WATER QUALITY IMPLICATIONS OF FOREST FERTILIZATION IN THE MISSOURI OZARKS

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Abstract.--Nutrient losses from a Missouri Ozark oak forest following fertilization at four rates were analyzed using suction lysimetry. Large amounts of N, P, K, Ca, and Mg were lost from the site by stream flow and by deep seepage after heavy fertilization during a period of high rainfall. Subsequent tests using 1/3, 1/4, and 1/6th the original fertilizer rates resulted in lower nutrient losses during a period with normal or less than normal rainfall. Nitrogen in urea form was surface applied in all studies. Dosage rates in the high rate experiment were: N 1,345, P 587, K 477, Ca 657, and Mg 129 kg/ha. Most NH_4 and P loss in the high rate study occurred as channel flow. NO_3, K, Ca, and Mg losses were primarily in deep seepage over a 2-3 year period following fertilization. Estimated mass flow of the fertilizer elements indicated loss of 53 percent N, 6 percent P, 20 percent K, 44 percent Ca, and 220 percent Mg from the high rate tests. K, Ca, and Mg losses were 10-40 percent in the lower rate tests. N and P losses were minimal. Diameter growth of black oak was increased 70, 104, 54, and 3 percent in the first four growing seasons after fertilization at the highest rate. Foliar analysis showed increases in N and P only. Lower fertilizer rates resulted in lower diameter growth increments indicating that maximizing growth with soluble fertilizers poses a threat to water quality.

Additional keywords: Nonpoint scource pollution, nutrient budget, fertilization of oak, nitrate leaching, urea fertilization of forests.

INTRODUCTION

The use of forest fertilization as a management tool requires a knowledge of the fate of the introduced chemicals and their impact on the environment. The benefits of increased timber production must be weighed against the hazards of stream and ground water pollution when these chemicals are applied.

Contamination of streams and groundwater in the Missouri Ozarks is of special concern because the Karst topography of this area complicates the hydrologic picture. Internal soil drainage can be rapid because numerous solution channels in the underlying limestone bedrock permit direct flow to underground drainage systems. Subsurface streams commonly feed springs, some of which discharge several million gallons of water per day to streams.[3/] There is very little relation between surface and subsurface

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water flow patterns in the region and polluting substances that are introduced into surface watersheds may be found in wells or springs considerable distances away. To protect stream quality and to be of maximum benefit to tree growth, fertilizers need to be quickly assimilated by plants or retained in the surface soil by adsorption.

In this study elemental N, P, and K were applied at rates of 1,345, 587, 477 kg/ha respectively to determine stream and ground water contamination potential of a very acid silt loam forest soil in the Ozarks. Previous tests of tree growth response to nitrogen and phosphorus fertilization in similar forest soil conditions had indicated that maximizing tree growth would require very high application rates of nitrogen (Watt, 1974).

MATERIALS AND METHODS

Six small watersheds ranging from 0.4 ha to 0.6 ha in size were selected in the Sinkin Experimental Forest near Salem, Missouri. All watersheds had gradients of around 20 percent, and all were on the upper portion of 250 to 500 m slopes. A small intermittent stream channel exists near the base of each watershed. The predominant tree species is black oak (*Quercus velutina* Lam.) with lesser amounts of white oak (*Quercus alba* L.), post oak (*Quercus stellata* Wangenh), hickory (*Carya* spp. Nutt.), and shortleaf pine (*Pinus echinata* Mill) present. The trees were approximately 70 years of age.

The soils are a mixture of Clarksville, Coulston (*typic Paleudults*) and Hobson (*typic Fragiudalf*) series. The Hobson soils contain a fragipan at approximately 60 cm depth and also, in some places, a discontinuous sandstone layer below the pan. The Hobson soils were located on the upper slopes of the watersheds above the Clarksville and Coulston soils, and accounted for no more than 25 percent of the area of any one watershed. Other than restriction by the fragipan, the hydrologic properties of the three soils are similar. Surface horizons are a very cherty loam or silt loam with moderate to rapid permeability, low available moisture, and low natural fertility. Soil acidity is in the range of pH 4.5-5.0.

In April, 1973, watersheds 2, 3, and 6 were randomly selected to receive surface application of fertilizers containing N, P, K, Ca, and Mg. Ca and Mg was added as limestone to decrease the acidic reaction of the N and P fertilizers. The fertilizer was hand-applied and stream channels were avoided to prevent their contamination by direct fertilization. Three watersheds were maintained as unfertilized controls during the 2 years following the initial fertilization trials. In March, 1975, these former control watersheds were fertilized at rates equal to 1/3, 1/6, and 1/12 of the nutrient rate applied to the first three watersheds (Table 1).

Suction lysimeters were installed in the soil at six sampling locations on each watershed to monitor movement of the fertilizer into ground water; three lysimeter stations were located at approximately equal spacing on the contour across the upper third of the plot and three were similarly located across the lower third. At each of the six soil water sampling stations, three lysimeters were placed at depths of 15, 30, and 60 cm. Because of the fragipan layer, a few of the lowest lysimeters had to be placed slightly above the 60-cm-depth zone.

Table 1. Fertilization rates Sinkin Experimental Forest watersheds.

	Watershed Numbers			
	4 1/	5 1/	1 1/	(2, 3, 6) 2/
	kg/ha			
Nitrogen (urea 45 percent N)	112	224	448	1345
Phosphorus (triple superphosphate)	49	98	196	587
Potassium (Muriate of potash)	40	80	160	477
Calcium (Limestone & superphosphate)	27	54	108	657
Magnesium (Limestone)	11	22	44	129

1/ Fertilized 4/75.
2/ Fertilized 4/73.

Four additional lysimeters were installed in the gravels of the streambed of the intermittent stream draining each of the six experimental watersheds. A perforated ceramic tile was inserted into the streambed gravels about 30 cm. The lysimeter was installed at a 15 cm depth in streambed gravels inside the tile. Surface runoff in the channel could enter the tile through perforations and percolate to the ceramic cup.

Water samples from these streambed sites were withdrawn at the same frequency as that used for the soil water lysimeters. After the lysimeters were installed, water was sampled by pulling a vacuum (50 cm of Hg) during or just after each major rainfall. The sampler was allowed to draw in water for several days before collection.

Soil water samples were collected from the vacuum lysimeters twice (January and March) before the fertilizer was applied to watersheds 2, 3, and 6 in April, 1973. Following fertilization, samples were collected after each major storm (5 times) during the first year, five times during 1974, and four times in 1975. One sample was collected in 1976 but was only analyzed for phosphorous. The last sampling was done 36 months after the initial fertilization and 12 months after the lighter applications. Samples were preserved with chloroform and frozen until analyzed by the U.S. Forest Service Water Quality Laboratory in Ely, Minnesota. Total nitrogen was determined initially from total Kjeldahl-N (TKN) and nitrate-N plus nitrite-N analysis. However, in July, 1973, the lab changed to an UV oxidation method (Afghan *et al*, 1971) to determine total dissolved nitrogen and total Kjeldahl-N which was computed by subtracting nitrate-N and nitrite-N. Ammonia-N was determined only during the first 6 months. Phosphorous analysis was by sulfuric acid plus persulfate digestion. Potassium, calcium, and magnesium were determined by using standard atomic absorption methods.

Measurement of intermittent streamflow volume in each basin of the small watersheds was beyond the scope of this study. Accepted empirical methods were used to obtain an estimate of the mass flow of nutrients leaving the watersheds.

Scrivner and Brees (1968) have used long-term weather records to estimate the hydrologic budgets for the various climatic zones in Missouri. For the Sinkin Experimental Forest, annual precipitation of 1067 mm is divided into 711 mm of actual evaporation and 356 mm of runoff.

Hansen (1975) evaluated 6 years of streamflow data from four small University of Missouri experimental watersheds. Mean streamflow for all 6 years was 290 mm, varying from 203 to 378 mm among the four study areas.

Transfer out of the solum by percolation is limited by the permeability of the subsoil. Settergren and Boehm (1972) evaluated this deep seepage component on the University of Missouri experimental watersheds. In a year when total precipitation was 952 mm, streamflow from a 5.36 ha watershed was only 119 mm while deep seepage accounted for an additional 206 mm.

To obtain an estimate of deep seepage to the Clarksville-Coulston association on the Sinkin Experimental Forest, the months in which excess soil water was available were computed using the Thornthwaite and Mather (1957) tables for a soil with 254 mm of soil moisture storage capacity (Table 2). The 254 mm storage capacity exceeded estimates from moisture retention measurements on the Sinkin Experimental Forest. However, the large storage value provided a computational method of accounting for deep solum storage and reducing the surface runoff values to those measured in regional studies. Tryon (1972) estimated that forest vegetation draws water from a soil moisture reservoir of about 254 mm on soils of this region.

Table 2. Estimated stream channel flow, deep seepage, and precipitation by month, Sinkin Experimental Forest.

	1973			1974			1975			1976		
	Channel	Seep	Ppt.	Channel	Seep	Ppt.	Channel	Seep	Ppt.	Channel	Seep	Ppt.
	mm											
Jan.	--	--	--	5	79	83	28	117	144	--	20	21
Feb.	--	--	--	10	71	87	30	74	105	--	--	15
Mar.	--	--	--	11	71	119	10	112	132	2	28	79
Apr.	10	84	169	15	41	114	5	28	92	5	5	70
May	18	33	134	10	74	173	--	--	50	--	--	--
Jun.	5	--	122	8	--	85	--	--	77	--	--	--
July	64	--	232	--	--	17	8	--	99	--	--	--
Aug.	5	--	39	28	--	132	15	--	157	--	--	--
Sept.	--	--	115	5	--	123	10	--	118	--	--	--
Oct.	18	41	192	--	--	40	--	--	21	--	--	--
Nov.	36	86	148	5	--	107	5	--	87	--	--	--
Dec.	10	114	124	--	5	41	5	18	103	--	--	--

Monthly total water yield was divided into deep seepage and surface runoff. The surface runoff included the "quick-flow" component of subsoil water moving to enter the channel within the limits of the small study catchments. Using daily rainfall data, surface runoff was computed using SCS runoff curve 55 (Ogorsky and Mockus 1964) assuming good hydrologic condition on woodlots

on the Clarksville series. The sum of daily runoff values for each month was subtracted from the monthly water yield, as computed by the Thornthwaite water budget, to obtain estimates of deep seepage (Table 2).

These monthly totals were utilized to determine the volume of water which left each catchment by the two routes. The surface runoff (streamflow) component was applied to the nutrient concentration data obtained from water samples collected in the stream channel gravels by suction lysimeters. Nutrient contents of water passing to deep seepage on the upland portions of each watershed was assumed to be equal to the mean of samples from six suction lysimeters located at the 60-cm depth in upland positions.

The total water yield values in Table 2 were higher than the runoff reported by Hansen for the portion of the time for which comparative values were available (Table 3). Channel flow estimates were much lower than the streamflow in the University of Missouri catchments and in the Sinkin River (Figure 1). These differences may illustrate the entry of deep seepage into larger streams by underground routes (Barks 1978).

Table 3. Channel flow from University of Missouri experimental watersheds and estimates for Sinkin Experimental Forest.

	Univ. of Missouri Exp. Watersheds		Sinkin Exp. Forest		
	Stream Runoff	Ppt.	Computed 1/ Runoff	Ppt.	Estimated Channel Flow
	millimeters				
1972-73	747	2187	541 2/	1151 2/	102 2/
1973-74	328	1463	696	1260	155
1974-75	--	--	411	1285	112
1975-76	--	--	84	759	13 3/

1/ Includes deep seepage component (from Thornthwaite computation).
2/ January 1 through September 30, 1973 only.
3/ October 1 through April 30, 1976 only.

Tree growth was monitored in each watershed. The diameter of each tree larger than 1.15 cm was measured annually. Leaf samples were collected during the first 2 weeks in August, 1973-1976, for analysis of N, P, K, Ca, and Mg. Soils in each watershed and on unfertilized areas immediately adjacent to the watersheds were sampled in April, 1976, in 0-7.5 cm and 7.5-15 cm depth interval. Soils were analyzed for TKN, P, K, Ca, Mg, and Na content.

RESULTS AND DISCUSSION

Long-term average concentrations of dissolved nutrients from the control watersheds were:

NO_3-N	NH_4-N	TKN-N	Total N	Total P	K	Ca	Mg
0.07	0.34	0.44	0.50	0.09	0.81	1.32	0.97

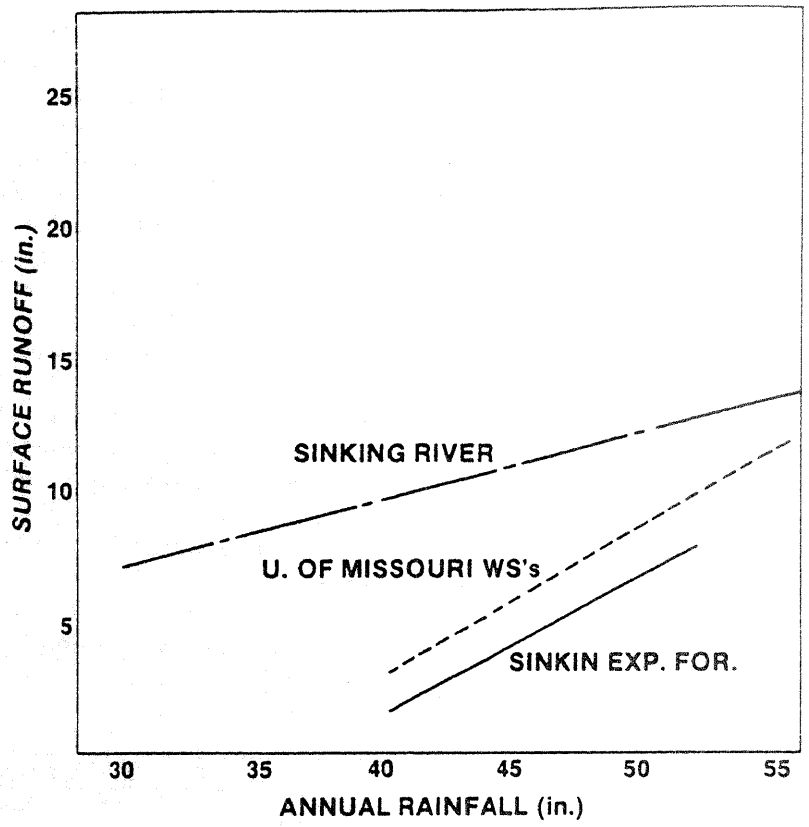

Figure 1. Surface runoff in relation to rainfall for the Sinkin Experimental Forest watersheds as computed from 1973-1975 data in comparison to rainfall-runoff relations on the University of Missouri experimental watersheds and the Sinking River.

There were no significant differences between values obtained from samplers located in the streambeds and from samplers located at 60-cm depths in upland soils. Similar concentrations were measured on the treated watersheds before fertilization. Concentrations of nutrients tended to be slightly higher in the dormant season than in the growing season under control conditions.

Nitrogen

Total nitrogen concentrations in the water collected in the stream channels was immediately increased following fertilization (Figure 2). Organic nitrogen and ammonia were the major forms of nitrogen present after the first rainfall. The TKN (organic-N plus NH_4-N) portion of total nitrogen decreased to less than 10 mg/l in the stream channels by December, 1973. Nitrate-N levels reached a peak of 89 mg/l at this time. Subsequently, NO_3-N represented the major form, about 60 percent, of nitrogen in channel flow through the next 2 years of observation. The initial high concentrations of TKN reflect the solubility of urea.

The second peak for nitrogen in the stream channels was due to a sharp increase in nitrate concentration, indicating that by June, 1973, both miner-

alization and nitrification were occurring. Nitrate concentration in the stream channels remained above the acceptable public health standard (10 ppm, NO_3-N) for 2 years after the addition of 1345 kg/ha of fertilizer-N. Although considerable urea was lost initially, approximately 10 percent of the total added, enough urea and ammonium was tied up in the soil to keep the mineralization and nitrification rate above background levels for over 3 years.

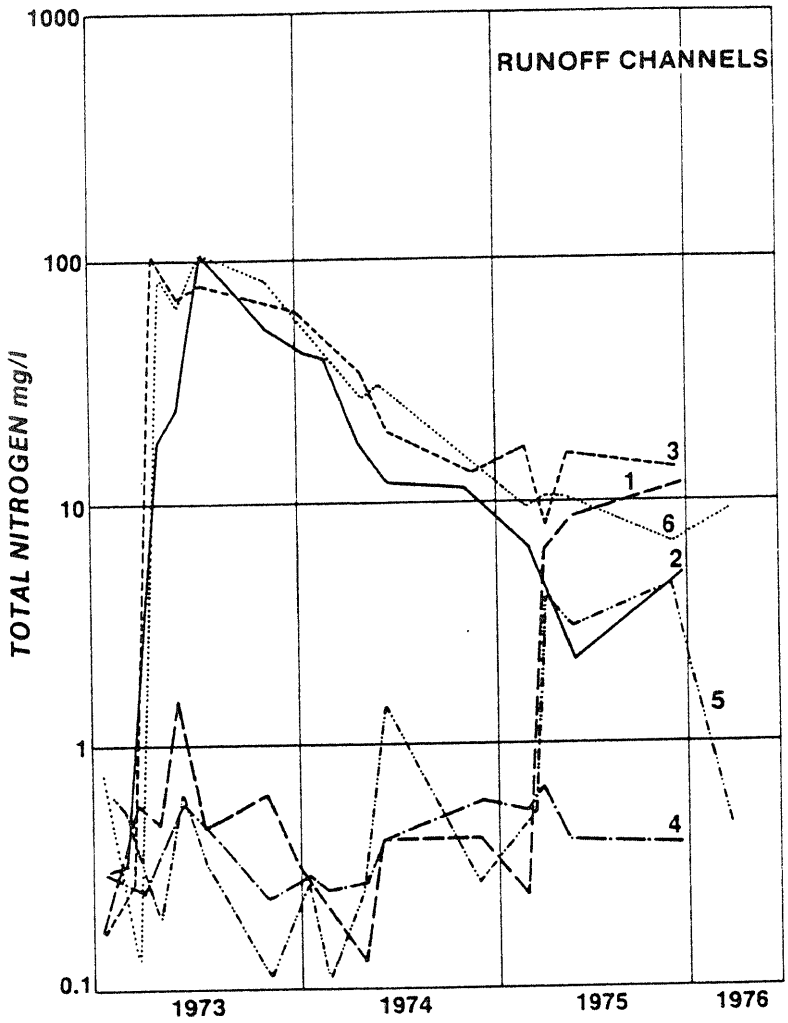

Figure 2. Total nitrogen in water sample from runoff channels of different watersheds, Sinkin Experimental Forest, in relation to fertilization levels.

The ammonium fraction was only monitored for 6 months, because of a change in laboratory procedures. However, by June, 1973, ammonium accounted for most of the Kjeldahl nitrogen in the runoff samples and organic nitrogen (urea) had essentially disappeared from the samples collected in the runoff channels.

Soil water samples from the upland portions of the watersheds fertilized at the heavy rate showed large increases in nutrient concentration during the summer of 1973. Total-N at the 60-cm depth is shown in Figure 3.

After 8 months of leaching, total nitrogen content was highest at the 60-cm soil depth. After the first month, nitrogen content in channel flow was essentially the same as the soil water concentration at the three sampling depths.

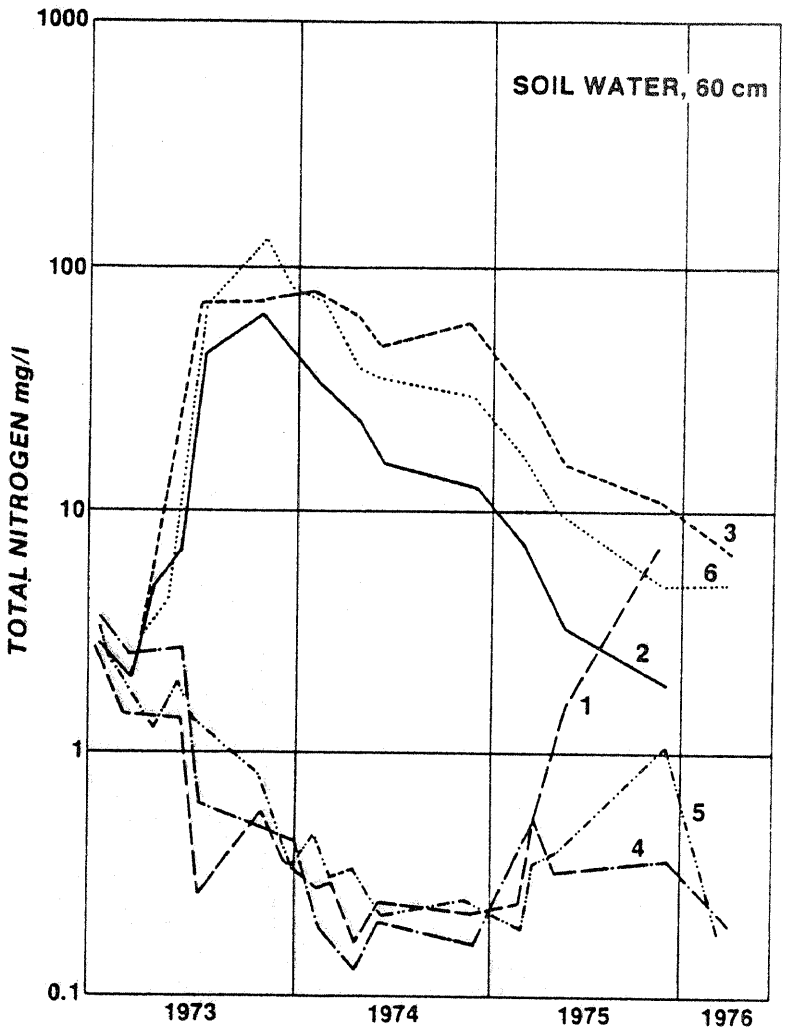

Figure 3. Total nitrogen, in soil water at 60-cm depths, Sinkin Experimental Forest, in relation to fertilization levels.

Phosphorus

Total-P exceeded 10 ppm in the stream channels immediately after fertilization. Within 4 months, total-P levels had decreased to less than 1.0 mg/l (figure 4) and remained slightly above background levels throughout the rest of the study.

Phosphorus concentrations increased slightly in the shallow soil water samples but never exceeded background levels at 60-cm. Phosphorus concentrations in the stream channels were higher than the soil water concentrations measured at any of the three soil depths throughout the measurement period, indicating that phosphorous was absorbed before it reached the 15-cm depth.

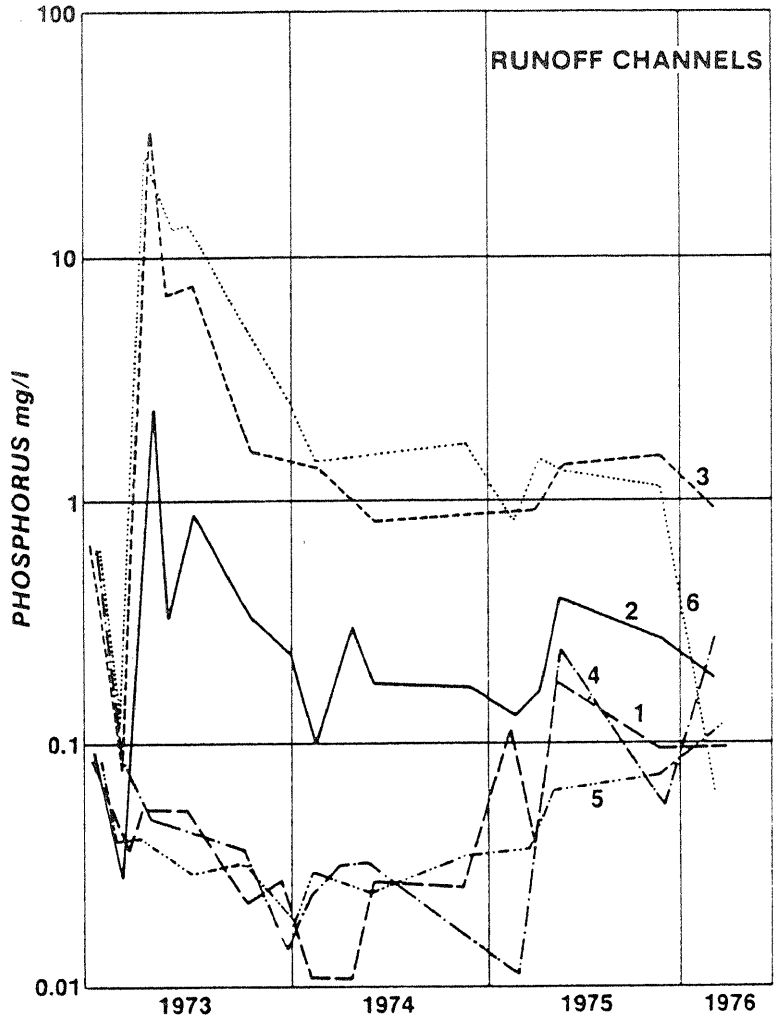

Figure 4. Total phosphorus in water sample from runoff channels of different watersheds, Sinkin Experimental Forest, in relation to fertilization levels.

Potassium, Calcium, and Magnesium

Elevated concentrations of K, Ca, and Mg in the stream channels indicated that significant amounts of these nutrients were also lost during the 2 years after fertilizer was added. This is illustrated by the pattern for K in Figure 5. Both potash and calcium in the treble superphosphate were highly soluble. With the abundant rainfall these chemicals moved quickly into the stream channels.

Potassium moved readily to lower soil depths (Figure 6). Calcium and magnesium also increased at the 60-cm depth. Average streamflow concentrations of potassium during the first year were much higher than soil water concentrations, indicating that the soil water flow path became important after heavy rainfall ceased. Magnesium concentrations in streamflow were slightly higher than the soil water concentration at 60 cm. Calcium concentrations were about the same in both streamflow and in soil water.

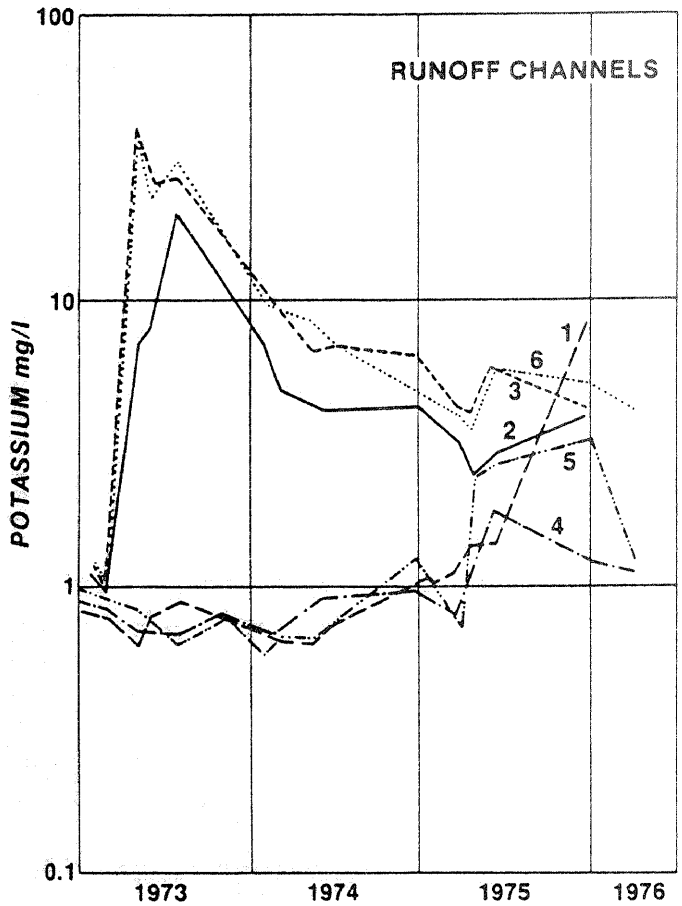

Figure 5. Potassium in water samples from runoff channels, Sinkin Experimental Forest, in relation to fertilization levels.

1975 Fertilizer Treatments

Following treatment of the three original control watersheds at lower fertilizer rates in 1975, there was no immediate flush of soluble nitrogen. This was due to the combined effects of low dosage levels and low rainfall. Nitrate-N concentrations increased throughout the year, approaching 10 ppm during the autumn runoff period under the highest (400 kg/ha) rate (Figure 2). Samples taken in April, 1976, showed that NO_3-N levels under the middle (200 kg/ha) rate had dropped to near control levels. Unfortunately April, 1976, samples from the 400 kg/ha rate watershed were not analyzed due to a laboratory error.

Phosphorus levels in the stream channel were slightly elevated (<1 ppm) during the summer and fall following fertilization; although no significant dosage relation was evident. Potassium (Figure 5), calcium, and magnesium concentrations increased in relation to dosage following the same general pattern as nitrate-N.

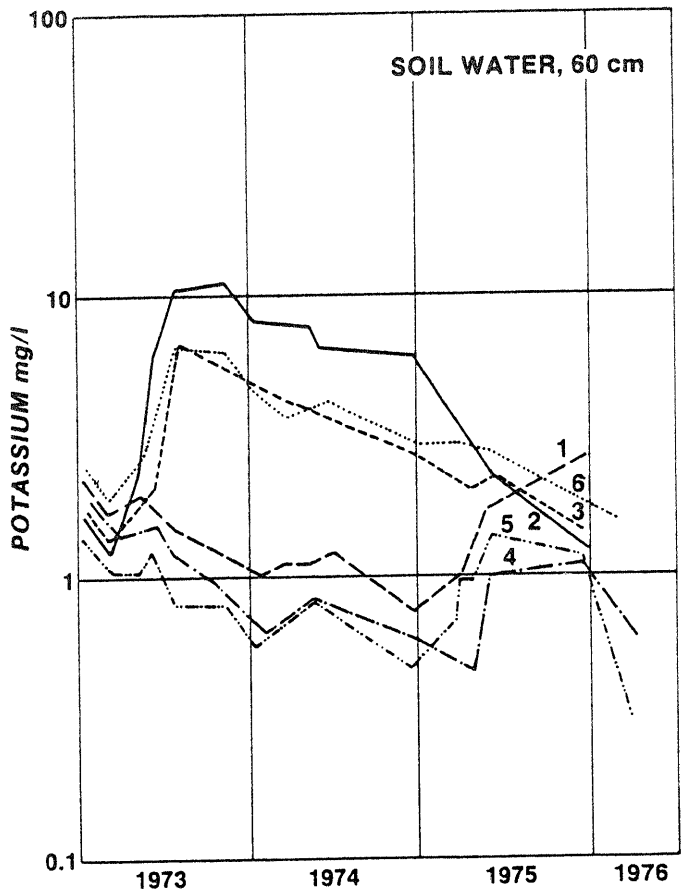

Figure 6. Potassium in soil water at 60-cm depth, Sinkin Experimental Forest, in relation to fertilization levels.

The soil water concentrations for all measured nutrients were highly variable and were not necessarily related to application rates. Mean concentration at 60 cm are shown in Table 4 for the three sampling dates for which data was obtained from all six lysimeter sets on these watersheds. Due to personnel and program changes, only limited information is available for 1976, and that was collected in March from watersheds 4 and 5. The concentrations were similar to 1975 values.

Correlation coefficients in Table 4 indicate that less than 60 percent of the variability in soil water concentrations of NO_3-N and total-N were related to fertilization rates in May and December, 1975. Phosphorous concentrations were unchanged at the 60 cm soil depth. Magnesium concentrations were most directly related to fertilization. Even though very small amounts of magnesium fertilizer were applied (11, 22, and 44 kg/ha).

Nutrient Losses in Streamflow

During the 3 years following application of fertilizer at the 1,345 kg/ha (1,200 lb per acre) nitrogen rate, over 50 percent of the added nitro-

gen was lost to stream runoff (Table 5). One-third of this loss was by channel flow, largely during the first 2 months after treatment. Soil water concentrations remained high, primarily due to NO_3-N, throughout the study period. About three-fourths of the nitrogen lost to deep seepage was in the form of nitrate. Ammonia volatilization by urea was not measured or estimated. However, other researchers (Patric and Smith 1978, Watkins 1972) have indicated it does occur and that nitrogen loss may be 1/4 to 1/2 of the applied urea-N on litter covered forest soils.

Table 4. Nutrient concentrations in three watersheds at 60-cm soil water depths by sampling date and treatment, 1975.

Date		WS #4 (112 kg/ha N)	WS #5 (224 kg/ha)	WS #1 (448 kg/ha)	r
		mg/l			
4-11	NO_3-N	0.07	0.01	0.06	0.02
	N Total	.53	.35	.56	.06
	P	.10	.33	.02	-.14
	K	.97	.46	1.16	.22
	Ca	1.83	2.39	6.05	.39
	Mg	1.55	2.07	11.1	.43
5-29	NO_3-N	.10	.01	.47	.56
	N Total	.32	.41	1.46	.64
	P	.02	.28	.07	-.01
	K	1.40	1.00	1.81	.29
	Ca	3.33	3.42	4.27	.18
	Mg	1.84	2.57	11.6	.62
12-23	NO_3-N	.01	.01	14.0	.49
	N Total	.38	1.91	17.5	.26
	P	.02	.19	.02	-.08
	K	1.14	1.12	2.68	.20
	Ca	2.13	7.65	10.7	.54
	Mg	2.11	7.41	10.5	.54
3-30-76 1/	NO_3-N	.02	.04	--	(.58)
	N Total	.20	.19	--	(-.05)
	P	.02	.01	.05	(.67)
	K	.63	.36	--	(-.41)
	Ca	1.95	1.95	--	(0)
	Mg	2.55	1.93	--	(-.36)

1/ Means based on two samples/WS.

Phosphorus losses were primarily due to channel flow during the wet period immediately after treatment. Soil water P levels did not change significantly at the 60-cm depth.

Potassium, calcium, and magnesium concentrations in channel water and soil water were increased 10-fold after fertilizers were added. Otchere-Boateng and Ballard (1978) have reported increased Ca and Mg in the soil solution of British Columbia forests fertilized with urea at the time of pH decline accompanying nitrification.

Table 5.

(a) Direct runoff and deep seepage component of nutrient flow from Sinkin Experimental Forest watersheds, April, 1973 through April, 1976.

Kind of Flow	Watershed Number 1/ 4	5	1	(2, 3, 6)
	kg/ha			
Direct Runoff				
Total Nitrogen	5	7	9	213
NO_3-N	<1	2	4	130
Phosphorus	<1	<1	<1	35
Potassium	3	3	4	46
Calcium	10	11	12	75
Magnesium	8	8	9	48
Deep Seepage				
Total Nitrogen	4	6	25	495
NO_3-N	1	1	14	354
Phosphorus	<1	<1	<1	<1
Potassium	16	15	24	52
Calcium	26	30	36	216
Magnesium	21	26	30	212

(b) Total mass movement of nutrients from Sinkin Experimental Forest watersheds, April, 1973 through April, 1975.

	kg/ha			
Total Nitrogen	10	13	34	708
NO_3-N	2	3	18	484
Phosphorus	<1	2	<1	58
Potassium	19	18	28	97
Calcium	36	41	48	291
Magnesium	29	34	39	260

(c) Percentage of fertilizer nutrient in runoff plus deep seepage, Sinkin Experimental Forest (for period of record following fertilization).

	Period 4/75-4/76			Period 4/73-4/76
Total Nitrogen	<1	2	6	53
NO_3-N	<1	<1	4	36
Phosphorus	1	1	<1	6
Potassium	19	8	10	20
Calcium	21	20	16	44
Magnesium	40	42	33	202

1/ Fertilized on following dates: WS's 4, 5, 1 - 4/75; WS's 2, 3, 6 - 4/73.

Computations of nutrient outflow were dependent on the accuracy of both the volume estimates for surface runoff and deep seepage. Mean concentrations of each element from the control watersheds are compared in Table 6 with the mean values reported for in-stream water at the University of Missouri watersheds (Hansen op. cit) and in Sinking Creek (Barks op. cit).

Table 6. Mean nutrient concentrations in four streams on University of Missouri Forest, in Sinking Creek, and in stream gravels on Sinkin Experimental Forest.

	Univ. of Missouri Forest-Stream No. 1	2	3	4	Sinking Creek	Sinkin Exp. For. 1/
	mg/l					
NH_4-N	0.49	0.42	0.54	0.16	0.06	0.34 2/
NO_3-N	.11	.11	.09	.12	.10	.051
Total P	.036	.040	.045	.011	.015	.033
Ca	1.5	1.8	1.4	17.7	28.0	1.3
Mg	.91	.95	.84	15.2	15.5	.97
K	1.06	1.02	.97	.71	.85	.81

1/ Mean of three control watersheds.
2/ Mean of five dates when NH_4 was analyzed.

Water collected from the gravels of the Sinkin Experimental Forest streambeds fell within the range of mean nutrient contents evaluated on the four University streams and in the Sinking River. This may be interpreted to mean that the channel water chemistry was accurately evaluated in the lysimeters. Rapid runoff events were inadequately measured by the lysimeters. Suction lysimeters have also been shown to underestimate P concentrations, especially at the lower range (Hansen and Harris 1975). The water quality estimates made at the 60-cm depth were applied to the deep seepage component. Little biological activity would be expected below this level, however denitrification losses below this depth are possible.

Total Nutrient Flow

About 53 percent of the nitrogen, not counting volatilization, was lost in the 3-year test period following fertilization of the three watersheds at the highest rate. Immediately after fertilizer application, over 90 percent of the nitrogen loss was in the organic form and occurred as stream runoff. Subsequent nitrogen losses over the study period were primarily in the form of nitrate, about 68 percent of the total. With the lower fertilizer rates, however, total N losses ranged from 1 to 6 percent, mostly in the nitrate form.

Approximately 6 percent of the added phosphorous was lost in surface channel flow soon after fertilization in 1973. No measurable P loss occurred at the lower fertilization rates. Twenty percent of the potassium added was lost in runoff over the 3 years at the high rate. Most of the potassium loss occurred gradually over the first year. Similar loss problems for potassium were shown during the first year at the lower rates.

About 44 percent of the Ca was lost over 3 years following large additions of urea and superphosphate. As with potassium, most of the calcium loss occurred during the first year. More magnesium was lost than we added as fertilizer. This may have been due to the replacement of native Mg by NH_4, Ca, and K.

Streamflow and deep seepage losses of nutrients were probably magnified by the excessive rainfall following the April, 1973, fertilization treatments (Table 2). During the 12 months following the high rate fertilizer treatments, 700 mm total runoff (190 mm runoff + 510 mm deep seepage) occurred. During the year following the 1975 fertilization applications only 155 mm total runoff (56 mm streamflow + 99 mm deep seepage) occurred. Thus the treatments cannot be directly compared for either concentration or nutrient flow patterns.

Soil Chemical Characteristics

Soil samples taken in October, 1976, from the 0-7.5 cm and 7.5-15 cm depth on all watersheds showed a significant increase in every element added during the high fertilization rates applied in 1973 (Table 7). The plots treated in 1975 at the three lower rates showed no nutrient increases above background levels.

Table 7. Chemical characteristics for soil horizon 0-7.5 cm and 7.5-15 cm soil depths in the Sinkin Experimental Forest watersheds, 1976.

Area1/	TKN	Total P	Ammonium Acetate Extractable Ca	Mg	K	Na	CEC	Base Sat.	pH	Cond.	Organic Matter
	%	µg/g	----------m.e./100 g----------					%		mhos/cm	%
					0 - 7.5 cm Depth						
Control	.097	472	1.41	.30	.13	.05	11.5	16.6	4.5	156	5.1
Low treats.	.100	459	2.38	.36	.17	.04	12.6	26.1	4.8	164	4.8
High treats.	.117	916	7.72	.71	.19	.06	16.8	45.5	5.0	217	6.2
					7.5 - 15 cm Depth						
Control	.055	344	0.70	.20	.09	.03	8.0	12.5	4.7	102	3.0
Low treats.	.045	399	0.17	.18	.12	.03	7.8	13.0	4.6	105	2.6
High treats.	.066	604	1.92	.27	.14	.04	9.2	26.4	4.7	116	3.1

1/ Control area samples taken adjacent to treated watersheds. Low treatment values are the average of the three different treatment levels on the control watersheds fertilized in 1975. High treatment values are the average of three watersheds originally treated at the high fertilizer rates.

There was no significant increase of organic-N in the soil. Phosphorous levels from 0-15 cm were about doubled and total cations, cation exchange capacity and base saturation increased under the high fertilization rate.

Growth and Plant Tissue Effects of Fertilization

Only black oak's (*Q. velutina*) growth stimulation could be statistically analysed. The increase in basal area on an individual tree basis, in watersheds fertilized in 1973 was 70, 104, 54, and 3 percent for 1973 through 1976 growing season, respectively. Increases in the first 2 years were significant at the $P = <0.001$ level.

Foliar analysis of four tree species (black oak, white oak, dogwood, and black gum) showed significant increases in N and P and only minor in-

creases or decreases in the other elements. Nitrogen level in the foliage from watersheds treated at the high rate was 56, 42, 75, and 42 percent above controls for black oak, white oak, dogwood, and black gum, respectively, at the end of the 1973 growing season. Differences were less in following years. Phosphorous levels in foliage were 17, 37, 75, and 55 percent above controls in 1973. Black gum increased in P to 73 percent in 1974, the only species to show a delayed uptake response. Nitrogen and phosphorous foliar levels from the lower rate tests were only equal to or slightly higher than the third year foliar levels of the high rate tests for the four species tested. Based on other fertilizer studies and the trends shown in this study, foliar levels of most elements, including N and P, may be expected to return to prefertilization levels in 4 or 5 years.

SUMMARY AND CONCLUSIONS

Missouri Ozark hardwoods were heavily fertilized in 1973 to determine the environmental impact. Large nutrient losses due to runoff and deep seepage were indicated in soil water samples from the stream channel and from upland locations. Early losses were due to the high solubility of the fertilizers and to high rainfall following treatment.

Over a 3-year period, an estimated 53 percent of the added nitrogen, 6 percent of the phosphorus, 20 percent of the potassium, 44 percent of the calcium, and magnesium, totaling more than 200 percent of the amount added as fertilizer, was lost in runoff and seepage. Much of this loss occurred in runoff during the first month after application. Sixty-eight percent of the estimated lost nitrogen was in the NO_3 form.

Three additional watersheds were fertilized at lower rates 2 years after the original applications. Little or no hazard to quality of soil water and channel runoff resulted.

Leaf tissue from all of the lower rate tests contained slightly higher levels of N and P one year after fertilization than the leaves of trees from the high rate tests after three growing seasons. Tree growth itself was less than that on the higher rate watersheds. Evidently, if highly soluble fertilizers are to be used, the fertilization levels needed to maximize growth would result in contamination that exceeds water quality standards.

Time of application is important. Highly soluble fertilizers should not be spread on watersheds when streamflow potential is high. Low losses resulted in 1975 when the fertilizer was added over a dry period. It is likely that a low streamflow period following treatment would have eliminated much of the phosphorous lost in 1973 and nitrogen leaching would probably have been delayed. However, much of the nitrogen would still have been lost because of eventual nitrification, transforming the nitrogen into highly mobile nitrate.

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