An Alternative Fertilization Monitoring Protocol

February 2015

Introduction

In recent years, an extensive network of area-based, G&Y monitoring plots has been established in treated and untreated portions of operationally fertilized stands throughout the BC interior in order to estimate per-hectare growth gains that have occurred following fertilization (Hawkins 2006). Preliminary analyses of post-fertilization measurement data from monitoring plots at several of these locations have yielded inconclusive results due to large variability in growth increment caused by inter- and intra-plot differences in tree size, stand density, and species composition. As a result, it has not been possible to reliably evaluate treatment response in these operationally fertilized stands.

Although potentially important in terms of wood supply, the amount of wood produced per hectare following a single fertilizer application is usually small relative to total stand volume. Therefore, methodologies used to detect area-based fertilization response (i.e., m^3/ha of wood produced) require that pre-treatment stand and site conditions within fixed-area G&Y sample plots be carefully controlled in order to minimize stand and site variability within and between treatment units. Unfortunately, this is generally not possible under operational conditions where, in addition to more variable stand and site conditions, the experimental requirements of replication and randomization cannot be readily achieved. As such, estimating area-based growth response using traditional G&Y methodology may simply be an unrealistic objective for an operational fertilization monitoring program. What may be needed is an alternative monitoring protocol that is designed to address more achievable objectives.

Instead of estimating absolute per-hectare growth gains following operational fertilization, a more achievable monitoring objective might be to evaluate relative fertilization response using a representative sample of individual trees of specific species, rather than fixed-area plots, as experimental units. This alternative approach will not produce the area-based estimate of growth response that is ultimately desired by forest practitioners. However, if properly designed and executed, it may adequately demonstrate whether or not the growth benefits obtained from operational fertilization projects are broadly consistent with those indicated from controlled fertilization research experiments. In mixed-species stands (i.e., stands with more than one major species), it may also indicate which species are most responsive, and which are least responsive, to fertilizer application.

Methods

The suggested methodology for an alternative monitoring protocol has been adapted from an approach used by Brockley (2010) in a retrospective study to estimate radial growth response of operationally fertilized subalpine fir (*Abies lasiocarpa*), and in an earlier growth assessment of operationally fertilized lodgepole pine (*Pinus contorta* var. *latifolia*) (Brockley and Yole 1985).

Definitions

The symbols used to describe fertilization response were defined by Brockley (2010) as follows:

A – growth increment after date of fertilization

B – growth increment before date of fertilization

E – estimate, for a fertilized tree, of the growth increment that would have occurred after the date of fertilization had fertilizer not been applied

R – absolute magnitude of growth response

I – an index of response

av – the average for all replicates

f – fertilized

u – unfertilized

k – a specific fertilized tree

l– a specific unfertilized tree

Theory

Tree growth response following fertilization (R_{fk}) is the difference between the post-fertilization growth of a fertilized tree (A_{fk}) and the growth that would have occurred had it not been fertilized (E_{fk}).

$$R_{fk} = A_{fk} - E_{fk} \qquad (1)$$

As explained by Brockley (2010), obtaining a reliable estimate of E_{fk} can be difficult, particularly in operational settings where the elements of sound experimental design (e.g., replication and randomization) are typically not rigorously employed. Brockley (2010) suggested that a reasonable estimate of E_{fk} might be obtained by multiplying the pre-fertilization growth of a fertilized tree (B_{fk}) by the average ratio of post- to pre-fertilization growth of sampled trees in a representative unfertilized stand [$av(A_{ul}/B_{ul})$]. Thus average response for several trees may then be calculated as follows:

$$av(R_{fk}) = av(A_{fk}) - av[(B_{fk}) \cdot av(A_{ul}/B_{ul})] \qquad (2)$$

Since A_{ul}/B_{ul} is apparently fairly insensitive to most site and stand dissimilarities (Ballard and Majid 1985), a relative index of response (I) can be calculated that will indicate whether a fertilization response has occurred.

$$I = av(A_{fk}/B_{fk}) - av(A_{ul}/B_{ul}) \qquad (3)$$

Using these two equations, the relative radial growth response of operationally fertilized stands can be estimated as follows:

$$\% \text{ response} = av(R_{fk}) / av[(B_{fk}) \cdot av(A_{ul}/B_{ul})]$$

and/or

$$\% \text{ response} = I / av(A_{ul}/B_{ul})$$

Reliable estimation of relative fertilization growth response using this alternative approach is dependent on the selection of appropriate stands for monitoring projects and the selection and measurement of a representative sample of individual trees (i.e., experimental units) within unfertilized and fertilized portions of the stands.

Monitoring Intensity

An appropriate sampling intensity for an operational fertilization monitoring program is necessarily a trade-off between the desire to reliably estimate fertilization growth response and the need to be cost effective. It is recommended that one monitoring project using the alternative protocol be undertaken for every 500 ha of fertilized area. At this relatively low intensity, it is very important that the individual stands selected for monitoring are representative of the operational fertilization project as a whole.

Selecting Suitable Stands for Monitoring

In an effort to minimize variability, and thus increase the possibility of detecting a treatment response, fertilized and unfertilized sample trees must share similar characteristics (e.g., species, diameter, live crown characteristics, inter-tree competition, BEC site series, silvicultural treatment history).

Because of these requirements, the careful and deliberate selection of appropriate fertilized and control (i.e., unfertilized) monitoring areas prior to operational fertilization are very important steps in the monitoring process.

Appropriate monitoring areas will be those stands (i.e., polygons) that exhibit predominantly uniform site and stand conditions that are representative of a relatively large portion of the entire fertilization project for that administrative area. Also, there must be a representative portion of the fertilized stand that can be easily demarcated and set aside as a control (i.e., unfertilized) area, or a nearby unfertilized stand that shares similar site/stand conditions with the fertilized stand. For monitoring purposes, suitable control areas should be at least 5 ha in size.

Selecting Suitable Sample Trees

It is very important to select sample trees (i.e., experimental units) that accurately reflect the fertilization response potential of the stand as a whole. The absolute radial growth response in a fertilized stand generally increases with increasing tree size. However, the relative (%) response may be smaller for the larger trees and larger for the smaller trees (Gardner 1990; Brockley 2006). Therefore, confining sampling to smallest trees might overestimate relative response, whereas confining sampling to the largest trees might underestimate relative response. For each species of interest, monitoring purposes may be best served by selecting sample trees with diameter at breast height (dbh) approximating the quadratic mean diameter (QMD) of that species within the stand. Because QMD assigns greater weight to larger trees, it is always larger than the arithmetic mean. The QMD represents the diameter of the tree of average basal area.

Where available, dbh data obtained from permanent sample plots (PSP's) that were previously established within the stand using the area-based monitoring protocol described by Hawkins (2006) may be used to calculate a separate QMD for each species for which an estimate of fertilization growth response is desired. Depending on how recently the data were collected, the calculated QMD may be adjusted upward by collecting several increment cores from representative trees (i.e., those trees approximating the calculated QMD) and examining recent growth rings.

In stands without previously-established area-based monitoring plots, it will be necessary to establish several temporary sample plots (TSP's) within representative portions of the control and fertilized areas in order to obtain a reliable estimate of QMD. Depending on stand uniformity and species composition, collecting dbh data from a total of 5–10, 7.98-m radius (0.02 ha) TSP's will likely enable the calculation of a sufficiently reliable estimate of QMD for each species of interest.

Regardless of whether dbh data is obtained from PSP's or TSP's, the following formula will be used to calculate QMD:

$$\text{QMD} = \sqrt{(\sum D_i^2)/n} \qquad (4)$$

where:
D_i = dbh of a specific tree (> 7.5 cm dbh) of a specific species within a given plot
n = total number of trees of a specific species (> 7.5 cm dbh) within all plots (unfertilized and fertilized) within a treatment block

Field Sampling Procedures

1. By using a grid pattern or a series of transect lines, systematically walk through representative portions of the fertilized and unfertilized areas, selecting healthy trees of the specified species and size (QMD ± 1.5 cm). All selected trees of a particular species should share similar stand (i.e., stand density, crown position, live crown characteristics) and site (e.g., BEC site series) characteristics.
2. Select a total of 30 sample trees per species within each of the unfertilized and fertilized areas. Trees may be selected within previously-established area-based monitoring plots, but tree selection need not be confined to the existing plots.
3. Locate breast height (1.3 m above ground at highest point) of each sample tree, adjusting slightly upwards or downwards as necessary to avoid branch whorls.
4. Carefully measure and record the dbh of each sample tree.
5. Extract two increment cores (at 90^0 from each other) from each sample tree at the exact bole position where dbh was measured. As a minimum, each core shall be long enough to span the entire post-fertilization growth period as well as the 10 years of growth prior to fertilization.
6. The two cores from each tree shall be stored using the following procedure:
    a) Seal one end of a plastic drinking straw (with tape or staple);
    b) Immediately upon extraction from the tree, carefully insert one of the two cores into the prepared straw;
    c) Staple or melt (with lighter) the straw immediately above the inserted core;

d) Insert the second core into the portion of the same straw above the stapled or melted section;
e) Seal the other end of the straw (with tape or staple).

7. Clearly label each straw with treatment unit, treatment (U=unfertilized; F=fertilized), sample number (1 to 30), dbh, and species (Sx=spruce; Bl=true fir; Df=Douglas-fir, Pl=lodgepole pine).
8. Bundle together the 30 plastic straws of each species from each of the unfertilized and fertilized portions of each treatment unit and place in separate freezer bags. Clearly label each freezer bag with treatment unit, treatment, and species as in 7 above.
9. Freeze all bagged core samples until shipping can be arranged to the Ministry of Environment Laboratory in Victoria.

Increment Core Measurement

Core ring widths will be measured at the Ministry of Environment laboratory using the WinDendro automated core analysis system.

For each increment core, measurement data will be used to identify each of the following:

1. Time at which fertilization occurred (*X*);
2. End of 5th growing season before fertilization (*Y*);
3. End of 5th growing season after fertilization (*Z*).

Basal area (BA) increment is a more sensitive and more reliable indicator of relative growth response than dbh increment. By using the dbh measurement recorded for each sample tree, the estimated dbh at points *X*, *Y*, and *Z* should be calculated and recorded. By using the dbh estimates for points *X*, *Y*, and *Z*, the stem basal area (BA) for each of the three points can then be calculated.

For individual cores samples from the unfertilized portion of the stand, the BA difference between *X* and *Y* is B_{ul} in Equations 2 and 3. Likewise, the BA difference between *X* and *Z* is A_{ul}. For individual cores sampled from the fertilized stand, the BA difference between distances *X* and *Y* is B_{fk} in Equations 2 and 3. Likewise, the BA difference between distances *X* and *Z* is A_{fk}.

Data Analysis

For each species, a paired *t*-test will be used to retain or reject the hypothesis that the population means of $av(A_{fk})$ and $av[(B_{fk})\cdot av(A_{ul}/B_{ul})]$ in Equation 2 are the same. A *t*-test will also be used to test for differences between $av(A_{fk}/B_{fk})$ and $av(A_{ul}/B_{ul})$ on the right side of Equation 3. However, in neither case is there any basis for statistical inference of fertilization response since there is only one true replicate of the unfertilized and fertilized treatments (i.e., the unfertilized and fertilized treatments were assigned to two different stands and the individual trees were sub-sampled from within these two stands). This is a necessary reality when dealing with operationally fertilized stands.

Literature Cited

Ballard, T.M., and N. Mahid. 1985. Use of pre-treatment increment data in evaluating tree growth response to fertilization. Can. J. For. Res. 15: 18-22.

Brockley, R.P. 2006. Effects of fertilization on the growth and foliar nutrition of immature Douglas-fir in the Interior Cedar-Hemlock zone of British Columbia: six-year results. B.C. Ministry of Forests and Range, Victoria. Research Report 27.

Brockley, R.P. 2010. Assessing the fertilization response potential of subalpine fir (*Abies lasiocarpa*): a retrospective study. B.C. Min. For. Range, Victoria. Ext. Note 93.

Brockley, R.P. and D. Yole. 1985. Growth response of lodgepole pine to operational fertilizer application near Burns Lake, B.C. B.C. Min. For., Victoria. Res. Rep. RR85005-HQ.

Gardner, E.R. 1990. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: 15-year growth response. Forestry Canada, Pacific Forestry Centre, Victoria, BC. BC-X-319.

Hawkins, C. 2006. Growth monitoring scheme for an operational forest fertilization program. B.C. Min. For. Victoria. Unpubl. contract report.

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February, 2015