EFFECTS OF FOREST FERTILIZATION WITH UREA ON STREAM WATER QUALITY—
QUILCENE RANGER DISTRICT, WASHINGTON

by
Duane G. Moore, Research Soil Scientist

ABSTRACT

Aerial fertilization of two units on the Quilcene Ranger District of the Olympic National Forest with urea at 224 kilograms nitrogen per hectare (200 pounds nitrogen per acre) in April 1970 provided the opportunity to monitor water quality in small streams immediately adjacent to the treated areas. Applied fertilizer did reach surface streams in the form of urea-, ammonia-, and nitrate-nitrogen, but maximum concentrations measured were well below established permissible limits for public water supplies. Concentrations of urea-N never reached 1.0 part per million, ammonia-N increased only slightly above background, and the highest level of nitrate-N found was 0.121 part per million. Fertilizer nitrogen entered streams only in the form of nitrate after the first 3 weeks, and 95 percent of the total loss over 7 months occurred within the first 9 weeks after application. Fertilizer nitrogen lost during the 7-month monitoring period was about 0.25 percent of the total applied. Introduction of these small amounts of nitrogen into forest streams spread out over a period of several weeks should have little measurable impact on eutrophication.

Keywords: Fertilization (forest), water analysis, urea.
INTRODUCTION

Increasing demands for wood fiber from a decreasing production base have resulted in acceleration of intensified management practices on forest lands. Use of chemical fertilizers is one of the most promising methods for increasing annual growth, and forest fertilization is rapidly becoming an operational practice in many areas of the United States. As is often the case, however, development of the practice has progressed ahead of definitive information on environmental impact.

Initial "trial and error" investigations were carried out in Europe and Australia from about 1900 to 1925 (Gessel 1969, Groman 1972); thus, the concept of fertilizing the forest is not new. However, it is only in recent years that advances in all fields of forestry and more favorable economic conditions have made operational forest fertilization feasible. Most of the forest soil fertility and tree nutrition research has occurred in the past 20 years, and large-scale forest fertilization began only in the last decade.

Within the past several years, considerable concern has been expressed over the possible toxic or eutrophic effects of fertilization of agricultural lands on water quality (Stanford, England, and Taylor 1970). This concern is being extended to all fertilizer use, including fertilization of forested watersheds. In addition to possible detrimental effects on water quality, the use of chemical fertilizers to increase growth of forest trees may affect water yield or other soil, watershed, and recreational values. Specific information is needed on these effects to accurately assess the environmental impact of forest fertilization.

In April 1970, a 113-hectare fertilization project on the Olympic National Forest provided the opportunity to monitor water quality in small streams immediately adjacent to two treated areas. Specific objectives of the monitoring were to determine (1) how much fertilizer nitrogen, if any, enters surface streams, (2) whether concentrations of nitrate, nitrite, and ammonia nitrogen reach levels considered toxic, and (3) whether the total amount of nitrogen entering the streams is sufficient to cause eutrophication in downstream impoundments.

STUDY AREA

The study area is located on the Quilcene Ranger District, Olympic National Forest, on the east side of the Olympic Peninsula in Clallam County, Washington. Project units were established on lower elevation glacial soils in areas that were in need of fertilization but where direct application of fertilizer to stream channels could be avoided. Jimmycomelately Creek, adjacent to Unit 1, drains north into Sequim Bay, and Trapper Creek (Unit 2) drains into Snow Creek which flows east and then north to Discovery Bay.

Topography of the area is a complex of glacially modified foothills, toeslopes, valley bottoms, and outwash plains. The deep glacial and colluvial soils are drained by streams that conform to dendritic patterns and range from low to moderate density (Snyder, Bush, and Wade 1969). Elevation ranges from 625 to 730 meters on Unit 1 and from 427 to 625 meters on Unit 2. Annual precipitation at the study site is estimated between 1,020 and 1,270 millimeters. Most of the precipitation occurs during the winter. Summers are dry, and streamflow often drops to less than 2.83 liters per second (l/s) in small headwater streams.

Soils of the study area have developed
in glacial till and outwash deposited during early Wisconsin time by a western lobe of the continental glacier (Snyder, Bush, and Wade 1969). Bedrock occurs at 4 meters or more beneath the soil surface. The Elwha soil series (Unit 1) and the Blyn series (Unit 2) are both Brown Podzolic soils with an effective depth of 40-100 centimeters. Surface horizon textures range from loam to silt loam while subsoil horizons are usually gravelly sandy loams. Permeability of both soils is rapid in the surface soils and moderate to slow in the subsoils.

Vegetation on 60 percent of Unit 1 was a 10-year-old stand of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Ground cover by this species was about 30 percent. Total ground cover by crop trees and subvegetation was about 85 percent. The remaining 40 percent of this unit was a dense 70-year-old stand of Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Vegetation on Unit 2 was a well-stocked, 40-year-old plantation of Douglas-fir. There was very little streamside vegetation along Jimmycomelately Creek (Unit 1) adjacent to the fertilized area. However, there was a fairly dense stand of red alder (*Alnus rubra* Bong.) along Trapper Creek adjacent to Unit 2.

**METHODS**

Urea fertilizer (46-percent N) was aerially applied at 492 kilograms per hectare (224 kilograms N/ha) to the Jimmycomelately unit on April 14 and to the Trapper Creek unit on April 15, 1970. Total inorganic fertilizer applied was 24,150 kilograms urea to Unit 1 (49 hectares) and 31,734 kilograms urea to Unit 2 (64 hectares). Boundaries of the units were carefully flagged and fertilizer was spread by helicopter. Half the fertilizer was applied to the units by making parallel flights, and half was applied by crossflying. The units were laid out so that fertilizer would not be applied within 60 meters of a stream. Roads and road rights-of-way were also avoided.

Monitoring stations for stream water sampling were established at points upstream and downstream from each fertilized area in late March 1970. Samples were obtained on April 1, 8, and 14 to establish background levels of urea-, ammonia-, nitrate-, and nitrite-nitrogen. Samples were collected at 2-hour intervals on the day of treatment, every 4 hours the next day, then daily through the first week. Additional samples were taken at 2, 3, 4, 6, and 9 weeks, and then every 4 weeks throughout the dry summer months. Monitoring continued until after the first fall storms, a total period of about 7 months.

Stream water samples were collected in 4-liter plastic containers, treated with mercuric chloride (40 mg/l) to prevent biological transformations of nitrogen, and shipped to the Station's Corvallis laboratory for chemical analysis. All samples were analyzed for urea-, ammonia-, nitrate-, and nitrite-nitrogen using standard methods for water analysis (Newell, Morgan, and Cundy 1967; Wood, Armstrong, and Richards 1967; Federal Water Pollution Control Administration 1969).

Jimmycomelately and Trapper Creeks were not gauged, and streamflow was estimated with a standard velocity head rod each time samples were taken. Precipitation data were from a rain gage at each sampling site during the monitoring period.
RESULTS AND DISCUSSION

Pretreatment levels of soluble nitrogen were extremely low in Jimmycomelately Creek. Nitrate-N was present at 0.001 to 0.003 parts per million (p/m) and urea-N was present in only a few samples. Ammonia-N was below the level of detection (0.004 p/m) in all pretreatment samples, and nitrite-N was not detected in any samples during the entire monitoring study. More evidence of wildlife was apparent along Trapper Creek and pretreatment samples from this stream contained an average of 0.013 p/m urea-N. Nitrate-N was present in pretreatment samples at a concentration of 0.055 p/m, possibly because of the dense stand of red alder along Trapper Creek. Ammonia- and nitrite-N were not present.

Posttreatment concentrations of nitrogen were not corrected for background. In most instances, the background level was too low for correction to influence interpretation of results. In addition, the actual concentrations of nitrogen are more important in terms of levels that may be toxic to nontarget organisms. A correction was made for background, however, in calculating the amount of applied nitrogen lost in the streams.

Concentrations of urea-, ammonia-, and nitrate-N began to increase in downstream samples from both streams shortly after application began. Loss of applied nitrogen followed the same pattern on both units (figs. 1 and 2), and the data will be discussed together. Urea-N began to increase within 3 hours after application started, reached a peak concentration of 0.71 p/m in 5 and 8 hours, and then began to decrease even though fertilization was not yet complete. The unit boundaries were laid out to avoid direct application
to the stream channels, but some contamination obviously occurred. Standard agricultural grade urea fertilizer was used because the large-granule forest grade was unavailable. Dust from the application was observed drifting to nontarget areas. Three consecutive samples (2-hour intervals), from the upstream station on Jimmycomelately Creek, were contaminated by drifting dust during application.

Levels of urea-N continued to decrease the day following fertilizer application and had fallen to nearly pretreatment concentrations in 4 days. Low concentrations of urea-N were found in Jimmycomelately Creek for 2 weeks. Storm activity during early May resulted in small additional losses of urea-N from both units.

Ammonia-N increased in both streams concurrent with increases in urea-N, but only small amounts of applied fertilizer were lost in this form. Peak concentrations of 0.04 and 0.01 p/m ammonia-N were measured about 6 hours after fertilizer application began. Ammonia-N returned to background levels within 1 week.

Nitrate-N began to increase slowly during the day of treatment and reached a peak concentration of 0.042 p/m in 48 hours at the downstream station on Jimmycomelately Creek. The peak concentration of 0.121 p/m nitrate-N in Trapper Creek was reached in 24 hours. When the higher background level of nitrate-N in the latter stream is considered, both streams show a comparable increase. Levels in both streams decreased slowly throughout April and May, and concentrations returned to and remained at pretreatment levels from June through November 4.

Precipitation was measured at each unit during the entire monitoring period (table 1), and at least 25 millimeters of rain fell each month from July through September. Streamflow levels dropped

<table>
<thead>
<tr>
<th>Date</th>
<th>Unit 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-20</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>4-22</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>4-29</td>
<td>30</td>
<td>53</td>
</tr>
<tr>
<td>5-6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5-13</td>
<td>57</td>
<td>76</td>
</tr>
<tr>
<td>5-27</td>
<td>4</td>
<td>1/9</td>
</tr>
<tr>
<td>6-17</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>7-15</td>
<td>16</td>
<td>29</td>
</tr>
<tr>
<td>8-12</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>9-9</td>
<td>41</td>
<td>51</td>
</tr>
<tr>
<td>10-8</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>11-4</td>
<td>59</td>
<td>97</td>
</tr>
<tr>
<td>Total</td>
<td>318</td>
<td>444</td>
</tr>
</tbody>
</table>

1/ Estimated. Rain gage stolen.

Precipitation data for the climatological station at Quilcene indicate that over 610 millimeters of rainfall were recorded during November and December 1970, and that over 60 percent of the annual rainfall normally occurs from November through February. Data from other monitoring studies indicate
that a second nitrate-N peak may have occurred (Moore 1972; Malueg, Powers, and Krawczyk 1972; Burroughs and Froehlich 1972), but it was not possible to continue sampling these streams during the winter months.

Total amounts of applied nitrogen entering the two streams during the 7-month monitoring period were estimated by averaging nitrogen concentrations and streamflow volumes between sampling dates. These estimates are summarized in tables 2 and 3. Urea-N accounted for about 36 percent of the measured loss, while an average of 60.5 percent entered the streams as nitrate-N. The total estimated loss of 21.53 kilograms nitrogen from the Jimmycomelately unit is equivalent to 0.44 kilogram N/hectare (0.20 percent of that applied). Comparable estimates for the Trapper Creek unit are slightly higher: 0.58 kilogram N/hectare, or 0.26 percent of the applied nitrogen. Perhaps of equal importance is the apparent contribution of the red alder along Trapper Creek to base level nitrogen loss rates. Red alder is known to add large amounts of nitrogen to the soil on sites where it grows (139 kilograms N/hectare/year, Franklin et al. 1968), and a portion of this added nitrogen was apparently lost in Trapper Creek. During the 7 months covered by this study, the background loss rate in Trapper Creek was about six times greater than that measured in Jimmycomelately Creek, 0.19 compared with 0.03 kilogram nitrogen per hectare.

Table 2.--Nitrogen lost to Jimmycomelately Creek from Unit 1, Quilcene Ranger District, during the first 7 months after application of 224 kilograms N/ha

<table>
<thead>
<tr>
<th>Nitrogen form</th>
<th>Downstream</th>
<th>Control</th>
<th>Net loss</th>
<th>Percent of total loss</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kilograms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea-N</td>
<td>18.66</td>
<td>9.94</td>
<td>8.72</td>
<td>40.49</td>
</tr>
<tr>
<td>Ammonia-N</td>
<td>1.44</td>
<td>--</td>
<td>1.44</td>
<td>6.70</td>
</tr>
<tr>
<td>Nitrate-N</td>
<td>13.38</td>
<td>2.01</td>
<td>11.37</td>
<td>52.80</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>33.48</td>
<td>11.95</td>
<td>21.53</td>
<td>--</td>
</tr>
</tbody>
</table>

1/ Background loss rate from April 14 to November 4, 1970, equals 0.03 kg N/ha.

2/ Loss of applied nitrogen, 21.53 kilograms from 49 hectares, approximately 0.44 kg N/ha (0.20 percent of that applied).
Table 3.—Nitrogen lost to Trapper Creek from Unit 2, Quilcene Ranger District, during the first 7 months after application of 224 kilograms N/ha

<table>
<thead>
<tr>
<th>Nitrogen form</th>
<th>Downstream</th>
<th>Control</th>
<th>Net loss</th>
<th>Percent of total loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kilograms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea-N</td>
<td>40.83</td>
<td>29.10</td>
<td>11.73</td>
<td>31.26</td>
</tr>
<tr>
<td>Ammonia-N</td>
<td>0.22</td>
<td>--</td>
<td>0.22</td>
<td>0.58</td>
</tr>
<tr>
<td>Nitrate-N</td>
<td>104.30</td>
<td>78.73</td>
<td>25.57</td>
<td>68.16</td>
</tr>
<tr>
<td>Total</td>
<td>145.35</td>
<td>1/ 107.83</td>
<td>2/ 37.52</td>
<td>--</td>
</tr>
</tbody>
</table>

1/ Background loss rate from April 15 to November 4, 1970, equals 0.19 kg N/ha.
2/ Loss of applied nitrogen, 37.52 kilograms from 64 hectares, approximately 0.58 kg N/ha (0.26 percent of that applied).

SUMMARY AND CONCLUSIONS

Streams flowing adjacent to two small forest fertilization projects in the Quilcene Ranger District were monitored for possible impact on water quality over a period of 7 months following fertilization at 224 kilograms urea-N per hectare. Unit boundaries were laid out to avoid direct application to stream channels, but some contamination did occur during application due to minor problems with drifting fertilizer dust. Direct application of urea prills to streams also occurred but was minimal; concentrations of urea-N never reached 1.0 p/m at downstream monitoring stations. In other fertilization projects where no attempt was made to avoid streams within the treated unit, concentrations of urea-N in stream water have ranged from 1.39 to 44.4 p/m (Thut 1970; McCall 1970; Moore 1970; Burroughs and Froehlich 1972; Malueg, Powers, and Krawczyk 1972).

Applied fertilizer entered surface streams in the form of urea-, ammonia-, and nitrate-N, but maximum concentrations measured never approached levels known to be toxic (10 mg/1 N as nitrate-plus nitrite-N is recommended maximum limit for public water supplies (Federal Water Pollution Control Administration 1968)). Applied nutrient lost during the monitoring period was very small, about 0.25 percent of the total fertilizer nitrogen applied. Losses in the form of ammonia-N occurred in the first 4 days. Nitrogen losses in the form of urea were 70 to 90 percent complete in 1 week, but small losses continued for up to 3 weeks. Virtually all of the fertilizer nitrogen entering the streams after the first 3 weeks was measured as nitrate, and this form of nitrogen accounted for 53 and 68 percent of the total measured loss of applied nutrient from the two units monitored. Over 95 percent of the total loss for the
Monitoring of the two streams was discontinued after the November sampling because of inaccessibility of the project area during winter months. It is possible that additional losses of applied nitrogen in the form of nitrate could occur during winter storms. However, peak concentrations would probably be lower than those measured just after application because of the dilution effect of higher streamflow. Low soil and water temperatures during the winter months greatly retard nitrification; and as soon as any accumulated nitrate-nitrogen is leached out of the soil, concentrations in the stream would drop rapidly to pretreatment levels. The present study did not offer the opportunity to observe any effects of increased nitrogen on eutrophication in downstream impoundments, but the small amounts of nitrogen entering the stream over several weeks would not be expected to have any measurable impact.

Acknowledgment

The author wishes to thank the following personnel of the U.S. Forest Service, Olympic National Forest, for their assistance in conducting this investigation: Bill Long, Jim Halvorson, Don Holmes, Donna Schultz, Bill Roeder, Larry Lysen, Robert Holweg, and particularly Harold Beamer and Ronald Johnson.

LITERATURE CITED

Burroughs, Edward R., Jr., and Henry A. Froehlich

Federal Water Pollution Control Administration


Franklin, Jerry F., C. T. Dyrness, Duane G. Moore, and Robert F. Tarrant

Gessel, Stanley P.

Groman, William A.

McCall, Merley

Malueg, K. W., C. F. Powers, and D. F. Krawczyk
Moore, D. G.

Moore, Duane G.

Newell, B. S., B. Morgan, and J. Cundy

Snyder, Robert V., George S. Bush, Jr., and John M. Wade


Thut, Rudolph N.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

Fairbanks, Alaska
Juneau, Alaska
Bend, Oregon
Corvallis, Oregon
La Grande, Oregon
Portland, Oregon
Olympia, Washington
Seattle, Washington
Wenatchee, Washington

Mailing address: Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
Portland, Oregon 97208
The FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.