K. W. Malueg
C. F. Powers
and
D. F. Krawczyk
Pacific Northwest Water Laboratory
200 S. W. 35th Street
Corvallis, Oregon

Effects of Aerial Forest Fertilization with Urea Pellets on Nitrogen Levels in a Mountain Stream

Introduction

Over the past two decades, forest fertilization has progressed from the experimental to a practical management stage. Today, in this country as well as other timber-producing countries, fertilizers are applied to increase forest production. Although phosphorus and other elements have been shown to increase forest production in some parts of the world, nitrogen has most often proved effective in stimulating forest growth (Gessel *et al.,* 1965; Broadfoot, 1966; Klem, 1968). In the Pacific Northwest and western Canada, increased production of Douglas-fir clearly illustrates increased growth response to nitrogen fertilizer (Gessel *et al.,* 1965; Reukema, 1968; Brix and Ebell, 1969).

Recently, large-scale fertilization has been effected through aerial application. During 1969, the authors undertook a limited study in cooperation with Willamette Industries, Inc., Dallas, Oregon, on the effects of aerial forest fertilization on nitrogen levels in a mountain stream. The study considered only the response of the various forms of nitrogen in the stream to the aerial fertilization. Effects of urea pellets introduced directly into the water during the application were taken into account, in addition to washoff and leaching from the adjacent forest land during the next several months.

Methods

The study area was located in Linn County in the western foothills of the Cascade Mountains about 28 miles (45 km) east-southeast of Albany, Oregon. Urea was applied to a 569-acre (230 ha) tract of previously unfertilized forest land, lying at altitudes of approximately 1480 to 2080 ft (451 to 634 m). Forest cover consisted primarily of well-stocked, 35-year-old Douglas-fir. The tract was drained by Crabtree Creek, a small, steep-gradient stream, on which the investigation was conducted. The topography was moderate with steep pitches into the stream beds.

Buckshot size urea pellets[1] were broadcast by helicopter over the study area (Fig. 1) on May 15-19, 1969, at a concentration of 437 lbs/acre (490 kg/ha) which is equal to approximately 200 lbs N/acre (224 kg/ha). Actual periods of fertilization were 1800 to 1930 on the 15th, 0700 to 2000 on the 16th, 0700 to 1800 on the 17th, and

---

[1] Cominco American Inc., Portland, Oregon forestry grade (46-0-0).

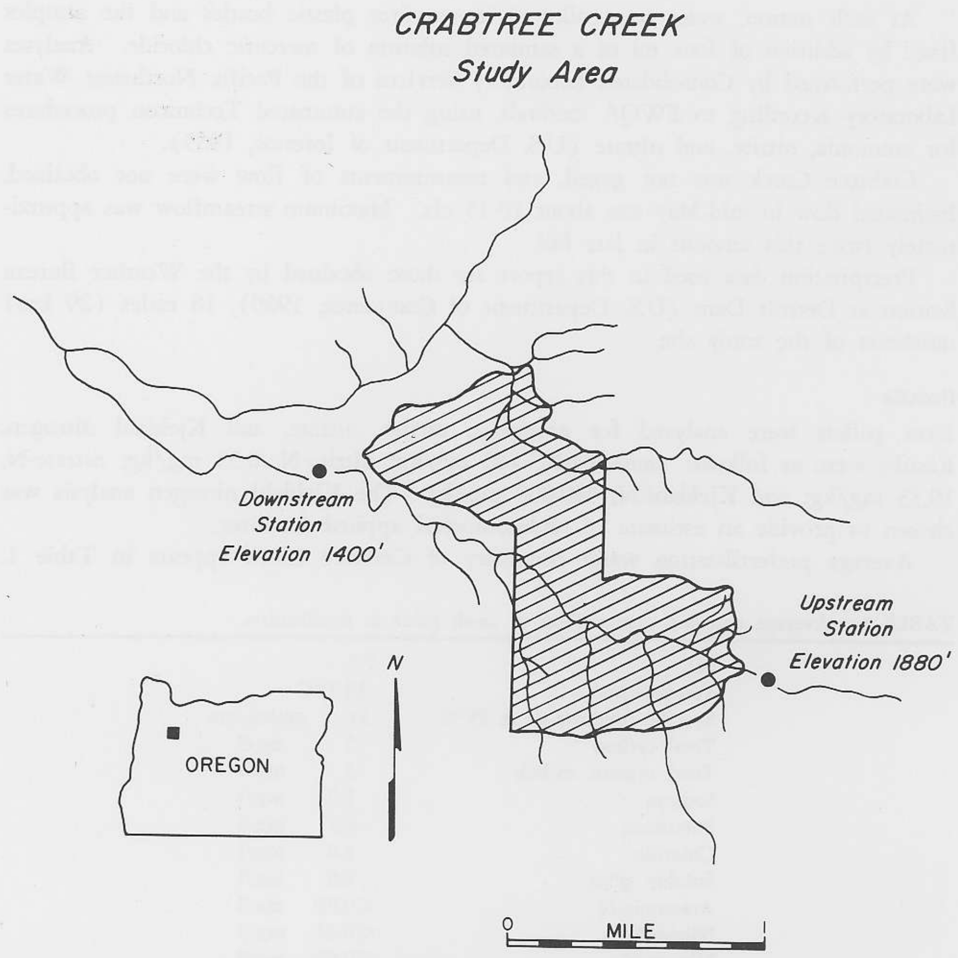

Figure 1. Location of Crabtree Creek study area and sampling stations.

0730 to 1400 on the 19th. The boundaries of the area were marked with colored balloons to provide guidance for the helicopter pilot. Samples were obtained at two monitoring stations, one upstream and one downstream from the fertilized area, on May 6, 7, 9, and 15 to establish the prefertilization chemistry of the stream. Nitrogen levels existing at that time will hereafter be referred to as base-line levels. Fertilizing was initiated on the 15th, but sampling was carried out on that date before the overflights began. Samples were collected approximately every two days for two weeks after fertilization was completed. Intermittent sampling was then continued until January 1970 as a check on further input of fertilizer-nitrogen to the stream as a result of fall-winter rains.

In addition to nitrogen, the primary focus of the investigation, a number of other chemical analyses were made on the samples collected prior to fertilization to provide a chemical characterization of the water. During the monitoring study following aerial fertilization, water samples were analyzed only for ammonia, nitrite, nitrate, and Kjeldahl nitrogen.

At each station, water was collected in one-liter plastic bottles and the samples fixed by addition of four ml of a saturated solution of mercuric chloride. Analyses were performed by Consolidated Laboratory Services of the Pacific Northwest Water Laboratory according to FWQA methods, using the automated Technicon procedures for ammonia, nitrite, and nitrate (U.S. Department of Interior, 1969).

Crabtree Creek was not gaged, and measurements of flow were not obtained. Estimated flow in mid-May was about 10-15 cfs. Maximum streamflow was approximately twice this amount in late fall.

Precipitation data used in this report are those obtained by the Weather Bureau Station at Detroit Dam (U.S. Department of Commerce, 1969), 18 miles (29 km) northeast of the study site.

Results

Urea pellets were analyzed for ammonia, nitrite, nitrate, and Kjeldahl nitrogen. Results were as follows: ammonia-N, 140 mg/kg; nitrite-N, 0.53 mg/kg; nitrate-N, 19.33 mg/kg; and Kjeldahl-N, 440,000 mg/kg. The Kjeldahl nitrogen analysis was chosen to provide an estimate of undecomposed applied fertilizer.

Average prefertilization water chemistry of Crabtree Creek appears in Table 1.

TABLE 1. Average chemical composition of creek prior to fertilization.

pH	7.5	
Temperature	10.5°C	
Specific conductance at 25°C	21	µmhos/cm
Total carbon	5	mg/l
Total organic carbon	3	mg/l
Sodium	1.2	mg/l
Potassium	0.2	mg/l
Chloride	1.0	mg/l
Soluble silica	9.0	mg/l
Ammonia-N	<0.01	mg/l
Nitrite-N	<0.01	mg/l
Nitrate-N	<0.01	mg/l
Kjeldahl-N	0.4	mg/l
Orthophosphorus	0.004	mg/l
Total phosphorus	0.013	mg/l

Ammonia, nitrite, and nitrate nitrogen were undetectable before fertilization. Kjeldahl-N, however, was present at a concentration of 0.4 mg/l. Except for nitrite, which remained undetectable for the duration of the study, rises occurred in all nitrogen forms following the urea application. Kjeldahl-N increased from 0.2 mg/l on May 15 at the downstream station to more than 24 mg/l on the 16th (Fig. 2). A small concurrent rise from 0.3 mg/l to 1.4 mg/l occurred at the upstream station. The next day values downstream and upstream had fallen to 2.0 mg/l and 0.8 mg/l, respectively; this decline coincided with the cessation of fertilization in that area. By the next sampling date, May 19, Kjeldahl-N had further declined to near prefertilization levels at both stations, although fertilization continued in adjacent areas through the 19th of May. The rise on May 24 at the upstream station to 2.8 mg/l cannot be explained; however, it is the only significant increase of Kjeldahl-N that occurred at either location after May 16.

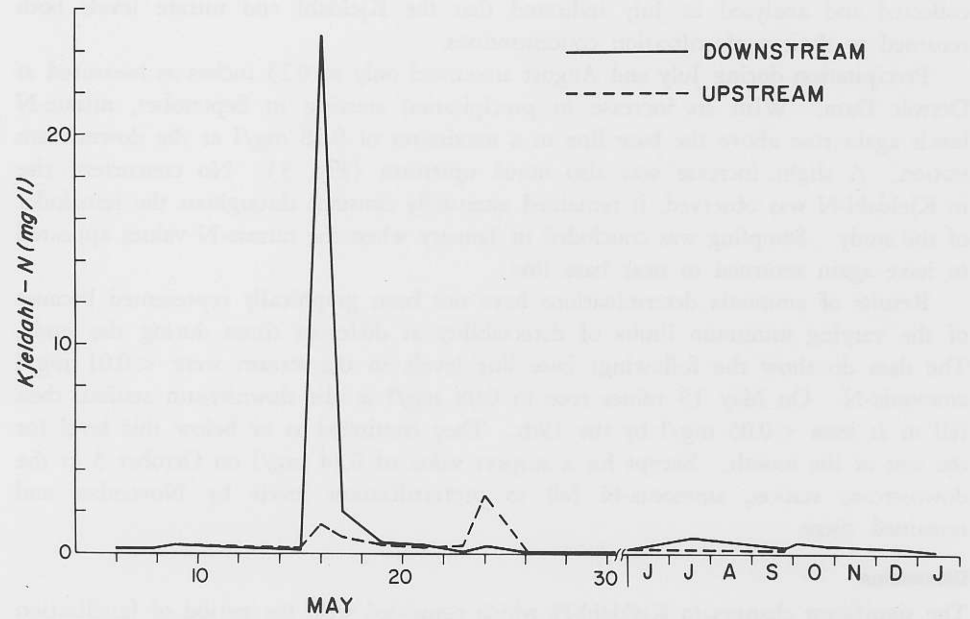

Figure 2. Concentration of Kjeldahl-Nitrogen from May 1969 to January 1970.

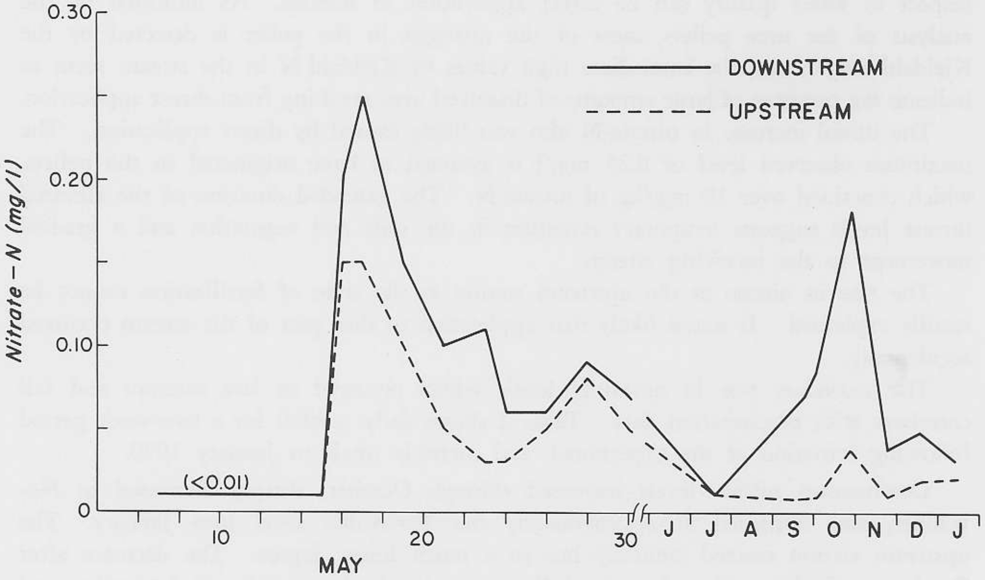

Figure 3. Concentration of Nitrate-Nitrogen from May 1969 to January 1970.

Nitrate-N (Fig. 3) also showed a notable increase from May 15 to 16, from less than 0.01 mg/l at both stations to 0.2 mg/l at the downstream station and 0.15 mg/l upstream. Downstream nitrate-N further increased to 0.25 mg/l on the 17th. Levels then decreased throughout the month of May both upstream and downstream. Samples collected and analyzed in July indicated that the Kjeldahl and nitrate levels both returned to their prefertilization concentrations.

Precipitation during July and August amounted only to 0.23 inches as measured at Detroit Dam. With an increase in precipitation starting in September, nitrate-N levels again rose above the base line to a maximum of 0.18 mg/l at the downstream station. A slight increase was also noted upstream (Fig. 3). No concurrent rise in Kjeldahl-N was observed; it remained essentially constant throughout the remainder of the study. Sampling was concluded in January when the nitrate-N values appeared to have again returned to near base line.

Results of ammonia determinations have not been graphically represented because of the varying minimum limits of detectability at different times during the study. The data do show the following: base line levels in the stream were <0.01 mg/l ammonia-N. On May 16 values rose to 0.08 mg/l at the downstream station, then fell to at least <0.05 mg/l by the 19th. They continued at or below this level for the rest of the month. Except for a suspect value of 0.24 mg/l on October 3 at the downstream station, ammonia-N fell to prefertilization levels by November and remained there.

Discussion

The significant changes in Kjeldahl-N which coincided with the period of fertilization strongly suggest the effect of direct application to the water. This is in agreement with Cooper (1969) who noted that a major problem of forest fertilization with respect to water quality can be direct application to streams. As indicated by the analysis of the urea pellets, most of the nitrogen in the pellet is detected by the Kjeldahl test; hence, the immediate high values of Kjeldahl-N in the stream seem to indicate the presence of large amounts of dissolved urea resulting from direct application.

The initial increase in nitrate-N also was likely caused by direct application. The maximum observed level of 0.25 mg/l is assumed to have originated in the pellets, which contained over 19 mg/kg of nitrate-N. The extended duration of the elevated nitrate levels suggests temporary retention in the soils and vegetation and a gradual movement to the receiving stream.

The rise in nitrate at the upstream station at the time of fertilization cannot be readily explained. It seems likely that application to that part of the stream occurred accidentally.

The secondary rise in nitrate-N levels which occurred in late summer and fall correlates with precipitation data. Table 2 shows daily rainfall for a two-week period following initiation of the experiment, and monthly totals to January 1970.

Downstream nitrate levels increased through October, sharply decreased in November, and remained at approximately the November level into January. The upstream station reacted similarly but to a much lesser degree. The decrease after October might be attributed to the following: (1) the heavy rains in September and October may have resulted in movement of most of the nonassimilated fertilizer into the stream during that period, or (2) there may have been a more or less continuous supply of nitrate to the receiving stream throughout the fall and into January but the concentrations were reduced as the volume of flow of the stream increased.

It is interesting to compare the results of our work to Cole and Gessel (1965) who reported from their work with lysimeters that 65 percent of the nitrogen from

TABLE 2. Precipitation as recorded at Detroit Dam.

Daily	Inches	Monthly	Inches
May 14	.57		
May 15	.12	June	8.26
May 18	.01	July	0.15
May 19	.72	August	0.08
May 20	.19	September	3.91
May 25	T*	October	7.29
May 26	.25	November	5.06
May 27	.61	December	15.62
May 28	.13	January	24.19
May 29	T*		
May 30	1.18		

* Trace

a urea application to a Douglas-fir forest passed through the top one inch (2.5 cm) of the forest floor during a 30-day period of heavy rains. This same work, however, showed essentially no nitrogen lost beyond the 36-inch (91.4 cm) soil depth.

An attempt was made to correlate daily precipitation records with the May nitrate samples. Although there was a general decline in nitrate during May following fertilization, a temporary rise which occurred at both stations near the end of the month corresponded closely to increased precipitation.

The results of our study appear to agree well with those of McCall (1970), who found that aerial application of fertilizer resulted in rapidly increased urea concentrations in the water, and that this was probably due to direct fallout into the water. He also found that urea levels decreased to background values in a relatively short time and that after a month the nitrogen lost from the land appeared to be in the form of nitrate only.

From the point of view of eutrophication, aerial forest fertilization with urea can be a process by which an important algal nutrient is added to the aquatic ecosystem. As shown in this study, direct application to the water can increase nitrogen levels manyfold. Although, as in the case of Crabtree Creek, these elevated values rapidly returned to base line levels, the nitrogen had not disappeared from the water but was simply displaced downstream. Depending on the size and rate of flow of the affected waterway, directly applied nitrogen could be of importance in stimulating unwanted biological production. Therefore, efforts should be made wherever possible to prevent such direct applications.

Our study has further shown that fertilization of the watershed immediately adjacent to the stream results in movement of nitrogen to the water during periods of rainfall. As Cooper (1969) has pointed out, attention must be paid to the riparian zones adjacent to streams, where fertilizers have only a short distance to move to reach the water. He has also noted, however, that fertilization of sites at a distance from streams is less apt to be a problem.

This problem of effect of forest fertilization on adjacent water courses should receive continuing study. Samples should be collected with a greater frequency and composited according to measured stream flow so that an estimate of fertilizer lost to the water course can be calculated. A thorough study of this type would delineate the ground rules for future fertilizer applications.

Acknowledgments

We are most grateful to Willamette Industries for making this study possible. We are especially indebted to Mr. Robert L. McNitt who acted as liaison for the company and gave much assistance in setting up and maintaining the field program, and to the late Mr. Albert Odermatt who carried out the stream sampling.

Literature Cited

Brix, H., and L. F. Ebell. 1969. Effects of nitrogen fertilization on growth, leaf area, and photosynthesis rate in Douglas-fir. Forest Sci. 15 (2): 189-196.

Broadfoot, W. M. 1966. Five Years of Nitrogen Fertilization in a Sweetgum-Oak Stand. U.S. Forest Serv. Res. Note SO-34. 3 p.

Cole, D. W., and S. P. Gessel. 1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. p. 95-104. *In* C. T. Youngberg (ed.) Forest-soil Relationships in North America. Proceedings of Second North American Forest-Soils Conference. Oregon State Univ. Press, Corvallis, Oregon. 532 p.

Cooper, C. F. 1969. Nutrient output from managed forests. p. 446-463. *In* Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences. Washington, D.C. 661 p.

Gessel, S. P., T. N. Stoate, and K. J. Turnbull. 1965. The Growth Behavior of Douglas-fir with Nitrogenous Fertilizer in Western Washington—A First Report. Univ. Washington Res. Bull. No. 1. 204 p.

Klem, G. S. 1968. Qualities of wood from fertilized forests. TAPPI 51 (11): 99A-103A.

McCall, M. 1970. The Effects of Aerial Forest Fertilization on Water Quality for Two Streams in the Capitol Forest. Washington State Dept. of Ecology, Daniel J. Evans, Governor; John A. Biggs, Director. 20 p.

Reukema, D. L. 1968. Growth Response of 35-Year-Old, Site V Douglas-fir to Nitrogen Fertilizer. U.S. Forest Serv. Res. Note PNW-86. 9 p.

U.S. Department of Commerce. Environmental Science Services Administration. 1969. Climatological Data. Vol. 75. Oregon. 253 p.

U.S. Department of Interior. Federal Water Pollution Control Administration, Division of Water Quality Research. 1969. FWPCA Methods for Chemical Analysis of Water and Wastes. Anal. Quality Control Lab., Cincinnati, Ohio. 280 p.

Received February 25, 1971.

Accepted for publication August 16, 1971.