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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 P₂O₅ 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 fertilizers 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 1955 and in the southwestern 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. Soils 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.

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Effects of fertilization on growth rates were reported by Lameon (1985) 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 these 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 60 percent, and average elevation is 610 m. The soils are Calvin chernozem with loamy-skeletal, mixed, mesic, Typic Dystrochrepts. 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 rubrum L.). On the south-facing watersheds, northern red oak, chestnut oak (Quercus prinus L.), red maple, white oak (Quercus alba L.), sugar maple, and sweet birch were most abundant. Sample area of all trees larger than 10.2 cm in diameter (measured at approximately 140 cm above groundline) averaged 20.1 m²/ha on the south-facing watersheds and 22.9 m²/ha on the northwest-facing watersheds.

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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 P2O5 as triple superphosphate. The choice of these fertilizers and application rates was based on research by Auchmood and Fillip (1971). 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 prescribed amount of fertilizer was hand-broadcast with cyclonic 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 1-2 and 5-6 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 390-8 Perkin Elmer atomic absorption spectrophotometer. Nitrate and phosphate were determined colorimetrically with a Bausch and Lomb Model 10 spectrophotometer and Hitec UV IV and Pons UV 115 powder pill colorimeters, respectively (Batcher et al. Co. 1971). Sample pH and conductivity were determined with a Model 10 Corning meter and Industrial Instruments Solubility meter, respectively. Samples collected in 1986 and 1987 were analyzed as follows: Anders: Dionex model 10 Ion chromatograph; Cations: Model 580 Perkin Elmer atomic absorption spectrophotometer; pH: Altec-Digital, pH meter; conductivity: Model 109, Beckman 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 each watershed pair was similar, averaging about 28 µS/cm. Monthly streamflow was low during the first 5 months after fertilization (Fig. 2). In October 1979, streamflow increased in response to abundant rainfall, and specific conductance of streamflow from both fertilized watersheds increased to 150 µS/cm (Fig. 3). Average monthly conductance illustrates 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 3: Average monthly conductivity (µS/cm) of streamflow from Watersheds 2-2 and 2-4. Specific conductance of Watersheds 2-20 and 10-22 responded similarly.](image)

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. 1993), we expected major changes in streamflow concentrations of nitrate-nitrogen and calcium after fertilization.

Nitrate-Nitrogen. Nitrate-H increased 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, 1979, and the maximum from the northwest-facing fertilized watershed was 13 mg/L on October 4, 1979. 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 (0.5 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.
Calcium. Calcium concentrations increased sharply about 3 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).

![Graph showing calcium concentrations](image)

Figure 5.—Average monthly streamflow concentrations of Ca (mg/l) from Watershed 3-2 and 5-4. Calcium concentrations of streamflow from Watershed 3-2 rapidly decreased after fertilization, while concentrations from Watershed 5-4 showed a gradual decrease.

Phosphate—phosphorus. Since 224 kg/ha of P-2O5 were applied to the watersheds, streamflow was monitored for changes in concentrations of P2O5-P. Before fertilization, concentrations of all sampled streams averaged about 0.05 mg/l P2O5-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 P2O5-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; Duane 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.

![Graph showing pH changes](image)

Figure 6.—Average monthly streamflow concentrations of P2O5-P (mg/l) from Watershed 3-2 and 5-4. There was no obvious effect of fertilization on P2O5-P concentrations.

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 nitrites 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 phosphorus 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. 1982) except for 3 weeks in September and October 1976 when NO3-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 Appalachian region has 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 NO3-N are presented (Fig. 7). On the northwest-facing watersheds, nitrate-N concentrations were diluted...
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 northeast-facing and southwest-facing slopes. By contrast, phosphate output levels showed no obvious changes as a result of fertilization.

LITERATURE CITED


