Fertilization and Water Quality

by

DUANE G. MOORE

Forestry Sciences Laboratory

Pacific Northwest Forest and Range Experiment Station

Forest Service, U.S. Department of Agriculture

Corvallis, Oregon

Fertilization of forested watersheds is a rapidly growing management practice in many areas of the United States. Operational forest fertilization began in the Douglas-fir region of the Pacific Northwest in 1963 and in the southeastern pine region in 1968. Between 1963 and the end of 1969, approximately 90,000 acres were fertilized in western Oregon and Washington. Another 100,000 acres were fertilized each year in 1970 and 1971, and present estimates indicate that the annual rate of fertilization will exceed 200,000 acres within the next 5 to 10 years.

In the Pacific Northwest, including northern California and Alaska, the major coniferous commercial timber types have responded only to additions of nitrogen. In the Southeast, both nitrogen and phosphorus fertilizers are applied to forest stands by conventional ground equipment or helicopter. Coniferous plantations on sandy soils in the Northeast and in the Lake States have responded to additions of potassium.

Concern for Water Quality — In forestry, we have typically considered fertilizer nutrients only in terms of their beneficial and necessary role in plant nutrition. We have considerable information indicating that fertilization can contribute significantly to increased growth rates and thus help meet the demands of a growing population for wood fiber. However, problems of excess nitrogen and phosphorus in surface and ground water have attracted worldwide attention within the general framework of concern over environmental quality. Acceptance of commercial scale forest fertilization programs, aside from sound proof of their effectiveness, will depend on the demonstrated safety of this practice in terms of unaltered water quality.

Concern over possible deleterious effects of forest fertilization with nitrogen on water quality is based wholly upon extrapolation of experience on cultivated land to forested land. There is an enormous literature concerning the effects of farm fertilization on water quality but essentially none concerning the effects of forest fertilization. Part of the hypothetical problem is concerned with maintaining levels of nitrate nitrogen in water below levels shown to be toxic to human beings and other organisms. The threshold of such toxic levels has been estimated to be between 10 and 50 parts per million. (The Public Health Service in its drinking water standards sets a recommended limit for nitrate plus nitrite nitrogen of 45 parts per million.) Another facet of the problem concerns possible degradation of water quality by increasing the total nitrogen load to levels that encourage growth of algae and other unwanted aquatic organisms. Small increase might be significant in this regard, since there are known instances of sufficient nitrogen in rainfall to cause eutrophication in surface waters.

On the basis of our present level of knowledge of the forest ecosystem, we can hypothesize that fertilizing forest lands should have little or no effect on water quality. In contrast to cultivated lands, the forest soil generally has a highly organic layer over its surface, and organic matter content of the first few inches of mineral soil is almost always much greater than that in cultivated soils. This substantial amount of organic matter provides a large number of adsorption sites for applied chemicals. Further, most well-established forest stands, including understory vegetation, have a massive root system that offers great opportunity for interception and rapid uptake of chemical fertilizer nutrients.

A hypothesis alone is not adequate, however, in that it does not provide sufficient basis to say a problem does or does not exist. We need specific answers to such questions as, "What is the effect of fertilizing on water quality and aquatic organisms?" "On water yield?" and "What are the long-term effects of chemical fertilizers on the forest environment?"

Monitoring Fertilized Watersheds. — In an attempt to obtain at least preliminary answers to the above questions a research program was initiated in the fall of 1969 on four small watersheds at the head of Coyote Creek in the South Umpqua Experimental Forest in southwestern Oregon. This site was selected because adequate background hydrological data were already available, thus eliminating the necessity of an initial calibration period. Cooperative studies on the effects of various forest management practices on yield and distribution of streamflow and on water quality were initiated in 1964, and it was possible to include fertilization as an additional management practice in the treatment phase. These watersheds are typical of the mixed conifer area of southwest Oregon.

Each watershed is equipped with a 120-degree
V-notch weir gaging station and a Fischer-Porter digital recorder. A standard precipitation gage has been maintained at Watershed 2 since 1960. Maximum-minimum thermometers are installed near each of the gaging stations to record water temperatures. In August and September 1969, automatic proportional stream samplers were installed on each watershed, and sampling started on October 1, 1969. Detailed chemical analysis of streamwater samples from all four watersheds has been carried out since that time and will continue during the entire course of the study.

Chemical analysis of the stream samples for the fertilizer monitoring phase included determination of background levels of urea-, ammonia-, nitrite-, and nitrate-nitrogen. Because of the extremely low background levels encountered, it was necessary to develop modified analytical methods of sufficient sensitivity to quantify the rate of nitrogen loss from undisturbed forested watersheds. Pretreatment levels of urea-, ammonia-, and nitrate-nitrogen were 0.006, 0.005, and 0.002 parts per million, respectively. Nitrite nitrogen was never detected except as a trace (less than 0.001 part per million).

In March 1970, Watershed 2 was fertilized by aerial application of urea at the rate of 200 pounds nitrogen per acre. The boundaries and the gaging station were marked with yellow plastic bunting, and fertilizer traps were placed along transects across the watershed at three elevations and along the boundaries to estimate uniformity of application. Urea was applied by helicopter using the large forest prill formulation to avoid dust drift to adjacent watersheds. The drainage channel of this watershed is small and only very little surface water is exposed. Therefore, the total watershed was fertilized, and no attempt was made to leave an untreated buffer zone. Water quality was monitored by collecting grab samples at the stream gaging stations on Watersheds 2 (treated) and 4 (control) during and after fertilization. Following the close-interval sampling during the first 6 weeks after treatment, monitoring continued through use of the automatic proportional samplers.

Fertilization of this 169-acre forested watershed (WS 2) did not result in toxic levels of urea-, ammonia-, nitrite-, or nitrate-nitrogen in streams draining the treated area the first year after treatment. Urea concentrations increased slowly and reached a maximum of 1.39 ppm urea-N 48 hours after application started. All loss of applied nitrogen as urea occurred during the first 3 weeks. Ammonia-N increased to levels only slightly above background concentrations and never reached 0.10 ppm, but losses of nitrogen in this form, even though small, continued for 6 weeks. Nitrate-N reached a peak concentration of 0.168 ppm in 72 hours, was 0.140 ppm at the end of 2 weeks, and had essentially returned to pretreatment levels after 9 weeks. Nitrite-N was never detected except as a trace. Loss of applied nitrogen amounted to only 4 pounds for the entire watershed during the first 9 weeks after application (Table 1). Low streamflow due to limited precipitation throughout the summer and fall months resulted in essentially no loss of nitrogen during the next 24 weeks.

Early storm activity in November brought the soil moisture level back up to maximum storage capacity, and in December the nitrate-N concentration in samples for the fertilized watershed reached a second peak of 0.177 ppm. Both streamflow and nitrate-N levels remained high through December and January resulting in the loss of an additional 52.5 pounds of applied nitrogen, 92 percent of the total amount of fertilizer nitrogen lost during the first year.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Urea-N</th>
<th>NH₃-N</th>
<th>NO₃-N</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS 2</td>
<td>1.44</td>
<td>0.63</td>
<td>2.22</td>
<td>4.29</td>
</tr>
<tr>
<td>WS 4</td>
<td>0.05</td>
<td>0.14</td>
<td>0.10</td>
<td>0.29</td>
</tr>
<tr>
<td>Net loss</td>
<td>1.39</td>
<td>0.49</td>
<td>2.12</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Total loss of applied nitrogen from the fertilized watershed (169 acres) during the first year after application amounted to 57 pounds or 0.34 pounds of nitrogen per acre (Table 2). During the same period the total amount of soluble inorganic nitrogen lost from the control watershed (120 acres) was 4.75 pounds, or 0.04 pounds nitrogen per acre. Data for soluble organic nitrogen, total phosphorus, and exchangeable cation content of the stream samples indicate that there was no apparent effect of nitrogen fertilization on loss of native soil nitrogen or other plant nutrients.

**Time and Form of Nitrogen Lost.** — Initial losses of applied nitrogen were largely due to direct application of urea fertilizer to the drainage channel. These losses were measured first as an increase in urea nitrogen and then as a small increase in ammonia nitrogen, the latter as a result of hydrolysis of urea applied to open water. Urea hydrolyzed to the ammoniacal form in the forest floor or soil will be held as an exchangeable cation and will not be subject to leaching until further transformed to the mobile nitrate form by nitrifying bacteria. Nitrate nitrogen entering the stream shortly after application is probably leached from the soil immediately adjacent to the stream channel. Approximately half (47 percent) of the applied nitrogen lost during the first 9 weeks after application was due to direct application and half (53 percent) entered the stream as nitrate nitrogen. However, all of the applied nitrogen lost during this period amounted to only 7 percent of the total loss which occurred over the first year (Table 3).

1. Mention of product by name does not imply endorsement by the U.S. Department of Agriculture.
centrations of urea-, ammonia-, and nitrate-nitrogen returned to background levels the first time, most of the nitrogen loss would not have been measured. High streamflow coupled with a second peak in nitrate nitrogen levels during the winter storm period accounted for 92 percent of the total loss. In February and March 1971, streamflow remained high but most of the mobile nitrogen had already been lost, and nitrate nitrogen concentrations had returned to near normal.

Loss of nitrogen from the untreated watershed was very low, but the timing of loss shows essentially the same pattern as described for the treated watershed. Nearly 80 percent of the total loss occurred during the same 12-week period from mid-November through January. Precipitation and streamflow for the year, broken down into the same periods, helps to explain this pattern of nitrogen loss in that 55 percent of the total runoff also occurred during that 12-week period.

**Other Monitoring Studies.** - The data presented above represent only one set of field conditions. Other monitoring studies conducted on the Quilcene District of the Olympic National Forest and elsewhere in western Oregon and Washington represent a wide range in field conditions including different soil types and different ages and densities of over-story and understory vegetation. Fertilization of the mature stand on Watershed 2 at the South Umpqua Experimental Forest should represent the least possible threat to water quality, whereas fertilization of a very young, open stand on the Quilcene District on sandy soils may represent a much greater pollution hazard. However, monitoring data from both studies show essentially the same loss patterns and the same amounts of nitrogen entering surface waters. Direct application to stream channels was avoided on the Quilcene units, resulting in less loss as ammonia nitrogen, and total concentrations of soluble inorganic nitrogen never reached 1 part per million. Similar results have been reported for other monitoring studies.

**Summary.** - We now have preliminary answers concerning the amounts and forms of fertilizer nitrogen entering surface streams following the aerial application of urea to forested watersheds. Application rates of 200 pounds nitrogen per acre have not resulted in toxic levels of urea-, ammonia-, nitrite-, or nitrate-nitrogen in streams draining the treated area the first year after treatment. Total amounts of fertilizer nitrogen entering the streams are relatively small and would not be expected to have a measurable impact on the aquatic environment. Data from a number of monitoring studies representing a fairly wide range in field conditions have shown similar trends.

It should be stressed that the information presently available is only "preliminary" and answers only some of the questions being asked. Future studies must consider a greater range in field conditions, size of unit treated, and more specific information on the effect of time of application on amount and form of nitrogen entering surface and ground water supplies. At present, only one nitrogen carrier is being applied and fertilized areas have been treated only once. We have no information on the long-term effects of chemical fertilizers on the forest environment, nor on the effect of repeated nitrogen applications on water quality. Available information indicates we have no problem, but more complete information is needed on the effects of forest fertilization on the total nitrogen budget, mobilization, movement and nutrient cycling before we can accurately define the nature and extent of the impact of fertilizer on the forest environment.

Thank you. (Applause)

Mr. Sauerwein: Thank you very much, Duane. Our fourth panelist is Mr. Walter Fergerson of Crown Zellerbach Corporation, Camas, Wash. Walt is a native of California and was raised on a homestead in northern Montana. He graduated from Washington State University with a Bachelor of Science in Forestry and was a Junior Forester with the U.S. Forest Service during the CCC days in northern Minnesota. He transferred to the Soil Conservation Service in 1939 and was one of the first farm foresters in Oregon. He was also Soil Conservation Service Forestry Specialist for Oregon from 1962 to 1968, and, after retirement from federal service in 1968 he has been with Crown Zellerbach since that time. Walt coauthored his paper with Dr. Dean DeBell. Dr. DeBell was here but had to leave. I would just like to mention that Dr. DeBell is also with Crown Zellerbach since 1970, prior to that he had worked in the Southeastern Forest Experiment Station at Charleston, South Carolina, and received his training at Juniata College and at Duke University, getting his Ph.D. there in forest soils and tree physiology in 1970. Walt's subject is "Roads and Soils." Walt.