Chapter 14

Considering Fertilization in Forest Management Planning

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ABSTRACT. Forest fertilization in national forests should be considered within the framework of forestwide land management planning, where multiple-use direction allows this practice. Methods used by the Mt. Hood National Forest in Oregon, as well as other forests west of the Cascade Range, are described and illustrated. To optimize long-term sustained yield, fertilization is modeled using tools such as DP-DFSIM and FORPLAN, to compare mean annual increment at culmination (CMAI) and present net value (PNV) of entire rotations with and without fertilization. DP-DFSIM indicates that a single fertilization may increase growth 7-11% on a stand over a rotation. Forestwide analysis (FORPLAN) indicates an increase of 3.5% in the annual allowable sale quantity (ASQ) for the Mt. Hood National Forest, but many acres approved for fertilization would wait a decade, for economic reasons, while the goal would still be to optimize long-term volume growth. This "allowable cut effect" allows the gain from fertilization to be taken now. Methods include: modeling a single application of fertilizer ten years prior to the first commercial thinning in all land allocations where it would help meet management objectives; and simulating forestwide development and harvest schedules under selected intensive management regimes. When modeling the desired future conditions on a forestwide basis, it is important to consider fertilization not only to increase volume growth but also to meet other resource objectives.

After stand-level decisions regarding fertilization are made, the next step the Mt. Hood National Forest takes is to incorporate those priorities into forestwide modeling and planning. This level of planning spans periods up to 150 years and goes beyond current stand-level decisions and budgets. Fertilization assumptions on growth increases, amounts, and timing are incorporated into the long-range planning process just the same as assumptions for other silvicultural practices.

The overall framework of going from stand-level decisions to forest management planning fits within the Forest Planning System. This is described here to provide a better understanding of the arena in which the U.S. Forest Service operates. The newly completed Forest Land and Resource Management Plans in Oregon and Washington (primarily west of the Cascade crest) give direction on where to apply fertilizer, when we will take the gain from it, and predictions on how much gain will be observed. It then becomes a process of implementing, monitoring, and evaluating our assumptions that were modeled in the Plan. It is critical to understand this process, otherwise one could look to the Forest Plan economic modeling outputs as the final decision, which they are not.

Modeling fertilization forestwide takes tools such as FORPLAN (a land use allocation and scheduling computer model) to incorporate land allocation decisions with yield tables that have fertilization included. This discussion will attempt to make clear what modeling assumptions have to be made in order to determine the long-term sustained yield from a national forest. The policy of nondeclining flow of timber, combined with the allowable cut effect, shows that the gain from fertilization in young stands can be realized immediately by harvesting older stands in the first decades. The design of FORPLAN to optimize yields leads to some interesting outputs.

Finally, discussion will center on fertilization interactions with other forest uses and values. The Washington, D.C., Office of the Forest Service points the way by declaring that "fertilization can meet objectives of other resources as well as timber management through coordination." We will look at specific land allocation practices on the Mt. Hood National Forest that follow this direction. There are numerous land allocations, even where timber harvest is limited, on which fertilization can help produce desired future conditions. The Forest Plan, combined with human creativity, can

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incorporate fertilization in management not just to increase timber yields but to meet other resource objectives as well.

The Forest Planning System

Policies regarding fertilization from the Washington Office and Regional Office drive the forest-level planning process of the Forest Service. Reviewing this first allows a better perspective and displays the foundation of our decisions.

These major points are from the Forest Service Manual (USDA Forest Service 1990*a*):

1. Consider forest fertilization on an operational basis only where research indicates a reasonable assurance of the desired response, economic analysis reveals an acceptable return, and the treatment meets multiple-use direction for the site.

2. Although the economic analysis within the framework of the Forest Plan provides information on the types and amounts of TSI (timber stand improvement) needed, further economic analysis may be necessary to determine the most cost-effective method to carry out a treatment or to set priorities between projects when all of them cannot be financed.

3. Fertilization can meet objectives of other resources as well as timber management through coordination. Mitigation of some fertilization activities may be necessary to accommodate specific needs of other resources on specific areas.

Regional and forest-level policy follows this very closely and gives some additional detail as to how to carry this out: (1) Fertilization may be done in established stands where research or studies predict gains in volume or value. (2) Predicted effects should be included in an environmental analysis. (3) Fertilization should be based on a silvicultural prescription containing appropriate supportive information including stand examination data, economic evaluation, and multiple-use direction. (4) Established studies should be continued for at least ten years following treatment.

The Forest Planning System, as outlined by the National Forest Management Act (NFMA) of 1976, is illustrated in Figure 1, and the steps involved in planning fertilization on a forestwide basis are discussed below.

Planning

The Mt. Hood Forest Plan gives direction on: land allocations where fertilization is allowed, species groups and soil types where fertilization is allowed, stand prioritization processes, forestwide yield projections

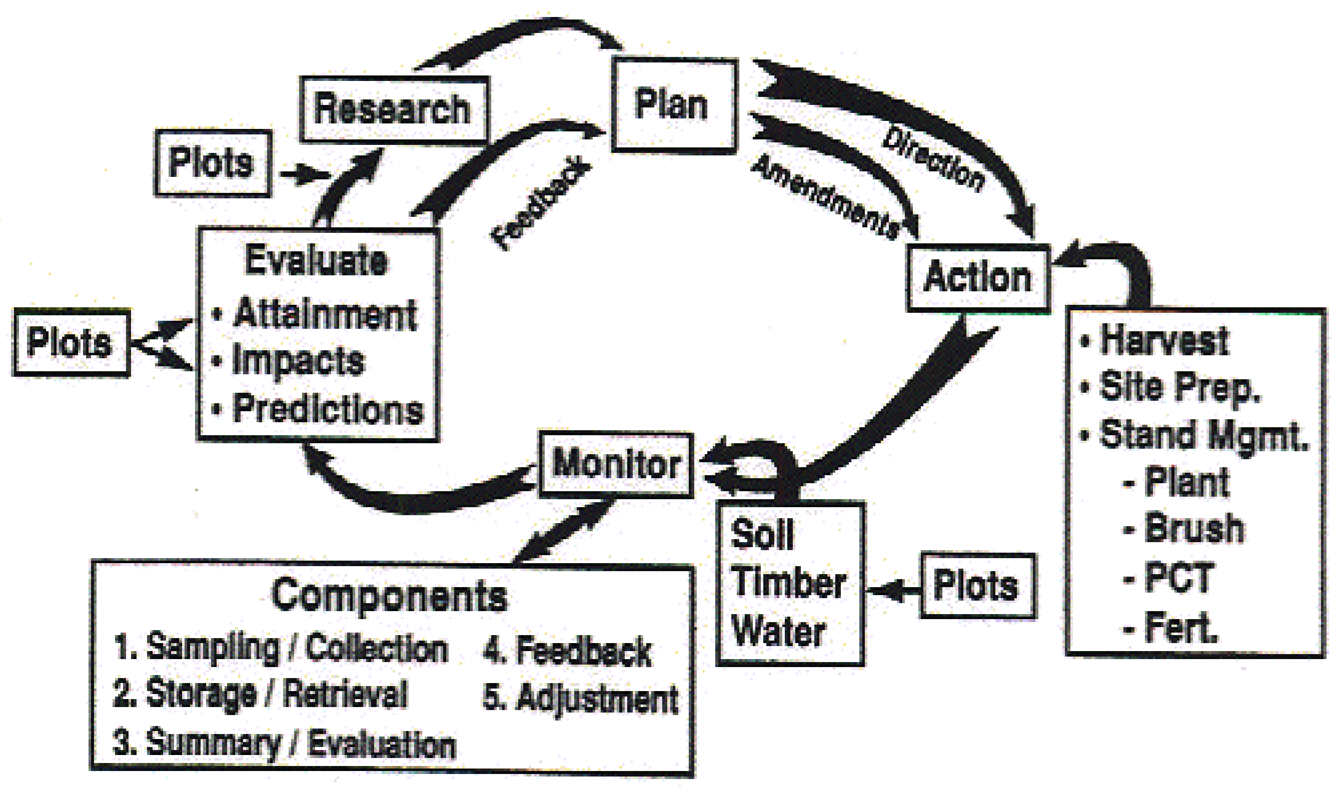

Figure 1. The Forest Service operates under the Forest Planning System from direction in the National Forest Management Act (NFMA) of 1976.

with and without fertilization, forestwide economic analysis decisions, long-range planning over a 150-year horizon, and when the gain from fertilization will be taken. If fertilization will help meet the desired future condition of certain land allocations, it is allowed as a management tool. Species groups and soil types are determined to be responsive to fertilization if research plots or studies demonstrate gains in volume or value. Soil types that are similar in nature to "proven" soil types are also included in the land base that could be fertilized.

Action

Action decisions automatically follow the policy and direction outlined above in the Forest Plan. This step involves the following: how many acres to fertilize on the forest per year or per decade, stand-level decisions regarding priorities for stand treatment and economic analysis of groups of stands, and operational decisions, such as multiple-district aerial fertilization contracts.

Selection of candidate stands for fertilization is done by prioritizing according to Regional policy and Forest Plan direction, based on physical, stand, and economic characteristics. Physical characteristics to consider include proven land type, site quality, and land classification. Stand characteristics include species composition, live crown ratios, general vigor and growth, stocking levels, and levels of *Phellinus* infection. Economic considerations include the sizes of crop and excess trees; the next anticipated commercial entry, commercial thin, or regeneration harvest; the size and distribution of areas to treat or access; and other operational factors. An example of priorities for stand treatment can be seen in Table 1.

Table 1—Example of how stands may be prioritized on a forest. For all stands, Douglas-fir makes up 60% or more of the crop trees, live crown ratios average 30% or more, and *Phellinus* incidence is less than 10% of the stand.

Priority	Site Class	Age	Commercial Entry Age	Soil Rating
1	IV	25 - 35	45	1
2	IV	25 - 35	45	2
3	IV	55 -100	65-110	1
4	IV	55 -100	65-110	2
5	III	25 - 35	45	1
6	III	25 - 35	45	2
7	III	55 -100	65-110	1
8	III	55 -100	65-110	2

Monitoring

This step is essential if we are to validate on the ground what we say we are going to do in the Plan. Steps involved in this phase include: monitoring accomplishment of acre targets; setting up administrative studies to be continued and measured for a minimum of ten years; and installing plots to measure (1) growth response in height, diameter, and volume, and (2) water quality.

Evaluation

The final step, which provides feedback to the Forest Plan, in all probability will lead to amendments and changes to the Plan. This cycle of validating our assumptions in the Plan is crucial to good land stewardship. During the evaluation step, the following are reviewed: (1) attainment of acreage targets over the years, (2) impacts on all resources, (3) predictions made of gains at the forest level and stand level, and (4) research plots from the Regional Forest Nutrition Research Project (RFNRP).

Now that we've come full circle in the Forest Planning System, let's go back to the Plan and discuss how fertilization responses are modeled, and the assumptions that are made at the forest level.

Modeling Fertilization on a National Forest

The methods illustrated here for the Mt. Hood National Forest offer several points of general interest; however, they are intended to be examples only. Different forest inventories, financial situations, and objectives result in different outcomes from forest to forest.

To analyze and model fertilization, the following steps are taken: (1) fertilization responses are projected at the stand level on a per-acre basis and economic opportunities are analyzed on a per-acre basis; and (2) fertilization responses are projected at the forest level by simulating forest development, harvest, revenue, and costs under intensive management at various levels.

Step 1. Projecting Fertilization Responses at the Stand Level

Fertilization responses at the stand level were obtained using the DP-DFSIM model (Dynamic Programming version of the Douglas-fir Simulator) (see Johnson and Sleavin 1984). Fertilization plot data from Oregon and Washington are included in this model. These yield tables were developed only for the Western Hemlock and Pacific Silver fir Plant Association zones, where Douglas-fir would be the primary crop species under management. (This represents 65% of the Mt. Hood National Forest). Three average site indexes were modeled to represent this total area (Ellen and Daoust 1990).

Numerous yield tables were developed with DP-DFSIM until the optimal volume-producing intensities were found. Those optimal intensities that had the highest present net values (PNV) were selected as the final yield tables to be entered into the forestwide model. An example of the different silvicultural intensities that were selected to be modeled for managed stands can be seen in Figure 2.

Since DP-DFSIM is an optimizing model, it displayed the intensity regime that would give the highest mean annual increment at culmination (CMAI) and also the best present net value of all the similar intensities. Choosing the best combination of CMAI and PNV narrowed the number of yield tables to 34, most of which had fertilization included, but some did not.

Certain limitations should be kept in mind when using this optimizing model: (1) One application of fertilizer, not multiple applications, gives a gain that best fits the plot data. (2) Since it is a Douglas-fir model, the per-acre gains may be optimistic for other species in

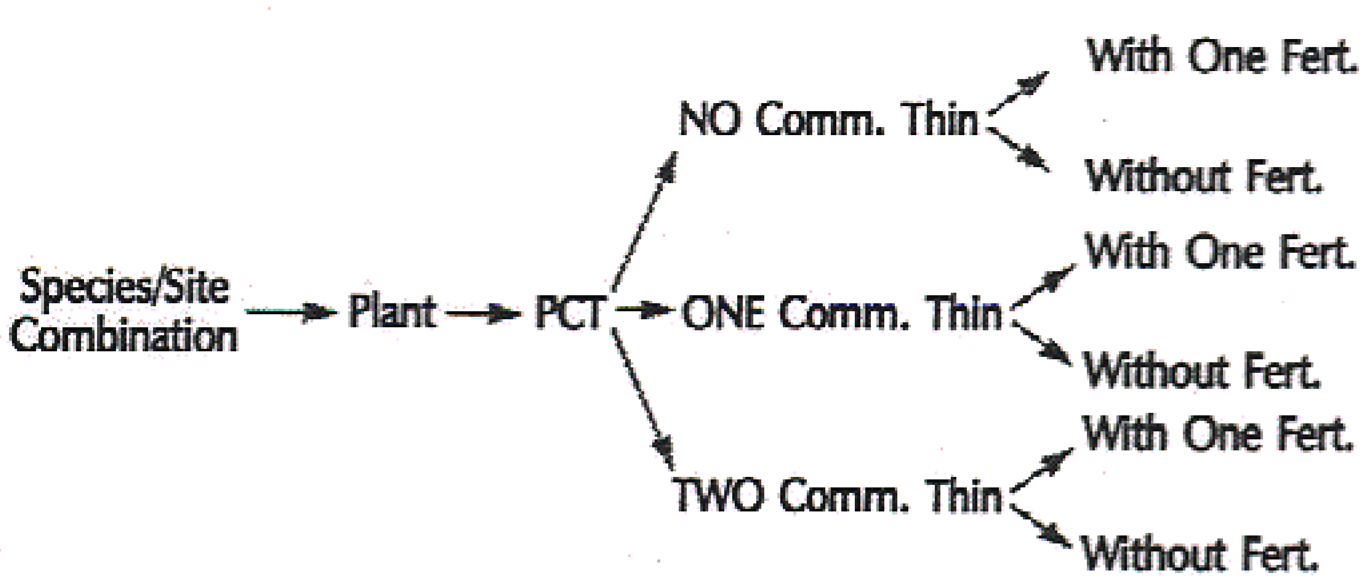

Figure 2. Example of the silvicultural intensities that were finally selected to represent the optimal choices for managed stands forestwide.

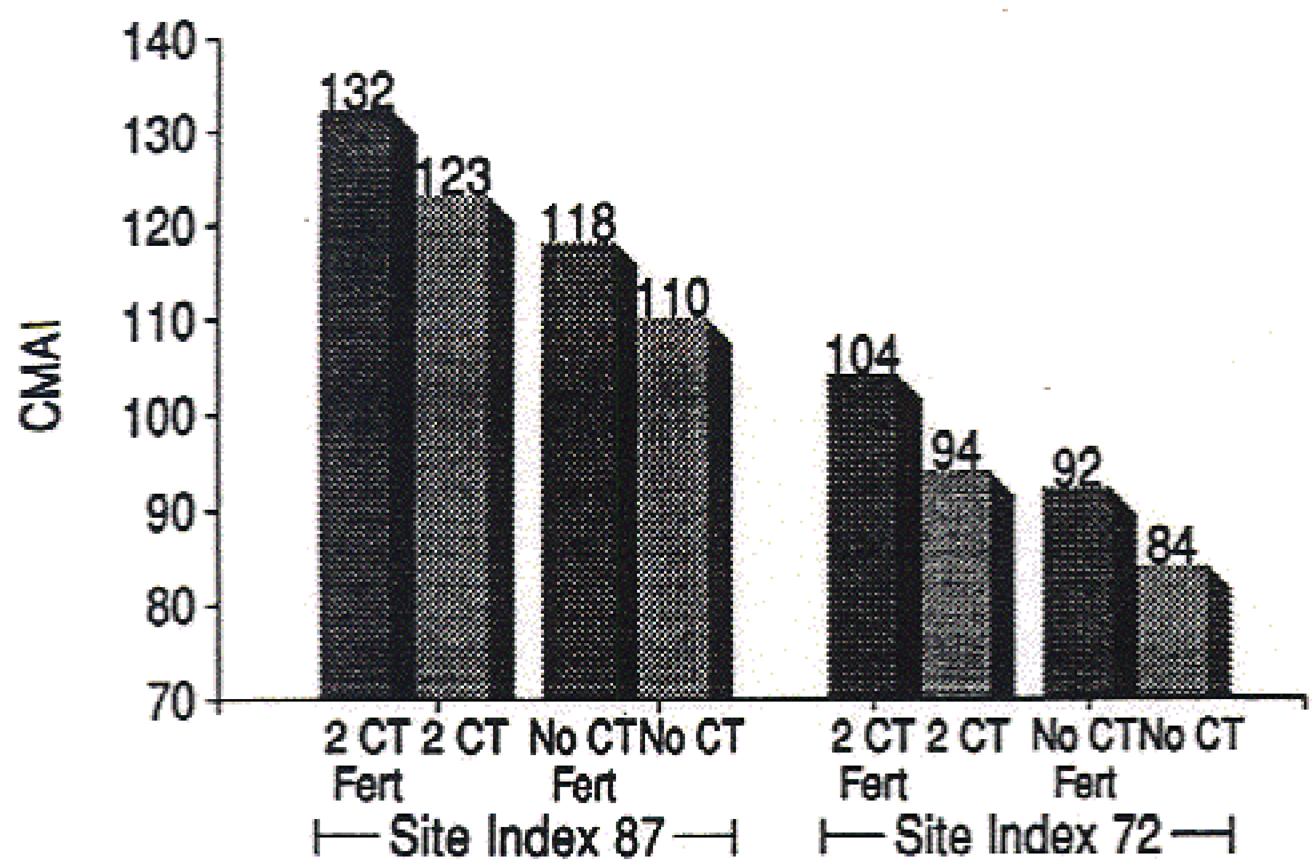

Figure 3. Optimal Douglas-fir yield for the Western Hemlock Zone. Examples of the percentage increase in CMAI experienced from fertilization on a per-acre basis, compared to no fertilization in the same yield table. Site index has a 50-year base (King 1966), and culmination of mean annual increment (CMAI) is in ft³/acre per year. Rotation lengths for these yield tables range from 75 to 115 years for site index 87, and 85 to 125 years for site index 72. (CT = commercial thinning, Fert = 200 lbs N/acre 10 years before CT).

stands. (3) Operational falldown is not represented in the gains observed from fertilization.

By comparing optimal intensities with and without fertilization, it was observed that this model, when given the option to fertilize, always chose to do one fertilization (at 200 lb N/acre as urea) ten years prior to the first commercial thinning—usually at age 35 or 45, depending on when the thinning occurred. Figure 3 displays some of the comparative CMAIs. This shows for the Western Hemlock Zone, with two site indices, that yield tables with fertilization would produce a 7.2 to 10.6% increase in CMAI over one rotation, compared to the same yield table without fertilization. This varies by species zone and site index.

The next step, projecting forestwide response to fertilization, involved taking these 34 yield tables from DP-DFSIM, combining them with 15 yield tables from the Prognosis model (for the east side of the forest) (see Stage 1973; Wykoff et al. 1982), and 40 empirical yield tables (for existing stands) from the Vegetation Inventory. All of these were available in the forestwide model described next.

Step 2. Projecting Fertilization Responses at the Forest Level

Projecting forestwide response requires taking the per-acre responses in the stand-level yield tables and applying them to the appropriate acres on the forest, then calculating long-term sustained yield (Forest Service Policy) that will not decline over time. The model

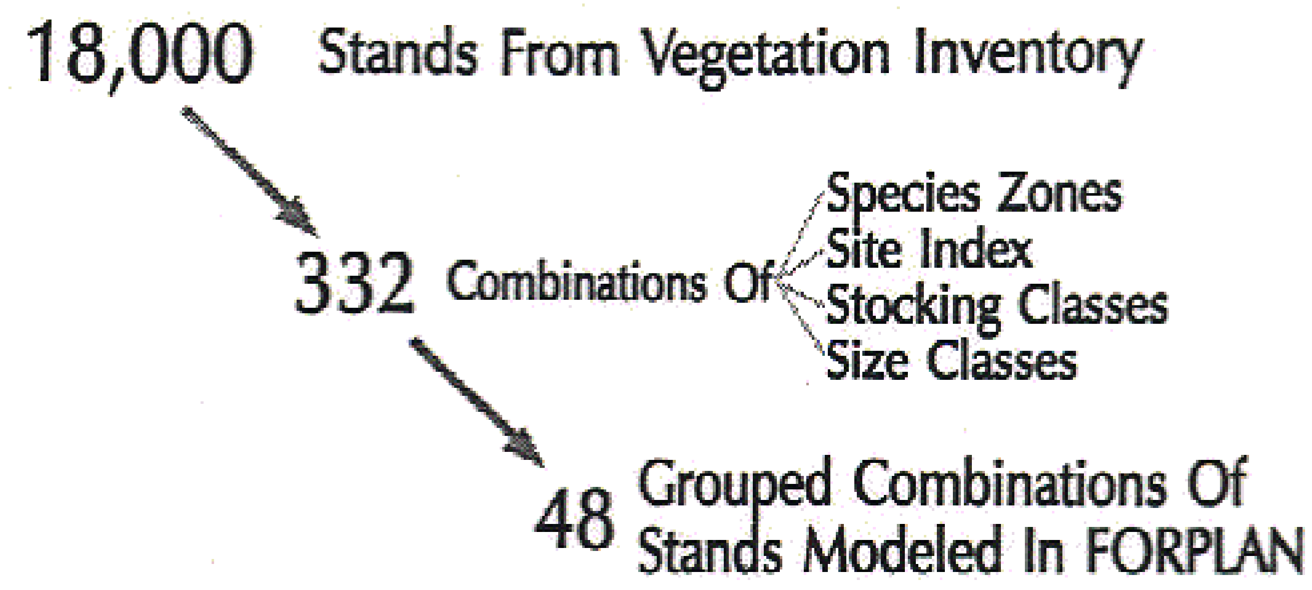

Figure 4. A perspective on decisions that are necessary in order to have a manageable forestwide model (FORPLAN).

that can do this is called FORPLAN. The Mt. Hood National Forest used this model to optimize outputs of commodities on a forestwide basis. FORPLAN does optimize, so the result of the final allowable sale quantity (ASQ) that is calculated is a combination of its efforts to select the highest volume-producing yield tables and its efforts to seek the most economical decision paths. The planning horizon is multiple rotations, usually 150 years into the future. Other multiple-use decisions are obviously made outside this model, or hard-wired into the model so as to end up with professionally acceptable answers.

The number of decisions FORPLAN has to make is tremendous, and to expect to model every stand on the forest is not practical. Judgments have to be made as to what factors to model, how many groups of stands to model, and how many land allocations will be represented. Figure 4 displays this narrowing down of the stands to a size that can effectively be modeled in FORPLAN. Obviously, and intentionally, this model is just an approximation and does not represent each stand accurately. It should be mentioned, however, that the 48 grouped combinations of stands modeled in FORPLAN all have statistically sound samples from the Vegetation Inventory, and this was a major factor in decisions to decrease model complexity.

The FORPLAN outputs are numerous, but those of interest in this discussion are the ASQ calculated with and without fertilization and the number of acres FORPLAN chooses to fertilize in each decade. Using the results of the specific yield tables that included fertilization, the specific acres that allowed fertilization, and the timing of harvests on those acres, FORPLAN calculated a 3.5% increase in long-term sustained yield ASQ for the Mt. Hood National Forest (See Figure 5). The ASQ level is 30.8 million cubic feet per year without fertilization and 31.9 million with fertilization. This gain is equivalent to a 6.2 million board feet timber sale on a district in any given year!

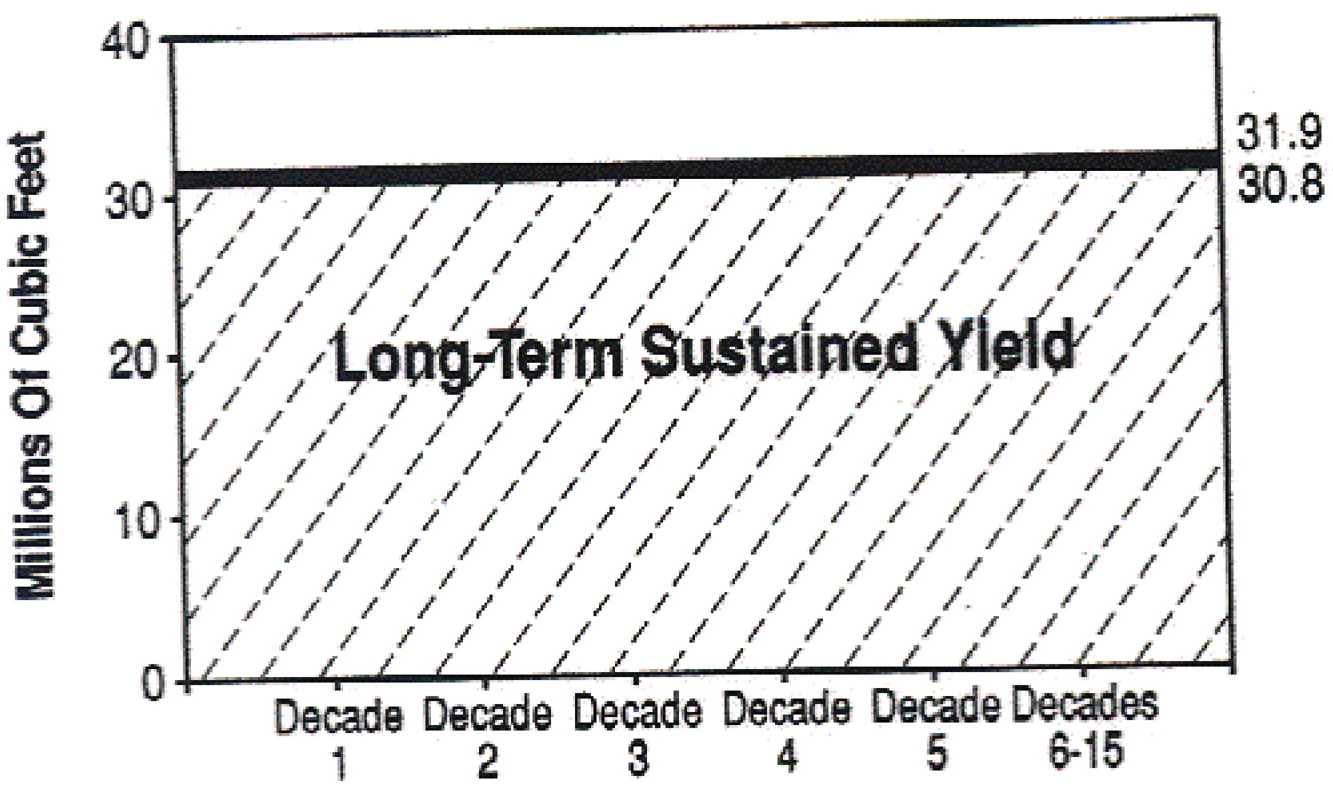

Figure 5. Fertilization on the Mt. Hood National Forest increased the yearly ASQ (long-term sustained yield) by 3.5% (1.1 million cubic feet per year).

The actual stand level gains from fertilization are obviously realized at the time of commercial thinning and/or regeneration harvest, with increased cubic foot volume. When to take the credit for this gain is another decision. Credit could be taken: (1) in *future* decades from volume gain directly from younger stands that respond, as shown in Figure 6; or (2) *now*, from the allowable cut effect (see below), where, given a policy of long-term sustained yield, harvest levels are held constant, and current harvest levels are directly sensitive to current and future growth rates.

The Mt. Hood National Forest policy is to follow a long-term sustained yield approach to timber harvest, mainly for local community stability in timber products, jobs, and cash flow to local counties. This allows the forest to realize the gain from fertilizing now, because mature or overmature stands in the forest inventory provide flexibility to harvest immediately extra growth gained from fertilizing immature stands. For example, when growth is increased by fertilizing young stands,

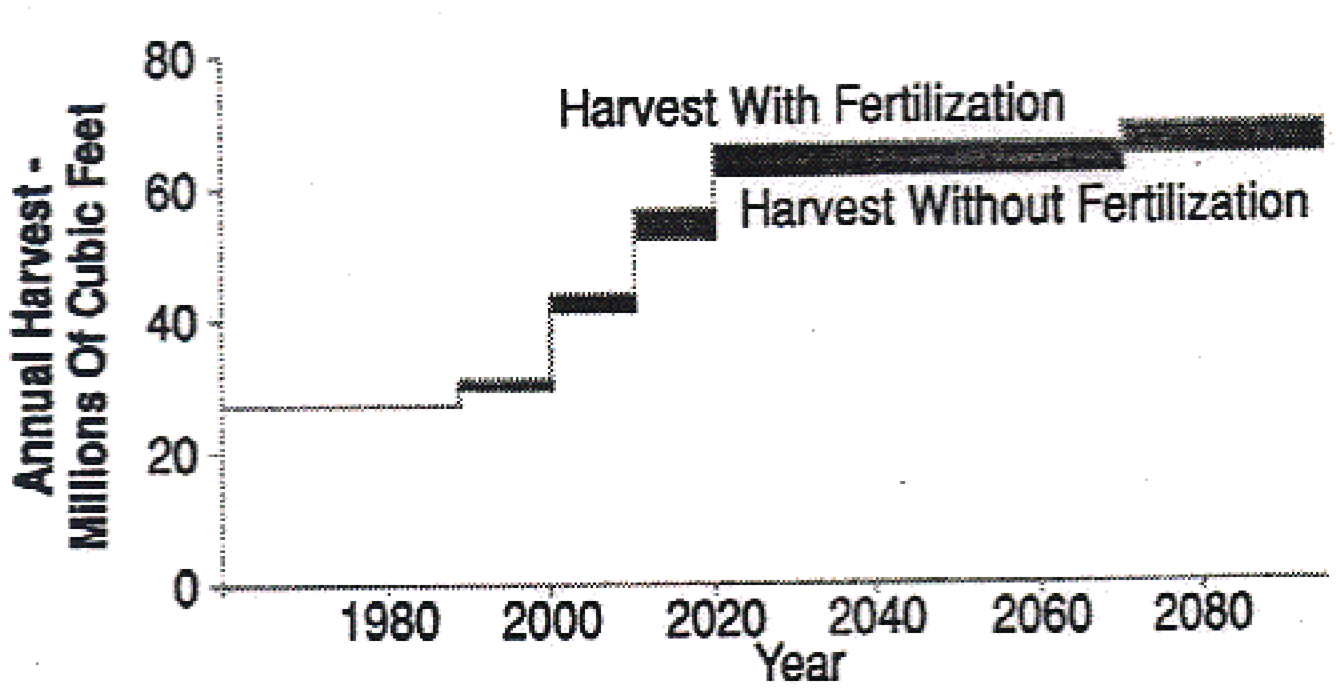

Figure 6. When do you take the gain? One way: "The State of Oregon takes credit for additional harvest at the time of commercial thinning and clearcutting, as stands respond" (Voelker 1981).

the harvest and resulting cash flow from mature stands may increase immediately. The increase in current harvest that occurs before any treated stands are actually harvested is called the allowable cut effect (Miller and Fight 1979).

The number of acres fertilized by decade is another FORPLAN output that deserves attention. Because this model optimizes for wood and economics, decisions made regarding timing of activities are economically driven on a forestwide, not a stand-level, basis. It is for this reason that FORPLAN chose to not fertilize any acres in the first decade. The outputs for first, second, and fifth decades look like this:

Decade 1 - 0 acres fertilized
Decade 2 - 13,000 acres fertilized
Decade 5 - 54,000 acres fertilized

There are many reasons why this model does not choose to fertilize during the first decade—all are internal assumptions built into the model itself that rely heavily on economic decisions. While trying to maximize long-term sustained yield, this model will harvest older stands rapidly the first couple of decades while looking for the promise of young stands to produce rapid growth in the future. To be economical, FORPLAN also schedules to harvest the fewest number of acres, and the most cost-efficient acres. The model also uses discrete time periods (decade points), and age-class distributions must fall into those decades. Some age classes ready for fertilization in the first decade do not get selected for commercial thinning in the second decade, and so forth. Thus some overriding factors of professional judgment must come into play to adjust the FORPLAN results to more closely match stand-level professional decisions.

We know from past work that fertilization pays on a stand basis. When calculating benefit-cost ratios for different situations, it was found that "the ratio was positive for all situations examined for the State of Oregon" (Voelker 1981). Reviewing the stand level PNV calculated from DP-DFSIM on this forest, a positive value with fertilization regimes was constantly derived. So we look at investments made at the stand level, rather than forestwide modeling approximations. Our approximations from modeling must be validated, however, through *monitoring* and *evaluation* (see Figure 1) to make sure we do not deviate from outputs substantially.

Short-range plans should follow long-range plans but must be kept flexible because of fluctuations in the funds available for management work. Some practices can be accelerated in years of above-average funds and postponed in years of below-average funds. Fertilization has two attributes that contribute to such flexibility. First, unlike timber sales, reforestation, and release, fertilization does not need to be done at precise times within a decade. The entire decade's worth of fertilizing could be done in any one, two, or three years of the decade. Second, the administrative costs of locating, contracting, and supervising fertilization work are low in relation to the management investment for most other forestry work (Voelker 1981).

The ASQ level is a snapshot in time, our best approximation of what can be produced on given acres. The ASQ on the Mt. Hood National Forest has dropped dramatically from the Timber Management Plan of the 1970s to the Final Forest Plan of the 1990s. Other factors are influencing the amount of timber that is cut. Although monitoring and evaluation fine-tune our silvicultural practices, this is not the main reason timber harvests have dropped substantially. The main reason is that land is being allocated to other uses and values, such as recreation, wildlife habitat, spotted owl habitat, special emphasis watersheds, and so forth. We therefore need to discuss how fertilization can be used in interaction with other forest uses.

Interactions with Other Forest Uses and Values

Forest Service policy states: "fertilization can meet objectives of other resources as well as timber management through coordination. Mitigation of fertilization activities may be necessary to accommodate specific needs of other resources on specific areas."

There are many land allocations on the Mt. Hood National Forest that allow fertilization if it is consistent with the desired future condition of that allocation, and with the species zones and soil types there. Below are some examples from the Mt. Hood National Forest Land and Resource Management Plan (1990*b*). An asterisk (*) indicates that additional standards exist for these areas.

Fertilization is acceptable but timber harvest is not:
- wilderness areas
- special interest areas
- unroaded recreational areas
- developed recreational areas
- winter recreation areas
- outdoor education areas*
- bald eagle recovery areas*

Neither timber harvest nor fertilization is allowed:
- key site riparian areas
- spotted owl habitat conservation areas (unless it enhances habitat)

Both timber harvest and fertilization are allowed:
- designated wild, scenic, and recreational rivers*
- scenic viewsheds
- roaded recreational areas
- pileated woodpecker/pine marten areas
- special emphasis watersheds*
- earthflow areas
- wildlife winter range, summer range
- timber emphasis areas

Fertilization is discouraged:
- general riparian areas
- the Bull Run watershed for the city of Portland

There are many opportunities to meet desired future conditions using fertilization as a tool. Scenic viewsheds may require rehabilitation of certain areas, and fertilization could be a tool to achieve that goal faster. In watersheds where a given percentage of a drainage must be in an "undisturbed" condition, fertilization could be used to get younger stands growing faster so as not to be in a "disturbed" condition. These are just a few examples to think about.

Conclusions

When considering fertilization in forest land management planning, the proper perspective must be maintained. This is done by incorporating fertilization into the Forest Planning System of planning, action, monitoring, and evaluation, just as other management practices are. Methods involved in the planning phase are: (1) projecting fertilization responses at the stand level using appropriate models; (2) selecting yield tables that represent good wood yields and economic returns; (3) determining where fertilization is acceptable; and (4) projecting fertilization gains at the forestwide level using appropriate models. The Forest Service policy of a long-term sustained yield over time allows the current harvest levels from mature stands to increase immediately, due to growth increases from fertilizing young stands (allowable cut effect).

Wherever appropriate, fertilization should be incorporated into forest management planning, not only for better volume growth, but to meet desired future conditions of other resources.

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Questions and Answers

Almost all the questions received from the presentation had to do with monitoring operational fertilization response on the Mt. Hood National Forest (how, what, where, and when).

Selection of Sample Areas

Clearcut Selection. The following information was gathered on clearcuts that were to be aerially fertilized: plant community, unit age, slope, aspect, Douglas-fir site index, elevation, soil type, and trees per acre. Units were stratified into six groupings based on these variables, with plant community and elevation being the strongest determinants of group membership. Two units were then randomly selected from each of the six groups: one prospective plot, and one alternate in case field inspection proved the prospective plot to be unsuitable.

Plot Selection. Within each selected clearcut, an area was delineated that appeared suitable for a control plot. The main criteria for control plots were that sites be fairly representative of the unit as a whole and that they could easily be segregated from the rest of the unit during application. After selection of a control plot center, another plot center was located, within the area to be fertilized, that appeared to be similar to the control plot with respect to vegetation, site characteristics, and tree size/density. We did not take any tree measurements at the time of plot selection, but in retrospect we believe that measurement of tree diameters would have been desirable to ensure that there are no significant differences in mean diameter between control and fertilized plots.

Data Collection

Soils Data. Prior to fertilization, soil samples were collected from both control and fertilized plots. Mineral soil and forest floor samples were collected from five randomly located sites at each plot. For analysis, all the mineral soil samples for a plot were mixed together, as were all forest floor samples. Samples were sent to Oregon State University for analysis of total soil N, total C, and C:N ratio, for both mineral soil and forest floor samples.

Tree Data. On both control and fertilized plots, the 20 trees closest to plot center were marked for measurement. Trees were numbered consecutively and tagged with numbered metal tags at breast height (uphill side). Dbh (to the nearest 1/10 inch) and species were recorded for all trees. The 10 best crop trees were then selected for measurement of total height (to the nearest foot), current (last five years) radial increment (in 20ths of an inch), surrounding basal area (measured with a 20-factor prism with the tree as plot center), and crown ratio (a single digit code, from stand examination procedures). Radial increment was measured from an increment core taken at breast height on the uphill side of the tree. Height was measured with a clinometer; in retrospect, direct measurement with a range pole would have been a more accurate method.

Data Analysis

Soils Data. All soil variables (total soil N, total C, and C:N for both mineral soil and forest floor) were subjected to a paired t-test to determine if there were differences in these factors prior to fertilization.

Tree Data. Tree data were entered on the Data General minicomputer through the Format Entry System (FES). Data were then transferred to Fort Collins Computer Center and loaded into SPSS-format files. The following variables are included in the data file: plot, current radial increment, control/fertilized, surrounding basal area, tree number, height, species, crown ratio, dbh, and year of measurement.

A calculated variable, basal area growth per tree (BAG), was also included:

BAG = Basal area growth per tree = BAC - BAC5, where
BAC = Current basal area of tree = $DBH^2 \times 0.005454$
BAC5 = Basal area of tree 5 years ago
= $[DBH - 2(CRI/20)]^2 \times 0.005454$, where
CRI = current 5-year radial increment

Reports of means and standard deviations were prepared, and analysis of variance was used for assessing response variables (height, dbh, current radial increment, basal area growth, and surrounding basal area) in the following categories: whole data set, by plot, by control vs. fertilized by plot, and by control vs. fertilized for the whole data set. SPSS was used for all statistical procedures.