spread onto the forest floor using a shovel or bucket. Conifer branches and salal were shaken to remove compost from foliage, and compost on logs was brushed off. The average depth of compost was 1–2 cm. Control plots received similar traffic and shaking of vegetation. Concentrations of C, N, P, K, Ca, and Mg were measured in three samples of the compost and straw. Carbon and N were measured by combustion in Leco determinators; the other elements were measured as described earlier. Concentrations of available NH_4-N and NO_3-N were measured on the autoanalyzer following extraction with 2 M KCl (Page et al. 1982).

The height of the 25–31 cedar trees in each plot was measured annually in November or December, and foliage was collected from three and five trees per plot in 1994 and 1995, respectively, for measurement of nutrient concentrations. Differences between treatments were analyzed using one-way analysis of variance (ANOVA) and Bonferroni's multiple range test. Samples from the two plots per treatment were pooled prior to each analysis. Data with nonhomogeneous variances were log transformed prior to analysis.

To establish effects of the treatments on N availability, rates of N mineralization in the forest floor in each of the plots were measured in laboratory incubations in March 1996, almost 2 years after amendment. Five samples of the organic layer, including residual straw and compost, were collected from each plot on March 1, 1996. Live vegetation, coarse roots, and wood were removed. A portion of each sample was dried at 70°C and moisture contents were determined.

Fig. 1. Tree height 2 years prior to and 2 years after amendment with straw or compost. The arrow indicates the timing of the applications. Each value is the mean of 49–58 trees. Means with the same letter within years are not significantly different ($p > 0.05$) based on one-way ANOVA and Bonferroni's test.



One 5-g dry weight equivalent subsample of each fresh sample was extracted with 2 M KCl and initial concentrations of NH_4-N and NO_3-N were measured on the autoanalyzer. A second 5-g portion of each sample was incubated in a 1-pt jar (470 mL) at about 20°C for 29 days. Concentrations of CO_2-C in the headspace were measured weekly with an infrared gas analyzer (Clegg et al. 1978), after which the jars were opened for 15 min. After 29 days, the samples were extracted and final N concentrations were measured as described earlier. Three composite samples of salal leaves (5 leaves per sample) were also collected from each plot in March 1996, and concentrations of macronutrients were measured as described above. Differences between treatments were analyzed using one-way ANOVA and Bonferroni's multiple range test. Samples from the two plots per treatment were pooled prior to each analysis. Data with nonhomogeneous variances were transformed by using the reciprocal of the data prior to analysis. All analyses were conducted using SPSS for Windows version 6.0 software (SPSS Inc. 1993).

Results

The fish–wood compost had higher concentrations of total N, P, Ca, and Mg than the straw, but the straw had higher K concentrations (Table 1). There was substantially more KCl-extractable N in the compost than in the straw, particularly NO_3-N. The C/N ratio of the compost (28) was narrower than that of the straw (40).

Tree heights were greatest in the straw plots in 1994, prior to amendment, and increasingly so after amendment (Fig. 1). Annual height increments (Table 2) were smallest in the compost plot the year prior to amendment (1992–1993). The first year after amendment, height growth was greater in both treatments than in the control plots. The second year after amendment, height growth in the straw plots was greater than in the compost plots, and was twice that in the control plots.

Table 2. Annual height increments (cm) of cedar trees in control and treated plots prior to and following amendment in May 1994.

Treatment	*n*	1993	1994	1995
Control	58	35.3 (13.8)*a*	34.9 (11.5)*b*	39.3 (22.1)*c*
Compost	49	28.1 (12.8)*b*	52.1 (18.5)*a*	68.7 (19.5)*b*
Straw	54	45.1 (23.8)*a*	51.5 (23.5)*a*	80.2 (24.5)*a*

Note: Each value represents the mean (and standard deviation) of *n* trees. Means followed by the same letter within a column are not significantly different ($p > 0.05$) as determined by one-way ANOVA and Bonferroni's test.

Table 3. Foliar nutrient concentrations in cedar trees in control and treated plots prior to and following amendment in May 1994.

Treatment	%N	%P	%K	%Ca	%Mg	%S
1992						
Control	1.15	0.16	0.47	0.56	0.17	0.102
Compost	1.02	0.18	0.52	0.59	0.19	0.094
Straw	1.16	0.17	0.51	0.59	0.17	0.127
1994						
Control	1.06*b*	0.17*b*	0.45*c*	0.61*b*	0.18*a*	0.099*b*
Compost	1.63*a*	0.24*a*	0.81*a*	0.59*b*	0.16*a*	0.125*a*
Straw	1.61*a*	0.22*a*	0.73*b*	0.76*a*	0.18*a*	0.135*a*
1995						
Control	1.01*b*	0.16*b*	0.45*b*	0.56*a*	0.19*a*	0.105*b*
Compost	1.06*b*	0.20*b*	0.59*b*	0.55*a*	0.18*ab*	0.106b
Straw	1.39*a*	0.29*a*	0.95*a*	0.51*a*	0.15*b*	0.140*a*

Note: Means followed by the same letter within a column are not significantly different ($p > 0.05$) as determined by one-way ANOVA and Bonferroni's test.

Table 4. Foliar nutrient concentrations in salal leaves in control and treated plots 2 years after amendment.

Treatment	%N	%P	%K	%Ca	%Mg
Control	0.71*b*	0.06*b*	0.38*b*	1.16*b*	0.35*a*
Compost	0.93*a*	0.09*a*	0.40*ab*	1.71*a*	0.36*a*
Straw	1.02*a*	0.09*a*	0.49*a*	1.25*b*	0.33*a*

Note: Means followed by the same letter within a column are not significantly different ($p > 0.05$) as determined by one-way ANOVA and Bonferroni's test.

Concentrations of N, P, K, and S in cedar foliage were greater in plots amended with compost or straw than in the control plots at the end of the first growing season (1994). At the end of the second growing season after amendment (1995), cedar foliar concentrations of N, P, K, and S were significantly greater in the straw plots than in the control or compost plots (Table 3). Concentrations of N and P in salal leaves were also greater in straw- and compost-amended plots than in control plots in March 1996, 2 years after treatment (Table 4).

Concentrations of extractable N in forest floors collected in March 1996 from straw-amended plots were greater than those from control plots (Fig. 2). Extractable N concentrations after the 29-day incubation were also greater in forest floor samples from the straw plots than in the control or compost plots (Fig. 3). Both NH_4-N and NO_3-N concentrations were greatest in forest floor samples from the straw-amended plots. The amount of CO_2-C evolved from straw-amended forest floors during the 29-day incubation (6.5 ± 1.8 mg/g) was also greater than that from compost-amended (3.6 ± 2.0 mg/g) or control (2.5 ± 0.6 mg/g) plots.

Fig. 2. Concentrations of KCl-extractable N in forest floors amended with straw or compost 2 years after treatment. Each value represents the mean of 10 samples. Values for the three treatments with the same letters are not significantly different ($p > 0.05$) based on one-way ANOVA and Bonferroni's test.

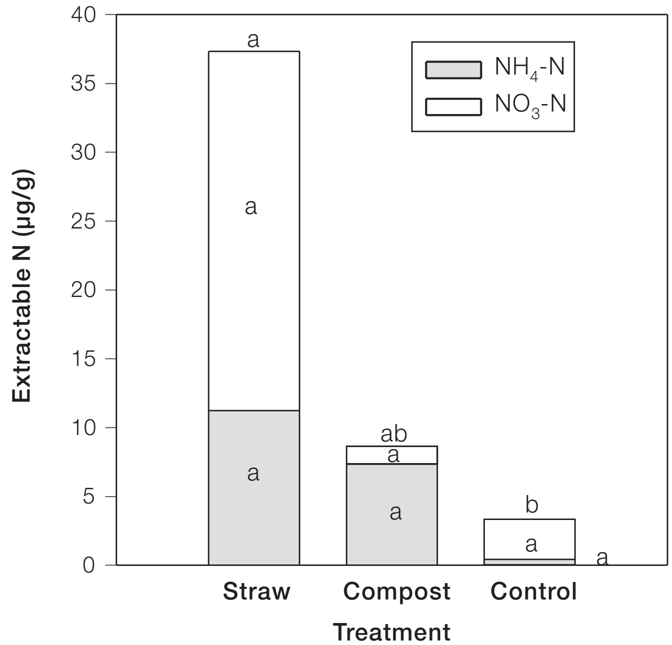
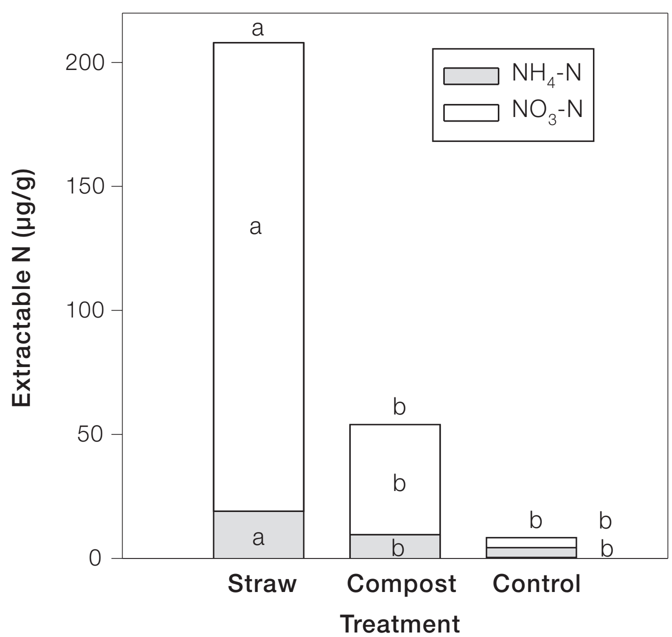


Fig. 3. Concentrations of KCl-extractable N in forest floors amended with straw or compost after 29 days of incubation at 22°C. Each value represents the mean of 10 samples. Values for the three treatments with the same letters are not significantly different ($p > 0.05$) based on one-way ANOVA and Bonferroni's test.



Discussion

We expected a larger increase in N availability from the fish–wood compost than the straw because at the time of application, it had higher concentrations of both total and extractable N and a smaller C/N ratio. Although cedar growth increased after compost application, foliar nutrient concentrations returned to pretreatment levels by the second year after application. Compost will likely have a similar effect as conventional fertilizer, i.e., increased growth for a few years as a result of nutrients taken up during the first year, but return of soil N to pretreatment levels after 1 year (Binkley 1986). The higher foliar nutrient concentrations and forest floor N availability in the straw-amended plots, in conjunction with increased tree growth, suggest a prolonged increase in N availability in these plots. A long-term increase in N availability was also measured when straw was applied to a jack pine forest in Quebec (Prescott et al. 1995*c*), where part of this effect was thought to be due to the reduction in the cover of ericaceous shrubs. In the present study, salal cover was not noticeably reduced by straw addition, so reduced competition was not responsible. We surmise therefore that the increased tree growth was a direct nutritional effect of the straw.

The straw may have had a "priming effect," i.e., stimulation of mineralization of soil organic N by addition of organic residues or N (Haynes 1986). Broadbent and Nakashima (1974) observed increased mineralization of N from an agricultural soil after adding fresh barley residue (Haynes 1986). Means of liberating the substantial reserves of humus-bound N on these sites have been sought, but earlier trials with starch and lime were not successful (Prescott and McDonald 1994). Due to mixing of straw and humus, it was not possible to sample the humus separately to establish if there had been an increase in the rate of N mineralization from the humus on these plots. Addition of ^{15}N-labeled straw is necessary to determine if there was a priming effect on N in humus.

Differences in the C chemistry of the two amendments may be responsible for their different effects on N availability, despite similar total N loadings (2000 kg N/ha). Compost is already partially decomposed, so it would provide little readily available C for microbial activity. After release of the extractable N, mineralization of the remaining material would be slow, so the increase in soil N availability following compost application would be short-lived. There may also be immobilization of N into the compost if it is not mature. Straw, like other fresh residues, contains available C which stimulates microbial activity (particularly cellulolytic fungi), resulting in larger and more active microbial biomass and faster mineralization (Haynes 1986). Turnover of the microbial biomass would prolong the period of increased N availability. Increased microbial activity was evident in the higher rates of CO_2 evolution from the forest floors amended with straw during the laboratory incubation. Soil fauna were much more apparent in the forest floor from the straw plots than from the compost or control plots, which would further stimulate mineralization and turnover of the microbial biomass. Bauhus and Meiwes (1994) also reported greater rates of CO_2 evolution and nitrification in fresh plant residues than in mature organic compost, which they atributed to the large pool of easily degradable organic substances in the fresh residue.

The response of cedar trees to straw and compost amendments can be compared with responses to other fertilizers measured in earlier trials on the same cutover (McDonald et al. 1994), although the trees were 2 years older when the present trial was established. The height increment of trees in the compost plots during the second growing season after application (68.7 cm) was similar to the second-year response to chemical (N + P) fertilizer (65.7 cm) and greater than responses to sewage sludge (57.8 cm) or fish silage (57.4 cm). The second-year height increments in the straw plots (80.2 cm) surpassed that in any of the other treatments. The increase in foliar N concentrations in compost and straw plots during the first season after application was similar to that in plots treated with sewage sludge, and much less than that resulting from additions of chemical fertilizer or fish silage. Therefore, the higher N concentrations in cedar foliage in straw plots after the second growing season cannot be attributed to internal recycling of N taken up during the first year, and so are further evidence of sustained higher N availability in the straw plots. This supports the suggestion that there may be a long-term increase in N availability in the straw-amended plots, as was observed in the earlier trial in jack pine (Prescott et al. 1995*b*). Although the application of fresh residues is more costly than conventional fertilization, it should be explored as means of promoting a long-term improvement in the productivity of forests on N-poor sites.

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