Chapter 19

Forest Fertilization in Interior British Columbia: The Forest Service Approach

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ABSTRACT. The British Columbia Forest Service began fertilization in interior forests of the province in 1985 as part of a provincewide program begun under the federal-provincial Forest Resource Development Agreement (FRDA). A detailed three-step process combining biological, operational, and wood supply considerations is used to select individual stands and rank them according to priority for treatment. The organization and scheduling of operations is described, as are the rationale and procedures for treatment monitoring, environmental monitoring, and response monitoring. Accurate growth and yield predictions head the list of information needed to strengthen the forest fertilization program. While the discussion in this paper is primarily about interior forests, much applies to coastal forests as well.

The first British Columbia Forest Service fertilization program began in 1978 and ran for five years. A total of 36,846 hectares were treated, with over 99% in the Vancouver Forest Region. The funding for this program was inspired at the political level and was not accompanied by long-term vision and commitment. After a hiatus of two years, a new program that was truly provincewide in scope began in 1985 under the federal-provincial Forest Resource Development Agreement (FRDA).

Development of the rationale for undertaking forest fertilization has been a complex process, with the program building both from the ground up and from the top down. Research findings, as well as the operational experience of other countries, had shown fertilization to be a treatment capable of stimulating substantial growth increases in a short period of time. With widespread future wood supply shortages forecast in our comprehensive Forest and Range Resource Analysis (1984), fertilization was included in the five-year FRDA program that ran from 1985 to 1990 and resulted in 51,973 hectares being treated, of which 54% (nearly 28,000 ha) was in interior British Columbia. The level of funding for both the total FRDA program and its fertilization component was determined by negotiations between the provincial and federal governments, rather than in response to demonstrated forest management requirements.

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The Fertilization Decision

The B.C. Forest Service task was to make the best use of the funds, based on needs and opportunities, over time and geographically throughout the province. There has long been a "Coast versus Interior" attitude in British Columbia, and particularly so in forestry. The Vancouver Forest Region, with its productive Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) biogeoclimatic zones, has long believed it should have the lion's share of any intensive silviculture program. Interior forests dominated by lodgepole pine (*Pinus contorta* var. *latifolia*) were, and still are to some degree, looked down upon by coastal foresters. However, the limited research results available (Weetman 1988; Brockley 1991; Brockley et al., this volume; Mika et al., this volume) and operational fertilization programs in Sweden (Hagner 1985, 1991) indicated that lodgepole pine had substantial potential to respond to nitrogen fertilization. Moreover, British Columbia has a considerable area of forests dominated by lodgepole pine: they make up 35% (nearly 14 million ha) of land classified as productive for forestry in provincial Crown forests.

Within this total of nearly 14 million hectares of lodgepole pine forest, there are some 2.25 million hectares of young stands of sufficient productivity to be considered candidates for fertilization. The extent of the interior forests, the size of the allowable cut from them, and the dependency of communities on them dictated development of a fertilization program that reflected the importance of these forests. A comprehensive table that we call the "allocation mechanism" was therefore developed to apportion funds between Regions for all intensive silviculture treatments, including fertilization. Factors in the allocation mechanism include long-term wood supply, area available for treatment, expected gains in both volume and value, regional treatment costs, several aspects of population dependency on the forest industry, and land productivity. With the total available funds for fertilization known, apportionment is then made between the six Forest Regions. Within a Region, further allocation is made between Forest Districts having the most suitable candidate stands and with the greatest concerns for future wood supply.

Stand Evaluation

Evaluation of individual candidate stands by the B.C. Forest Service is a three-step process of considering certain characteristics and factors grouped according to biological, operational, and wood supply criteria. Each characteristic or factor has a range of relative priorities, depending on how favorable the attributes are for a candidate stand.

Biological Characteristics

The first step is to evaluate the biological characteristics of a stand to determine whether it will respond to fertilizing. The first biological characteristic evaluated is species. Recognizing that research results are far from complete, we have set priorities based on current knowledge of response patterns. There is sufficient information to show that lodgepole pine responds positively to fertilization in interior forests, although much less research has been done on this species than on coast Douglas-fir. Lodgepole pine stands are therefore our first preference for fertilization in interior forests. Stands of lodgepole pine that also include spruce (*Picea engelmannii* and *P. glauca*), western larch (*Larix occidentalis*), or transition or interior wet-belt Douglas-fir are also fertilized. At present we do not treat stands of western redcedar (*Thuja plicata*), western hemlock, black spruce (*Picea mariana*), or interior dry-belt Douglas-fir, since we know virtually nothing of their response.

With species criteria met, we then consider site quality. Site quality ratings are listed as good, medium, poor, and low, in declining order. Poor and medium quality sites are preferred, since greater relative response is obtained. Stands on high quality sites are acceptable but are of lower priority, and we do not treat stands on the lowest quality sites.

Soil moisture regimes are considered, with the intent of avoiding sites where moisture is limiting tree growth either by deficiency or by excess. We thus prefer sites with moisture regimes representative of average conditions and do not treat very dry or very wet sites.

Stand age is important. Biologically, it is usually preferable to fertilize a young, developing stand than treat a more mature one, because nutrient demand is much higher when a tree is still building its crown mass. For this reason we give preference to younger stands, often 15 to 20 years old, especially since many lodgepole pine stands have regenerated after fire and are deficient in both nitrogen and sulfur—elements lost to the atmosphere by burning.

Research indicates that fertilization response is strongly affected by tree spacing, since trees need room to grow and unthinned stands offer little surplus growing space. We therefore fertilize only stands that have been precommercially thinned, or that will be thinned within a year of fertilization. Already thinned stands are preferred because the trees have had time for root systems to expand and stems to increase in diameter, thereby providing more stability when snow accumulates in the denser crowns that result from fertilization response. Fertilizing only thinned stands gains efficiency by promoting uptake of added nutrients by potential crop trees left after thinning.

In precommercially thinned stands selected for fertilization, leave-tree density must be specified based on the desired tree size at the first merchantable entry, or at rotation if no commercial thinning is planned. This is most important and requires a degree of imagination because the stand must be envisioned as it will exist some 15 to 20 or more years in the future, considering how crowded those very much larger trees will be. Fertilization accelerates normal stand development in responsive stands, and is accompanied by a considerable increase in crown mass. It is easy to underestimate the amount of room fertilized trees will need, and how rapidly that need will occur.

In order not to waste the fertilization investment by obtaining only a short response before these now rapidly growing stands close in and start to stagnate, priority has to be given to more widely spaced (e.g., 4 x 4 m) than more narrowly spaced (e.g., 3 x 3 m) stands. Stands spaced at less than 3 m should not be fertilized, because they will close in quickly and we assume the investment will be wasted.

Another basic biological characteristic to check is crown condition. Short or narrow crowns will benefit most from fertilization by increasing their mass, but little extra wood will be produced until after the crown mass has been adequately built up. Larger crowns will enable a more rapid increase in wood production, provided space for crown expansion is available through adequate tree spacing.

Foliage color and crown deformities are useful indicators of nutrient deficiencies, which should be further investigated by collecting samples for foliar analysis. Guidelines for sampling are established and the samples are run through a comprehensive analysis for a wide range of macronutrients and micronutrients. To date, we have found that lodgepole pine is consistently deficient in nitrogen and sulfur and that boron deficiency is widespread in the Prince Rupert, Prince George, and Cariboo Forest Regions.

The final biological characteristic evaluated is the prevalence of pests in the form of insects, disease, and small mammals. An acceptable degree of damage can vary by pest and by severity of impact. Much work remains to be done to quantify the real impacts of pests in terms of volume and value. We need ways to treat pests other than by just leaving extra trees in case some mortality occurs. Maintenance of a healthy forest is the key issue.

Operational Factors

Stands which pass the biological evaluation are next evaluated for operational feasibility to ensure that they can indeed be fertilized without incurring excessive costs. In this step, the first factor considered is distance from major highway or railhead, since distance affects fertilizer delivery costs. Obviously, closer stands are preferred.

Stand accessibility is a major consideration, affecting fertilizer delivery, ease of project layout, supervision and monitoring, and flight costs. Top priority goes to stands accessible from public highways and good forest roads, with those accessible by roads that require repairs or improvements ranking lower. If new road construction is required, we do not fertilize.

The need for road upgrading may depend on the equipment used by different contractors. Large helicopters and prebagged fertilizer require much larger heliports—and security for the stored bags—than operations with small helicopters using fertilizer delivered directly to heliports at the time of application. As a minimum, access to heliports must be suitable for trucks carrying large loads of fertilizer in all kinds of weather. Actual details are determined with individual contractors, but basic requirements are that heliports be no more than 1.5 to 2 km from the stand to be treated and at a higher elevation, if possible, to facilitate aircraft lift.

In considering the type of aircraft and the fertilizer transport and application systems to be used, flexibility and maneuverability are essential. Terrain and availability of landing facilities strongly favor the use of helicopters. In the fertilization program in coastal forests that ran from 1978 to 1982, fertilizer was prebagged into 1,500 kg loads and applied with a Bell 205 helicopter. This system had been developed for large, regular-shaped blocks on gentle terrain. As the second program under FRDA developed, many blocks were smaller and irregularly shaped, especially in interior forests. As a result, an application system using the smaller Hughes 500 helicopters, loaded by modified grain delivery trucks with an on-board weigh scale, became very competitive.

Slope is considered since it affects aircraft operations and also groundwater movement of fertilizer. Flat to gently rolling terrain is preferred, and steeper slopes (>40%) are rejected at present. But some local hills or high points are necessary as sites for the transponder component of the aircraft navigation system, used for accurate fertilizer application.

The individual stand or block size, and project size, achievable by aggregating adjacent blocks is an important operational consideration, with obvious economies of scale. Regular block shapes are preferable to irregular ones, although irregularity is often the reality reflecting the fire and logging history of the area. Block shape affects flight operations as well as the establishment of boundaries and the accuracy of application.

Season of year and climate also have to be considered for operations. Urea fertilizers should be applied in cool, moist conditions to preclude loss of nitrogen by volatilization and to promote dissolving and movement of nitrogen into the soil. For practical purposes this means early to mid-autumn in a normal year. Winter snowpack on forest roads generally prevents access in the spring, and fertilizing on deep snow is to be avoided due to potential runoff losses. When considering climate on a broad scale for operations, we can obviously start fertilizing earlier in the northern interior than in the southern interior, so schedules are set accordingly.

A final operational consideration is to check for any other uses or users of the land area to be fertilized, especially cattle grazing and domestic water supplies.

In 1986 some cows dined on spilled fertilizer in the Kamloops Region, but they did not grow too well afterward. In fact, they were probably the most expensive cows ever produced in that area. In retrospect, it was a cheap and useful lesson for the Forest Service and our contractors.

Wood Supply Factors

The third and final step uses wood supply considerations to rank operationally viable stands for treatment priority. This evaluation includes attention to such management objectives as mitigating reduction of allowable cuts, improving tree size or age class distribution, and achieving targeted wood product or species distribution. Obviously, priorities will differ according to individual Timber Supply Area (TSA) wood supply positions.

Age was discussed previously under biological characteristics and may also need to be viewed in relation to wood supply, especially if age class structure is limiting supply. First priority should be the age class needed to alleviate any future supply shortage. Tree size class may also affect priority, in regard to merchantability limitations. Consideration of the length of time between investment and payback would suggest that nearly mature stands should have priority for treatment. However, such stands are almost completely unmanaged in interior lodgepole pine, and response can be expected to be more limited, even after noncommercial thinning or partial harvesting.

The final wood supply factor considered here is distance from the candidate stand to mill site (or permanent marshaling or transfer point). Obviously, shorter distances are preferred for log transport.

In concluding the stand evaluation process, although many stand characteristics are considered, we do not rank stands by totaling priority points, since it is not possible to assign really meaningful weightings between factors. Since we have not had extensive areas of thinned lodgepole pine available that met all requirements, the three-step evaluation process has so far made it possible to select the stands for treatment without need for specific additional criteria. It is also essential to allow the field staff some room to use initiative and flexibility in stand selection. However, any stand that receives one or more "do not treat" rankings should be rejected for fertilization.

Operations

Forest Service activities start the year before fertilizer is to be applied. The District staff first selects candidate stands using the three-step process just described. In addition, a field examination is made of access roads to determine if any upgrading is needed to accommodate heavy truck traffic, keeping in mind that the application will be done in the autumn and early winter when heavy rains can deteriorate an otherwise adequate road. Potential heliports are identified, although final locations will be up to the contractor, based on the requirements of his particular aircraft. Once stands are identified and access checked, a proposal is submitted from the District to the Regional Office indicating which stands or blocks are to be treated, describing access and distances involved, and listing the areas in hectares.

The next April, after budgets are approved, the Regional Office consolidates several District submissions into a Regional program and develops advertisements for an information presentation that we call an "office viewing." The Region also advises Silviculture Branch of its fertilizer needs in terms of nutrient content (N, S, and B), amount, and delivery locations.

We use a request for proposals instead of a tender for low bid, since we have particular concerns about accuracy of application for economic, biological, and environmental reasons, and we have logistical concerns when scheduling operations over such a large province during a fairly short operating season. In our proposal guidelines we require contractors to provide details on equipment and how they will use it, their experience, personnel, and other details, as well as cost estimates. This enables us to make a comprehensive evaluation of a contractor's ability to accomplish a quality project, as well as doing it economically, and facilitates selection of the best overall contractor for the job, not just the cheapest. Low bid tenders could put us in the difficult position of having to accept a cut-rate contractor, with the probability of poor quality of application and all its consequences.

The Regions notify us at Silviculture Branch of their fertilizer needs so that we can take advantage of economies of scale in purchasing the fertilizer and so that deliveries can be coordinated. Our prescriptions are for 435 kg/ha of urea (46% nitrogen) in coastal forests and the same application rate of fertilizer in the interior but with a 40% nitrogen content plus 12% sulfur. We treat boron deficiencies by adding boron at 3.5 kg/Mg of fertilizer.

Fertilizer is applied using a 50% overlap on each successive swath to give sufficiently even ground coverage. Our preferred fertilizer has been forest-grade urea and urea-sulfur procured from Cominco in Calgary. In this product, micro-fine elemental sulfur is integrally combined with urea during the urea melt stage of manufacture; and boron is similarly added. This results in a superior product: each pellet is a composite of elements and there are no settling out or coating abrasion effects during transport. Unfortunately, Cominco's Calgary plant had to be dismantled because of old-age problems. We are going to have to consider the less desirable alternative of blending agricultural grade products, with different particle size and shape, to give the required elemental proportions of nitrogen, sulfur, and boron. Such a blend tends to stratify during transport, compounding the application problems that already result with particles of different sizes and shapes having different aerodynamic properties.

Since the number of potential contactors is limited, our office viewings are coordinated and often combined in order to save time and travel. For example, we usually hold a Northern Interior viewing at Prince George, where staff from the Prince Rupert, Prince George, and Cariboo Forest Regions each present details of their Region's fertilization program to a group of contractors. Guidelines for proposals are also presented so that contractors know the full range of information we are looking for. These office viewings are usually held in May, with a coordinated provincial closing date for submission of proposals usually set for late June. If contractors so desire, they can contact District staff to arrange a field viewing of treatment areas, road access, potential heliports, and so on.

After the closure date for submission of proposals, a representative from each Region and a Silviculture Branch coordinator meet to evaluate them. Awarding contracts includes ensuring that contractors are not overcommitted between Regions and that a balance is obtained that will result in a good job being done at a competitive price without undue scheduling complications.

With contracts awarded, the Regional Stand Tending Forester sets up a work progress plan with the contractor. This plan details the order in which blocks are to be treated and provides for sufficient equipment and personnel to complete the project on schedule. In 1989, contractors were given the responsiblity of subcontracting and scheduling the transport of fertilizer from the manufacturing plant to field sites, under the assumption that costs would be lower. (Prior to 1989, the Forest Service had included transport in the fertilizer supply contract.) I am not persuaded that this subcontracting arrangement actually resulted in a lower transport cost, since several smaller transport contracts were used rather than one overall provincial contract. The work load on Forest Service staff was reduced slightly, but I believe we need a more careful investigation of costs and benefits.

Our contracts detail start and finish dates, obligations of both parties, scheduling, standards of performance, payment, suspension and cancellation, fire prevention, liabilities, and operational specifications including provisions for environmental protection. These documents do not make light and exciting reading, but they are concise and to the point. Operations are not begun until cool, and preferably also moist, weather arrives in September or October, because we do not want to lose fertilizer to the atmosphere by volatilization. We also try to complete operations before a permanent winter snowpack is established. The time frame can therefore be quite tight.

Monitoring

Treatment Monitoring

An important District task during operations is treatment monitoring. We monitor application rate and accuracy for several reasons. First, the cost of fertilizer and its application is such that we want to be sure it is applied as uniformly as possible in the right place—we do not want it wasted. We also do not want significant under- or overapplication since response will not be sufficient in the first case and we get into declining returns in the second. Predictable gains in wood production depend on adherence to the prescription. Finally, we are concerned with accurate application for environmental reasons.

We have always insisted on use of an electronic navigation aid such as the Del Norte "flying flagman." As a result, some field staff developed an undue faith in the innate ability of a pilot to apply fertilizer in exactly the right amount in exactly the right place, without bothering to check if it really happened. Unfortunately, neither the equipment nor the pilots have attained infallibility yet, so we have developed an application monitoring procedure.

Our first effort was with traps to catch falling pellets. These 0.5 m^2 traps consisted of a circular rim supported on three legs and holding a tapered mesh net that guided pellets into a funnel container. After sampling, the contents of the funnel were emptied into a calibrated jar to determine the weight of pellets. A simple formula then gave an estimate of the application rate. Although the traps worked well as interceptors of pellets, they were limited in effectiveness for the following reasons: (1) they can be used only in open areas like landings or roads which run at right angles to the flight line and where there is no interception by tree crowns; (2) they blow over in light winds; (3) they are difficult to carry over slash and through trees; (4) they require level or gently sloping ground; and (5) a large number are needed to give valid results. Considering these problems, we had to develop a different method.

Application rate is a known function of fertilizer drop rate, airspeed, swath width, and swath overlap percentage. For each contractor, the drop rate and airspeed are calibrated under operational conditions before the start of operations. Swath width and swath overlap are easily measured on the ground using different colored flagging to mark the leading and trailing edges of each swath. A set of simple formulas has been developed so that with drop rate and airspeed known and swath width and overlap obtained through direct measurements, application rate per hectare is easily calculated. Swath width and overlap give a measure of application uniformity, as well as enabling a valid estimate of total fertilizer applied per hectare. If a contractor gets swath width, swath overlap percentage, and the per hectare application rate right, then we have a satisfactory performance. An acceptable application rate is within 10% of the target rate.

Environmental Monitoring

Although fertilizer is generally seen as a benevolent chemical, we take preemptive care to apply it accurately so that public attitudes remain supportive and we do not end up with the same concerns as are being expressed for herbicides. In addition to the compulsory use of electronic navigation equipment, treatment block corners and boundaries are marked on the ground so as to be visible from the air.

Maps and air photos with treatment block boundaries are also supplied to the contractor by the Forest Service. Before treating a block, the pilot will fly over such corner markers and log their coordinates into the flight computer to produce baselines for electronic guidance, thus ensuring careful application within block boundaries. In addition, before operations start, any water bodies or other sensitive areas are identified in consultation with wildlife and fisheries agencies, and appropriate buffer zones are demarcated to ensure they are not treated with fertilizers.

If livestock are grazing in project areas, coordination is required with the District Range Officer and the rancher to make sure that the cattle will not be there when operations begin. Contract requirements also stipulate cleanup on a daily basis of any fertilizer spilled at operational sites, since urea is toxic to wildlife and cattle if enough is eaten.

We have carried out several water quality studies in association with fertilization operations, and no significant changes to water quality have been detected.

Response Monitoring

Although keeping weather records during and after operations would seem to be a form of environmental monitoring, it is done mainly to help interpret stand response in the event that it varies from expectations. For example, hot, dry weather after fertilization can result in significant urea losses due to volatilization, with a consequent reduction in tree growth response. Unless we keep weather records for the period from application to the first significant precipitation, we will not be able to account for such variations.

Stand growth and yield responses are measured through the establishment of inventory plots in operationally treated stands, with controls in unfertilized stands having similar characteristics. An installation consists of a minimum of two samples, one in the treated area and one in a control. Each treatment and control sample consists of a minimum of four circular plots with a radius of 12.62 m (0.05 ha). All trees in each plot are tagged. Measurements taken for each plot include: (1) dbh on all trees; (2) top height of either ten trees or 25% of the trees with the largest dbh, depending on the number of trees per plot; (3) age; (4) crown dimensions (length, width, height to live crown, plus color and vigor); and (5) increment cores taken from the height trees. Pest and disease information is also recorded.

These plot installations are established before fertilization and are then scheduled for remeasurement at 5 and 10 years after treatment. We in Silviculture Branch have been having some differences with our mensurationist colleagues in Inventory and Research Branches regarding response monitoring. We want to obtain fertilization response data but they will provide only stand growth trends, since the data from these installations are not believed to be "statistically significant." Detailed response data are being obtained from research installations that are uniformly fertilized by hand rather than by aircraft, leaving us with the problem of incomplete research-operations linkages for response predictions.

Information Needs

Operationally valid growth and yield predictions for treated stands are at the top of the list of information needs. We do know some details but they are far from complete, and many species are totally lacking in fertilization response data. We need reliable predictive information across age classes, by site class, and for more of our commercial tree species.

The second greatest need is for a much better definition of wood supply and wood product objectives, by species and by Timber Supply Area (TSA), so that fertilization operations can be better focused for more economic returns.

My final information need deals with fertilizer availability. I noted earlier the demise of Cominco's plant in Calgary where they made a very uniform product with good aerial distribution properties. We may now have to live with a second-best alternative of blended agricultural fertilizers that can be expected to give variable distribution, and consequently variable results. I see a need for a major investigation into the possibility of using soluble fertilizers that could be applied as liquids. In theory, the addition of different elements would be very easy. However, we need information on such things as the stability of products in a mix, problems of detrimental effects of solutes on application equipment, the amount of fertilizer we can expect a tree to take up in its foliage in one application, and degree and duration of response. Application timing would have to be determined so that the foliage would not be burned. Another obvious question is the cost of this approach. This is a large and fascinating area for research, and we would welcome its being addressed.

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