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EFFECTS OF FOREST FERTILIZATION ON SELECTED ION CONCENTRATIONS IN CENTRAL APPALACHIAN STREAMS[1]

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Abstract.--Two small forested watersheds were fertilized in April 1976 with 336 kg/ha N as ammonium nitrate and 224 kg/ha P_2O_5 as triple superphosphate in order to determine fertilization effects on streamflow chemistry. Specific conductance and the concentration of nitrate-N and calcium in streamflow increased dramatically after fertilization. After reaching maximum concentrations in October 1976, fertilization effects declined gradually and concentrations were elevated only slightly in July 1979 when intensive sampling ended.

INTRODUCTION

Modern agriculture requires the use of inorganic fertilizer to maximize crop yields. Since the demand for all forest products is expected to increase during the next few decades (USDA For. Serv. 1982), foresters naturally ask if fertilization will increase the growth rate of trees. Forest fertilization is a relatively new management practice that is limited to areas where potential growth is greatest. Operational forest fertilization began in the Pacific Northwest in 1965 and in the southeastern pine region in 1968 (Moore and Norris 1977). Nitrogen and phosphorus usually are applied because the major coniferous timber types have responded best to these two nutrients (Ballard 1984).

A study of forest fertilization in the central Appalachians began in 1973 on the Fernow Experimental Forest near Parsons, West Virginia. Studies were imposed to determine nitrogen and phosphorus fertilizer effects on: (1) Overstory and understory growth rates; (2) Leaf size and annual leaf litter production; (3) Selected chemical characteristics of streamflow.

[1]Paper presented at the 7th Central Hardwood Forest Conference, Southern Illinois Univ., Carbondale, Illinois, March 5-8, 1989.

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Effects of fertilization on growth rates were reported by Lamson (1980) and effects on leaf production were reported by Kochenderfer and Wendel (1982). This paper reports the effects of fertilization on streamflow chemistry and defines the duration of those effects.

THE STUDY AREA

The study was conducted on the Fernow Experimental Forest in the central Appalachian Mountains near Parsons, West Virginia. Two pairs of small adjacent watersheds were chosen: one pair had a southern exposure and one pair had a northwestern exposure (Fig. 1). Slopes are steep, averaging 30 to 40 percent, and average elevation is 610 m. The soils are Calvin channery silt loams (loamy-skeletal, mixed, mesic, Typic Dystrochrept). These soils are well-drained and strongly acidic, with moderate permeability.

Vegetation is dominated by second growth hardwoods with a scattering of older trees that were left after logging between 1900 and 1910. The most abundant species on the northwest-facing watersheds were American beech (Fagus grandifolia Ehrh.), northern red oak (Quercus rubra L.), sugar maple (Acer saccharum Marsh.), sweet birch (Betula lenta L.) and red maple (Acer rubra L.). On the south watersheds, northern red oak, chestnut oak (Quercus prinus L.), red maple, white oak (Quercus alba L.), sugar maple, and sweet birch were most abundant. Basal area of all trees larger than 12.5 cm in diameter (measured at approximately 140 cm above groundline) averaged 24.1 m^2/ha on the south-facing watersheds and 22.9 m^2/ha on the northwest-facing watersheds.

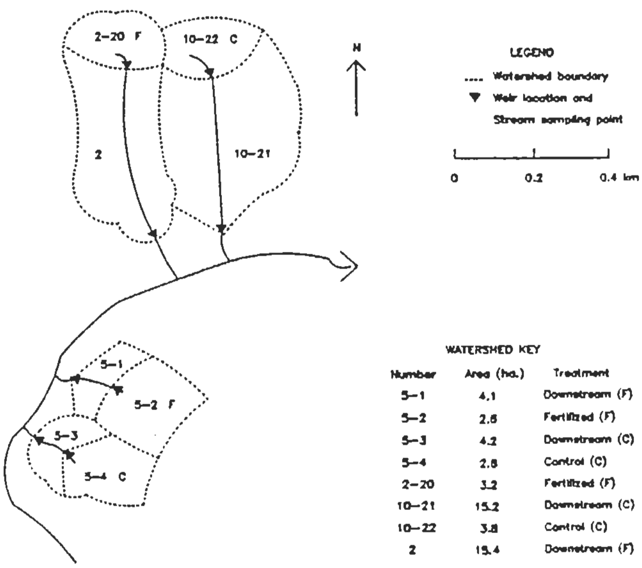

Figure 1.--Location and relative size of watersheds in this study.

Annual precipitation is distributed evenly between the dormant and growing seasons, averaging 148 cm on a nearby control watershed for a 29-year period. Annual runoff from the control watershed for the same period averaged 63.5 cm, 15.2 cm during the growing season and 48.3 cm during the dormant season. Potential evapotranspiration on the Fernow Experimental Forest was estimated at 55.9 cm per year (Patric and Goswami 1968).

METHODS

Streamflow was measured at the mouth of each watershed with a sharp-crested V-notch weir and FW-1 water-level recorder. Monthly streamflow volumes were summarized by computer at the Coweeta Hydrologic Laboratory at Otto, North Carolina.

Each stream was grab-sampled with plastic bottles just upstream from the weir beginning in August 1972. Samples usually were taken every 7 days; however, some sampling periods were slightly longer or shorter depending upon accessibility, weather, etc. No sampling periods were shorter than 5 days or longer than 9 days, and all streams were sampled on the same day. To assess the downstream dilution effect of fertilization on stream chemistry, samples also were collected downstream from both subwatershed pairs (Fig. 1). The drainage area of the downstream sampling point below the south fertilized watershed is about 15.4 ha and the distance is about 450 m. Comparable area and distance downstream from the northwest-fertilized watershed is 4.1 ha and 150 m.

The watershed pairs were calibrated for selected stream chemical constituents over a 33-month period: on April 28 and 29, 1976, one of the northwest-facing watersheds (northwest-fertilized) and one of the south-facing watersheds (south-fertilized) were treated with 336 kg/ha N as ammonium nitrate and 224 kg/ha P_2O_5 as triple superphosphate. The choice of these fertilizers and application rates was based on research by Auchmoody and Filip (1973). They measured a significant growth increase by northern red oak and yellow-poplar after a similar application of fertilizer to a mixed hardwood stand on the Fernow Experimental Forest. A grid of 30.5 x 30.5-m squares was established on the fertilized watersheds, and a premeasured amount of fertilizer was hand-broadcast with cyclone seeders onto each of these squares. This procedure provided an even distribution of fertilizer. Care was taken to avoid applying fertilizer directly into the streams. The two untreated watersheds (northwest control and south control) were maintained in their natural condition.

Routine grab sampling continued on each of the 4 subwatersheds and 4 downstream locations through April 1979. Watersheds 5-2 and 5-4 were sampled biweekly in 1986 and 1987 to determine whether fertilization effects had disappeared.

The samples were analyzed at the Northeastern Forest Experiment Station's Timber and Watershed Laboratory in Parsons. The 1973-79 calcium, sodium, magnesium, and potassium determinations were made with a 390-B Perkin Elmer atomic absorption spectrophotometer. Nitrate and phosphate were determined colorimetrically with a Bausch and Lomb Model 10 spectrophotometer and Nitro Ver IV and Phos Ver III powder pillow chemicals, respectively (Hach Chemical Co. 1975). Sample pH and conductivity were determined with a Model 10 Corning meter and Industrial Instruments Solu-Bridge meter, respectively. Samples collected in 1986 and 1987 were analyzed as follows: Anions: Dionex Model 10 ion chromatograph; Cations: Model 503 Perkin Elmer atomic absorption spectrophotometer; pH: Altex digital pH meter; conductivity: Markson Model 1096 digital meter. Comparison tests between each old and new instrument indicated good agreement between each pair.

For this paper, stream-chemistry data were analyzed by plotting average monthly concentrations of each constituent over time. No statistical tests for fertilization effects were performed. Instead, graphs are used to illustrate changes in stream chemistry caused by fertilization.

RESULTS AND DISCUSSION

A graph for each constituent that was affected by the fertilizer is presented. Where both fertilized watersheds responded about equally, results from only one fertilized watershed and its control are presented. Downstream dilution effects are illustrated with graphs that show concurrent concentration at the outlet of the fertilized watershed and the sampling site downstream.

Specific Conductance. Before fertilization, specific conductance of streamflow from both watershed pairs was similar, averaging about 28 µS/cm. Monthly streamflow was low during the first 5 months after fertilization (Fig. 2). In October 1976, streamflow increased in response to abundant rainfall, and specific conductance of streamflow from both fertilized watersheds increased to 140 µS/cm (Fig. 3). Average monthly conductance fluctuated in response to monthly streamflow during the 1976-77 dormant season. Conductance decreased gradually after November 1977; when the study ended in 1979, conductance of the fertilized streams averaged about 40 µS/cm, about 10 µS/cm greater than that of the controls. In 1986 and 1987, streamflow conductance from both fertilized and control watersheds averaged about 32 µS/cm, indicating that the effects of fertilization on stream chemistry had essentially disappeared.

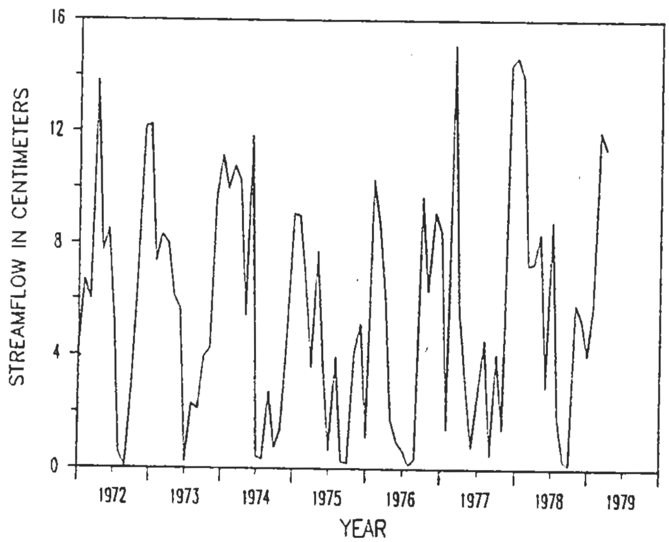

Figure 2.--Measured monthly streamflow from control watershed on Fernow Experimental Forest from 1973-79.

Although specific conductance is a sensitive indicator of total dissolved solids, it gives no indication of the concentration of individual ions. Thus, results for specific conductance indicate major changes in ionic strength of stream water after fertilization. On the basis of previous research (Aubertin et al. 1973), we expected major changes in streamflow concentrations of nitrate-nitrogen and calcium after fertilization.

Nitrate-Nitrogen. Nitrate-N responded in a similar fashion to specific conductance (Fig. 4). Concentrations increased from both fertilized watersheds 5 months after fertilization. Maximum monthly concentrations were 8.5 and 7.3 mg/l on the northwest-facing and south-facing fertilized watersheds, respectively.

Maximum concentration of individual stream samples from the south-facing fertilized watershed was 11 mg/l on September 27, 1976, and the maximum from the northwest-facing fertilized watershed was 13 mg/l on October 4, 1976. Nitrate-N concentrations increased and decreased in response to increases and decreases in flow rate from October 1976 to April 1978. After April 1978, concentrations decreased gradually and were only about 1.0 mg/l when the intensive sampling ended in 1979. In 1986 and 1987, nitrate-N was slightly higher in the fertilized (0.9 mg/l) than in the control (0.5 mg/l) streams; however, these differences are small when compared to the magnitude of the nitrate-N values immediately following fertilization

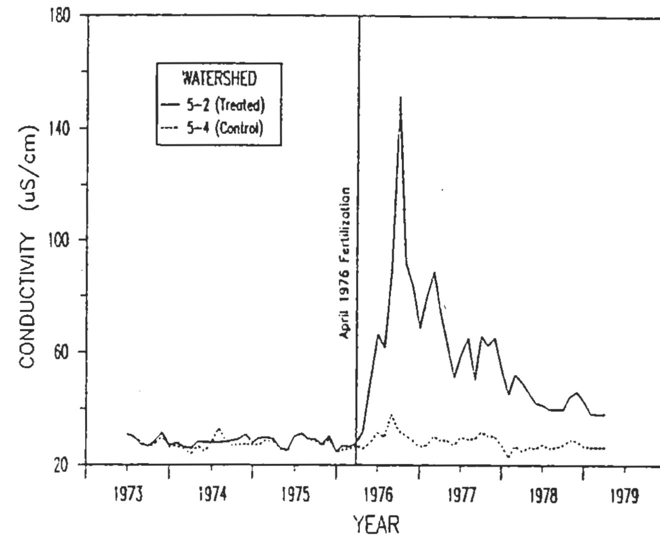

Figure 3.--Average monthly conductivity (µS/cm) of streamflow from Watersheds 5-2 and 5-4. Specific conductance of Watersheds 2-20 and 10-22 responded similarly.

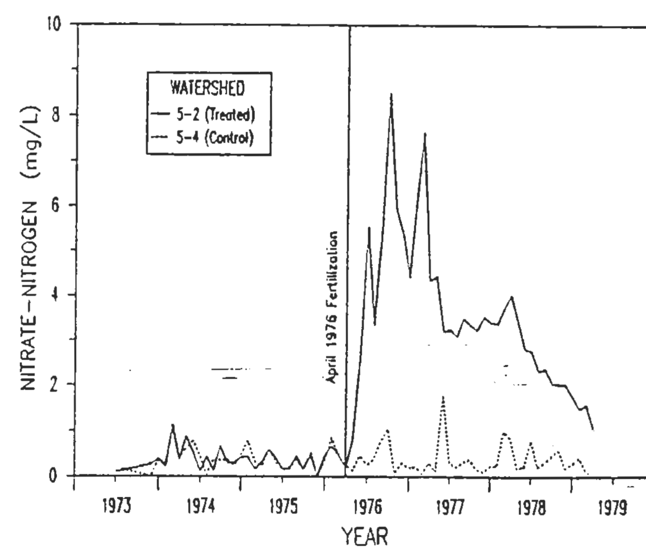

Figure 4.--Average monthly streamflow concentrations of nitrate-nitrogen (mg/l) from Watersheds 5-2 and 5-4. Nitrate-N concentrations of streamflow from Watersheds 2-20 and 10-22 responded similarly.

Calcium. Calcium concentrations increased sharply about 5 months after fertilization (Fig. 5). After the peak in October 1976, concentrations decreased rapidly until the growing season of 1977 began, then decreased gradually for the remainder of the study. When the study ended in 1979, calcium levels were still about 1 mg/l greater than before fertilization. In 1986 and 1987, average concentration of calcium in streamflow from fertilized and control watersheds was the same (1.9 mg/l).

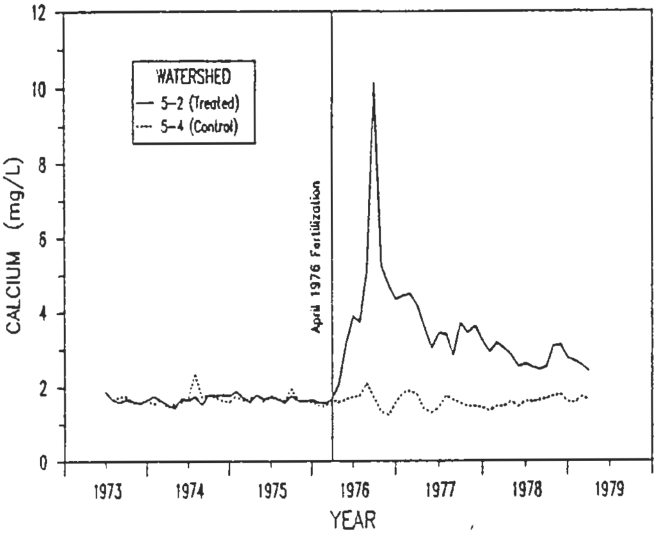

Figure 5.--Average monthly streamflow concentrations of calcium (mg/l) from Watersheds 5-2 and 5-4. Calcium concentrations of streamflow from Watersheds 2-20 and 10-22 responded similarly.

Phosphate-phosphorus. Since 224 kg/ha of P_2O_5 were applied to the watersheds, streamflow was monitored for changes in concentrations of PO_4-P. Before fertilization, concentrations of all sampled streams averaged about 0.05 mg/l PO_4-P. There were no obvious changes in concentration after fertilization (Fig. 6). This result was not surprising since other studies (Black 1968; Tiedemann et al. 1978) reported a low degree of mobility for PO_4-P. In acidic forest soils, phosphorus leaching is minimal, even after fertilization, because most of the phosphorus is quickly immobilized via solubility reduction reactions involving aluminum and iron (Black 1968; Khanna and Ulrich 1984). Some added phosphorus also may have been assimilated immediately or over time by microorganisms or vegetation.

Other Chemical Constituents. Average annual pH of streamflow from the fertilized watersheds decreased from 5.3 before fertilization to 5.05 during the first year after fertilization. During the last year of intensive sampling, pH averaged 5.2. The concentrations of potassium, sodium, and magnesium increased slightly after fertilization. However, because the magnitudes were small, no figures are presented here.

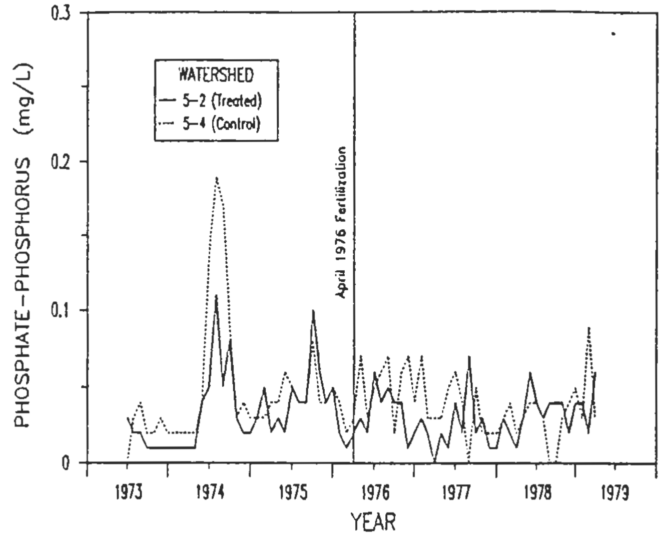

Figure 6.--Average monthly streamflow concentrations of PO_4-P (mg/l) from Watersheds 5-2 and 5-4. There was no obvious effect of fertilization.

The fertilizers caused indirect effects on ionic outputs. Calcium concentrations increased within a few months after fertilization, and levels remained elevated for more than 3 years. Changes in other constituents including pH, magnesium, and sodium were small. Briefly, when excess ammonium nitrate is applied to an ecosystem, the ammonium is oxidized by microbes to produce nitrate (Carlyle 1986), which is more mobile than ammonium. Also, production of hydrogen ions during nitrification can lead to increased cation loss and can increase the concentration of base cations in solution as a result of cation exchange (Carlyle 1986). These anion/cation processes probably were responsible for the observed increases in nitrate, calcium, and potassium concentration, and the slight decrease in streamflow pH levels.

Although concentrations of some ions increased following fertilization, water quality remained within drinking water standards (Public Health Serv. 1962) except for 3 weeks in September and October 1976 when NO_3-N concentrations exceeded the 10-mg/l standard. Even these excessive concentrations decreased to acceptable levels as the water flowed several hundred meters downstream where it became diluted with water from unfertilized areas. Thus, forest fertilization in the hardwood type of the central Appalachians seems an acceptable practice with regard to water quality.

Downstream Dilution. Downstream effects are important considerations of forest management activity on a headwater stream. Since nitrate is an important ion from the standpoint of municipal water supplies and human and domestic animal consumption, only the downstream effects on NO_3-N are presented (Fig. 7). On the northwest-facing watersheds, nitrate-N concentrations were diluted downstream as water from unfertilized areas mixed with water from the fertilized watershed. As expected, downstream dilution was greater on the south watershed because the unfertilized drainage area and resulting streamflow volume were approximately 3 times greater than for the northwest-facing watersheds (Fig. 1).

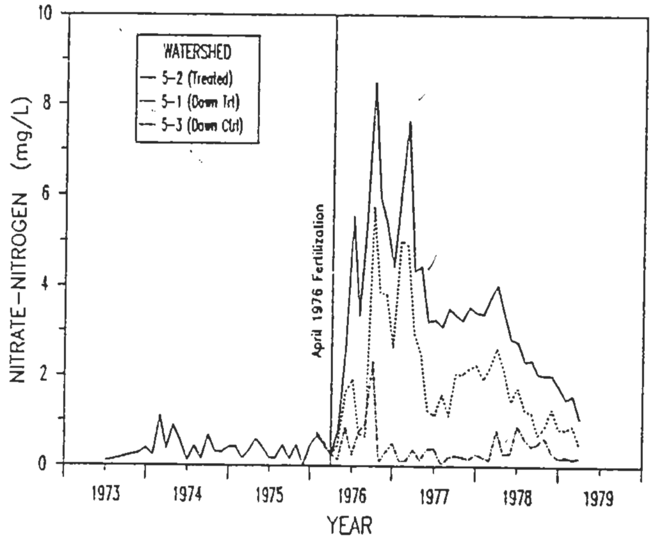

Figure 7.--Average monthly streamflow concentrations of nitrate-N (mg/l) from fertilized Watershed 5-2 (top graph), Watershed 5-1 located about 100 meters downstream of fertilized area (middle graph), and Watershed 5-3 control (bottom graph).

CONCLUSION

Stream-water chemistry was affected more by ammonium nitrate than by the triple superphosphate fertilizer. Nitrate-nitrogen concentrations increased sharply following fertilization, and these elevated levels remained for more than 3 years on both the northwest-facing and south-facing slopes. By contrast, phosphate output levels showed no obvious changes as a result of fertilization.

LITERATURE CITED

Aubertin, G. M., D. W. Smith, and J. H. Patric. 1973. Quantity and quality of streamflow after urea fertilization on a forested watershed: First-year results. In: Proceedings of the symposium on forest fertilization. USDA For. Serv. Gen. Tech. Rep. NE-3. p. 88-100.

Auchmoody, L. R., and S. M. Filip. 1973. Forest fertilization in the United States hardwoods. In: Proceedings of the symposium on forest fertilization. USDA For. Serv. Gen. Tech. Rep. NE-3. p. 211-222.

Ballard, R. 1984. Fertilization of plantations. In: Nutrition of plantation forests. Bowen, G. D., and E. K. S. Nambiar, eds. Academic Press, New York. 516 p.

Black, C. A. 1968. Soil plant relationships. John Wiley and Sons, New York. 792 p.

Carlyle, J. C. 1986. Nitrogen cycling in forested ecosystems. For. Abstr. 47(5): 307-336.

Hach Chemical Company. 1975. Hach water and wastewater analysis procedures manual. Hach Chemical Co., Ames, Iowa. 186 p.

Khanna, P. H., and B. Ulrich. 1984. Soil characteristics influencing nutrient supply in forest soils. In: Nutrition of plantation forests. Bowen, G. D., and E. K. S. Nambiar, eds. Academic Press, New York. 516 p.

Kochenderfer, J. N., and G. W. Wendel. 1982. Effects of fertilization and aspect on leaf biomass, leaf size, and leaf area index in central Appalachian hardwood stands. Muller, Robert N., ed. In: Proc., 4th central hardwood for. conf. Nov. 8-10, 1982, Lexington. University of Kentucky, Lexington. p. 102-112.

Lamson, Neil I. 1980. Effects of fertilization on four species in mature Appalachian hardwood stands. In: Proc., 3rd central hardwood for. conf. Sep. 16-17, 1980, Columbia, Missouri. p. 449-457.

Moore, Duane G., and Logan A. Norris. 1977. The use of fertilizers and pesticides in forest management and their impact on water quality. Aubertin, G. M., ed. In: Proc., "208" symposium on non-point sources of pollut. from for. land. Southern Illinois Univ., Dep. Forestry, Carbondale, Illinois. p. 233-255.

Patric, James H., and Niranjan Goswami. 1968. Evaporation pan studies--forest research at Parsons, WV. Agric. and For. 1(4): 6-10.

Public Health Service. 1962. Public Health Service drinking water standards. U.S. Dep. Health Educ., and Welfare, Washington, D.C. 61 p.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in eastern Washington. J. Environ. Quality 7(4): 580-588.

U.S. Department of Agriculture, Forest Service. 1982. An analysis of the timber situation in the United States 1952-2030. USDA For. Serv. Resour. Rep. No. 23. 499 p.