SOME EFFECTS OF UREA FERTILIZATION ON A FORESTED WATERSHED IN WEST VIRGINIA

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ABSTRACT

A 75-acre watershed on the Fernow Experimental Forest, near Parsons in West Virginia, was fertilized in May 1971 with 500 pounds of urea per acre. It had a dense stand of 12-year-old hardwood sprouts and seedlings, natural regrowth after clear-cutting in 1958. The effects on soil-plant-water relations have been observed since fertilization. Samples of mineral soil were analyzed for total nitrogen, phosphorus, potassium, calcium, and magnesium. The concentration of nitrogen, unchanged in north-slope soil, was significantly lower on south-slope soils during 1972 and 1973. Analyses of yellow-poplar buds for the same nutrients showed significantly increased content of nitrogen but only in 1972. A significant streamflow decrease of 1.23 inches accompanied a throughfall decrease of 0.89 inch in 1972. There was no change in stream pH or in its content of ammonium-N, phosphate-P, iron, potassium, copper, zinc, or manganese. Increased specific conductance after fertilization reflected temporarily increased stream content of calcium (3 years), nitrate (2 years) and of magnesium and sodium (1 year). Sulfate content of the stream decreased, but only in 1971. The disposition of urea-N is reckoned as about 20 percent lost to streamflow, up to 50 percent volatilized, 5 percent remaining in the standing phytomass, and the balance probably mobile in the soil and associated organic matter.

INTRODUCTION

Several reviews have summarized the knowledge concerning fertilization and its effects on forests of the eastern United States (TVA 1968, USFS 1973, Bernier and Winget 1975). These references thoroughly document the value of forest fertilization for increasing tree growth, so the effects were not re-measured in this study. Little is gained by repeating the voluminous information in these readily accessible references. One or more pertinent papers are cited as "lead-ins" to some of the results and discussion that follow. One such paper (Aubertin et al. 1973) provides first-year results of the study concluded by this report; it should be consulted for detailed background information and for first-year effects of fertilization not presented here. We emphasize the longer-term effects of urea fertilization on soil and water relations. The following brief description will orient readers to the study watershed, its treatment, and analytical methods.

The Study Watershed

This research was conducted on the Fernow Experimental Forest, in the Allegheny mountain region, near Parsons in north-central West Virginia. The study area is an east-facing watershed of 75 acres with an average slope of 40 percent. Elevation ranges from 2,100 to 2,800 feet. It supports a dense stand of hardwood sprouts and seedlings, natural reproduction after clearcutting in 1958. Predominant species include oaks, maples, beech, yellow-poplar, basswood, and black cherry. The stand averaged about 30 feet tall in 1970 with a basal area of 43 square feet per acre in trees more than 5 inches dbh. The soil, Calvin channery silt loam, is derived from sandstone and acid shale. Reaction normally ranged from pH 4.5 to 5.5. Soil depth ranges from 2 to 5 feet, with an average depth of 32 inches. Precipitation (average 58 inches/year) on the forest is sampled with a 19-gage network. Streamflow (average 23 inches/year) is recorded continuously using 120° V-notch weirs.

The nearby control watershed is similar in all respects except its tree cover, which is mature and undisturbed hardwood. Before fertilization, some dissolved solids (notably NO_3, Ca, Mg, and SO_4) were more abundant in streamflow from the treated watershed than from its control (Aubertin et al. 1973, table 5). These differences, well within the expected range of normal variation among forest streams, are attributed to the influences of limestone, nearby but not discovered in bedrock of the treated watershed.

METHODS

Samples of yellow-poplar buds and of mineral soil were collected in mid-April, 1971 through 1973. Buds were used because tree leaves seldom emerge until late in May. Buds and soils were sampled from randomly selected plots on the 71-acre portion of the watershed to be fertilized. Soil was sampled on 15 northerly and 4 southerly plots. The drier, shallower soils on south slopes supported smaller, more xerophytic tree species. Soils were sampled at the 0 to 2-inch and 2 to 10-inch depths. Buds were sampled on 15 randomly-selected plots containing yellow-poplar trees. Buds and soils were similarly sampled and analyzed from three plots on a 4-acre area near the western rim of the watershed that was not fertilized. The Agrico Company's laboratory at Washington Courthouse, Ohio, analyzed soil and bud samples for total N, extractable P, K, Ca, and Mg and measured soil pH.[1]

Methods to quantify the effects of watershed treatment on amount of streamflow were reported in detail by Reinhart et al. (1963), and on quality of water by Aubertin et al. (1973).

Water sampling was intensive, at intervals averaging 15 minutes just before fertilization and for 3 days afterward. More than 460 samples were taken in the first month after urea application, and more than 640 during the 1971 growing season. As occasionally happens in dry weather, the stream did not flow for part of the summer; at these times, intensive sampling was possible only during intermittent stormflow. Weekly sampling became the rule after constant flow resumed in September, with greater frequency during stormflows. This schedule was followed on the control as well as the treated watershed. Water samples were analyzed at the Parsons laboratory for specific conductance, pH, NO_3-N, ammonium-N, PO_4-P, SO_4-S, Ca, Mg, K, Na, Fe, Cu, Mn, and Zn.

Throughfall was observed during the growing seasons before (1970) and after (1971) fertilization. Methods and terminology were as recommended by Helvey and Patric (1965). Gross rainfall was sampled in a standard rain gage, at a forest opening near the middle of the treated watershed. Four circular plots of 0.1 acre were established in hardwood reproduction surrounding the forest opening. Throughfall was sampled in 20 food cans of 1-gallon capacity, randomly located on two of the circular plots. Can catch was measured per storm, then converted to average depth of throughfall. After storms, cans were placed at new randomly chosen locations within plots. The cans were moved to the other pair of plots monthly.

Treatment

A helicopter fertilized the study watershed in mid-May of 1971, spreading prilled urea supplied by the Agrico Chemical Company of Memphis, Tennessee. We planned to apply 500 pounds of urea per acre (230 pounds of nitrogen); actual distribution ranged from 400 to 600 pounds of urea per acre. No attempt was made to avoid placing it directly in the stream. The helicopter spread about half of this fertilizer in the late afternoon of May 14, flying north-south courses across the 71-acre treated portion of the watershed. The remainder was spread on east-west flights during the forenoon of May 15, again over the entire treated portion of the watershed. The 4-acre untreated tract near its western rim was not fertilized.

Although weather is not ordinarily reported as a treatment, it is so reported here because of the great influence it probably had on disposition of the urea. Weather of this pattern always is possible, though probably not common, anywhere in eastern United States.

A small (0.05 inch) shower of rain fell during the early evening of May 14. Three more drizzly showers of 0.16, 0.09, and 0.01 inch fell during the afternoon and evening of May 15. These rains dissolved most of the urea prills, leaving a whitish film over much of the forest floor. The entire application of fertilizer was dissolved but remained on or near the surface of litter covering the forest floor. These showers were insufficient in volume or intensity to carry the dissolved urea into the underlying mineral soil. Warm and often sunny weather prevailed through May 24. Several more showers, totalling only 0.81 inch of rain, fell between May 25 and June 1. With tree leaves emerging late in May, the forest floor was fully exposed to sun, rain, and wind for several days after urea was applied.

Rates of pan evaporation were high at Parsons from May 15 to 31, ranging from 0.09 inch on rainy days to 0.24 inch on sunny days (Environmental Data Service 1971).

RESULTS

A. Losses by Volatilization: Our evidence concerning volatilization is circumstantial. For example, Aubertin et al. (1973) observed an ammonia odor, detectable within 60 hours after urea application and persisting for about a week. At this time moss turned brown, mayapples and other ground vegetation suffered substantial leaf damage all across the watershed, presumably from ammonia poisoning or from ammonia salt concentration. No other changes in minor vegetation were observed.

We were unequipped to measure urea losses by volatilization but the literature provides clues to those likely. Watkins et al. (1972) reported 27 to 46 percent loss of the urea-N applied to litter-covered forest soils, with additional loss possible as nitrogen oxide. These losses persisted up to 20 days after application, although most occurred within the first 5 days. We hypothesize that under near-optimal conditions for volatilization, at least one-third and possibly as much as one-half of the urea-N applied is lost by volatilization. Most of the literature confirms that heavy applications of urea followed by high rates of evaporation can lead to losses of this magnitude (Morrison and Foster 1977).

B. Amounts in Soil: Results of soil analyses were highly variable; differences among all minerals except total nitrogen (Kjeldahl) were unrelated to urea application. Before fertilization, Duncan's multiple range test showed no significant difference among nitrogen contents of soil samples, regardless of their origin. Total nitrogen was significantly ($P < 0.05$) lower each year in soil from south-facing plots for 2 years thereafter (table 1). This result suggests a net decrease in nitrogen content of mineral soils on south slopes. The reasons for this are not known, but it probably was not caused by fertilization.

C. Urea-N Incorporated into the Standing Phytomass: Before fertilization, there was no significant difference in chemical composition of yellow-poplar buds, regardless of their origin on the watershed. After treatment, total (Kjeldahl) nitrogen content was significantly ($P < 0.05$) higher (0.26%) in buds of yellow-poplar from the treatment area (2.56% N) than in buds from the 4-acre untreated area (2.30% N). By 1973, buds from both areas again were similar in chemical composition.

With the following assumptions, the amounts of urea-N incorporated into trees can be estimated:

1. Nitrogen content of foliage on trees of the fertilized area increased 0.26 percent.
2. Annual foliage production of Appalachian hardwoods averages 3,400 pounds per acre (Helvey 1964).
3. About one-third as much nitrogen as went into foliage probably was incorporated into tree stems and roots.

If these assumptions are correct, about 12 pounds of urea-N per acre, almost 5 percent of that applied, was incorporated into the standing phytomass. These results agree well with reports by Day (1974) and by Duvigneaud and Denaeyer-DeSmet (1970). At leaf fall, the nitrogen in leaves was recycled (i.e. returned to the soil).

D. Throughfall: Regression analysis showed reduced throughfall after fertilization (table 2). The "before" equation is based on 18 storms in 1970, the "after" equation on 19 storms in 1971. Throughfall was not sampled in 1972 when leaves probably attained maximum dimensions. The "after" equation was applied to rainfall in the 1972 growing season to obtain an estimate of throughfall for that year. A literature review by Auchmoody and Filip (1973) concluded that tree leaf size, mass, and numbers are temporarily increased by nitrogen fertilization and that these responses often are greatest during the second year after fertilization. Their conclusions, too, suggest that throughfall is only temporarily decreased.

E. Streamflow Increase: Increased interception losses are known to decrease flow in forest streams. Swank et al. (1972) even predicted a 25 percent reduction of the regional water supply if conversion of southern hardwoods to pines of greater rainfall intercepting capacity continued.

Changes in water yield are quantified by regression analysis, using measured flows from the treated and control watersheds in equations based on pretreatment streamflow. During posttreatment years, the difference between measured flow and flow estimated by regression is accepted as the effect of treatment on water yield. The effect of urea fertilization on water yield was slight, with the only significant ($P < 0.05$) difference a 1.23-inch decreased yield during the 1972 growing season. The throughfall decrease for 1972 was of similar magnitude (0.89 inch) and presumably caused the decreased water yield.

F. Specific Conductance of Streamflow: Specific conductance provides an accurate index of total dissolved solids in streamflow. Before fertilization, conductance in water draining from the treated watershed was about twice as high as in water from its control (table 3), both well within the normal range of natural variation. Conductance nearly trebled after fertilization. Although it has declined since, conductance remains well above pretreatment levels, presumably because of slow and continued leaching of urea-N and associated cations. Reasons for the upward trend on the control watershed are not known.

G. Individual Ions in Streamflow: Methods described in detail by Aubertin et al. (1973) were used to quantify loading of individual ions in streamflow from the fertilized watershed. Average concentration of ions most affected are listed in table 4. Probably this slow return toward pretreatment concentration of these ions causes the slow decline of specific conductance shown in table 3. Concentration of ions not shown in this table and pH remained unchanged.

Estimates of significant plant nutrient outflow (table 4) from the fertilized watershed are listed below as pounds lost from the entire 75 acres:

Year	Ca	NO_3-N	Mg	Na
1971	1907	1634	409	59
1972	608	704		
1973	308			

These are losses attributable to fertilization; they do not include the greater loss of nutrients that occurs naturally in streamflow from all watersheds, regardless of treatment. The needed data were unavailable to Aubertin et al. (1973) to separate naturally occurring losses from additional losses caused by fertilization. On the basis of information then available, those authors reported 17.8 percent of the N applied as urea lost in streamflow during 1971. On the basis of regression analysis of the greater data resources since available, we estimate that 10 percent of the N applied as urea was lost in 1971, 4 percent was lost in 1972, and that subsequent losses were too slight for statistical significance. We estimate that not more than 20 percent of the urea-N was lost in streamflow. This quantity provides for unmeasured losses as urea during 2 or 3 days immediately after fertilization. It also includes continuing low-level losses suggested by specific conductance slightly above pretreatment values.

DISCUSSION

Norris and Moore (1971) stated that aerially applied chemicals will be distributed among four components of the forest environment: air, vegetation, the forest floor, and surface waters. We have accounted for approximate distribution of urea-N among three of these components; air (50%), vegetation (5%), and surface water (20%). The balance (25%) probably is in unsampled strata of the soil profile; possibly in soil below 10 inches but more likely in organic layers above the mineral soil. The organic layers ordinarily contain much of the nutrients seasonally cycled in the forest biomass. Continued leaching of urea-derived N with associated cations may account for the maintenance of specific conductance (table 3) and of ions in streamflow (table 4) above prefertilization levels. But specific conductance in the stream draining the control watershed also is increasing over time. Perhaps whatever causes this increase also maintains specific conductance above pretreatment levels on the fertilized watershed.

In light of this reasoning, consider the forest floor characteristic of the Fernow Experimental Forest. Overlain with litter, it averages about 1 inch of mull-type organic matter and weighs at least 2 tons per acre (Helvey 1964). Samples taken in 1972 ranged in pH from 5.4 to 5.8, a relatively high reaction favoring urea volatilization. Rain immediately after both applications of fertilizer probably carried the readily soluble urea into, but not through, this forest floor. Black (1968) stated that "losses of ammonia by volatilization are most pronounced if the source of ammonia is at the surface of the soil.... High temperatures also favor volatilization." Near-optimum conditions prevailed for volatilization, and that urea-N not so lost must have remained in or near the organic soil surface for weeks. Its fate there seems fairly certain: "Urea nitrogen is quickly distributed throughout the living complex, becomes a part of the nutrient budget, and is cycled within the ecosystem." (Norris and Moore 1971).

Relatively high temperatures, an ample source of carbon, and adequate rainfall a few weeks after fertilization probably provided conditions in the forest floor conducive to large increases in microbial populations and to rapid decomposition of organic matter. Surely, conditions for vigorous microbial activity in the forest floor were stimulated by the heavy application of nitrogen. We assume that much of the nitrogen so mineralized remained in organic soil layers until it was leached out by heavy rains in September 1971 (Aubertin et al. 1973). Some of the N applied as urea remains in the forest floor, where slow leaching over time probably accounts for concentrations of plant nutrients remaining above pretreatment levels in streamflow.

The amount of N applied in this experiment (230 pounds per acre) exceeds the generally recommended rate of 150 to 200 pounds per acre (Norris and Moore 1971). Perhaps this high rate of application exceeds the nutritional need of the trees, and thus contributes to continuing nutrient loss in streamflow. At any rate, the amount of N applied, as well as losses to streamflow, is far less than the amounts in forest soil. From 4 to 16 thousand pounds of nitrogen may be contained in 40 inches of forest soil, with perhaps 10 times as much calcium (Lutz and Chandler 1949). In view of these quantities, there is little reason for concern that forest productivity will be decreased by the continuing nutrient losses reported here.

Most of our water samples were obtained just above the stream gaging station. For nearly half a mile upstream, south-facing slopes are adjacent to and rise steeply (40 to 70%) from the channel. These slopes, the only areas showing significant loss of soil nitrogen, probably have been major sources of accelerated nutrient outflow in streams. Although limestone has not been identified in this watershed, it does outcrop close by. Perhaps its proximity explains why outflows of Ca and Mg from this watershed exceed those from other Fernow watersheds.

CONCLUSIONS

1. Volatilization soon after application caused largest losses of urea-N.

2. Nitrogen losses to streamflow were greatest during the first year after urea application and have continued at lower levels since.

3. A minor decrease in streamflow can be expected for a year or two after young hardwood stands are fertilized with urea.

4. We need closer observation of urea breakdown and of the distribution of breakdown products in the forest ecosystem to fully understand all effects of fertilization.

[1/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

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Table 1.--Average nitrogen content (Kjeldahl) of soil samples before and after urea fertilization. Results of the Duncan multiple range test are only for within-year comparison.

Year	Sample source (soil depth, in.)	South slopes	North slopes	Untreated
		----------percent----------		
1971[1]	0 - 2	0.58a[3]	0.62a	0.58a
1972[2]	0 - 2	0.34a	0.50b	0.56b
1973[2]	0 - 2	0.26a	0.45b	0.46b
1971[1]	2 - 10	0.18a	0.23a	0.26a
1972[2]	2 - 10	0.12a	0.19b	0.21b
1973[2]	2 - 10	0.09a	0.18b	0.17b

[1]Before fertilization.

[2]After fertilization.

[3]Average values followed by the same letter are not significantly different at $\underline{P}$ <0.05.

Table 2.--Throughfall after forest fertilization

Parameters	1971	1972
Growing season rainfall	27.95"	31.78"
Number of storms	80	83
Before fertilization		
$\hat{y} = 0.03x - 0.01n$[1]	22.40"	25.56"
After fertilization		
$\hat{y} = 0.75x + 0.01n$[1]	21.76"	24.67"
Decrease in throughfall	0.64"	0.89"

[1]$\hat{y}$ = estimated throughfall
x = gross rainfall for the growing season
n = number of storms for the growing season

Table 3.--Specific conductance (mmhos) in streamflow from the fertilized watershed

Year	Fertilized watershed	Control watershed
Long-term average-before treatment	34	16
1971	85	16
1972	57	18
1973	50	18
1974	48	18
1975	47	19
1976	47	20
1977	47	19

Table 4.--Average concentration of selected ions in streamflow from the fertilized watershed

Year	NO_3-N	SO_4-S	Ca	Mg	Na
	----------Mg per liter----------				
1970	0.80	6.6	2.60	1.09	0.91
1971	5.80*	4.7*	7.20*	1.90*	1.21*
1972	3.31*	5.4	4.20*	1.51	1.27
1973	2.17	5.8	3.51*	1.31	0.98
1974	1.73	6.1	3.64	1.16	1.10
1975	2.86	6.4	3.48	1.18	0.97
1976	2.48	5.8	3.65	1.32	0.89
1977	2.00	inc.	3.02	1.43	0.91

*Based on regression against similar data from the control watershed, these were the only concentrations significantly changed at $P < 0.05$.