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Research Report No. 115

INFLUENCE OF NITROGEN FERTILIZATION ON THE QUALITY AND QUANTITY OF STREAMFLOW FROM A FORESTED WATERSHED

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Water Resources Research Institute
Lexington, Kentucky

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Line 1, pp. 38, ... after treatment (Fig. 10); should be ...... after treatment (Fig. 9).

ABSTRACT

This project was designed to determine the effects of nitrogen fertilization on the quality and quantity of streamflow eminating from an eastern hardwood forest watershed. A 40.67 ha watershed, located in mountainous eastern Kentucky, was aerially fertilized in late April 1975. The forest stand was principally oak, hickory, and yellow poplar, 50 - 55 years of age and in a relatively undisturbed condition. A helicopter applied ammonium nitrate at a rate of 504 kg/ha. Because a large part of applied nitrogen fertilizer ends up in the highly mobile nitrate nitrogen form, this is the principal ion monitored in this study. No effort was made to avoid live streams during application and, consequently, very high levels of nitrate nitrogen were detected (640 mg/1) in streamflow within the watershed. Levels potentially toxic to humans and animals persisted in the streamflow for several days following application. Although elevated concentrations of nitrate nitrogen persisted in streamflow leaving the watershed over a two year period no algal blooms or excessive growth of aquatic plants were noted. Rather high concentrations of nitrate nitrogen were found in the soils of the watershed, with greatest concentrations in the surface layer (0 - 5 cm), intermediate amounts at 15 - 20 cm, and the lowest concentrations at the 41 - 46 cm depth. The effects of the fertilizer application on soils persisted less than one year in the 0 - 46 cm depth sampled. Analysis of streamflow records indicated a reduction in water yield the first and second growing seasons after treatment. Gross budgeting of nitrate nitrogen inputs vs. outputs suggests this anion accumulates on these relatively undisturbed watersheds at an annual rate of 3 to 5 kg/ha.

KEY WORDS: Water quality; forest fertilization; nutrient cycling; nitrate nitrogen flux; water quantity - forest fertilization.

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CHAPTER I

INTRODUCTION

Our affluent society has developed an ever-increasing appetite for wood fiber. The need for wood ranges from the traditional uses for construction and paper manufacture to more recent considerations of wood as an energy source. This increased demand for wood fiber is coupled with a decreasing forest land base. Non-timber uses of forests such as recreation, wilderness preservation, and other amenities are increasing rapidly and will preclude timber harvesting on large areas. Additionally, agriculture, urban expansion, highways, and surface mining are taking over lands previously producing timber. This situation dictates that each remaining area of commercial forest must be managed to produce higher yields of wood fiber.

Forest fertilization is a cultural practice that is rapidly becoming an accepted silvicultural tool to increase wood production (Leaf and Leonard, 1973). In addition to increasing commercial wood fiber production, fertilizers are used on forest lands for wildlife habitat improvement, to rehabilitate intensively used recreation sites, and for reclamation of surface mined areas. The most extensive uses of forest fertilization in the United States have been associated with coniferous species in the southeastern and northwestern states. The use of fertilizers on eastern mixed hardwoods is in its relative infancy (Auchmoody and Filip, 1973), hence background information concerning application techniques and, in particular, environmental response is lacking. Recent public concern with environmental quality has resulted in foresters and other land managers assuming a more critical attitude towards the effects of their practices on ecosystems.

Little documented evidence is available on how forest fertilization might affect streamflow from hardwood forests in the eastern United States although the potential impact has been discussed (Hilman and Douglas, 1967; Hornbeck and Pierce, 1973). Experience with fertilization practices on agricultural lands suggests that varying amounts of the applied nutrients will leave the area of application and move into surface or groundwater systems, resulting in possible accellerated eutrophication and/or degraded potable water supplies. However, forest ecosystems are quite different from agricultural systems and it would be misleading to try to draw parallels (Bengston and Kilmer, 1975).

Nitrogen is generally acknowledged as the most limiting nutrient in relation to forest growth (Groman, 1972). A large portion of applied nitrogen fertilizer ends up in the form of nitrate nitrogen, which is the most mobile and easily transported form of this particular nutrient (Patric and Smith, 1975). What, then is the disposition of nitrogen fertilizer when applied to hardwood forests in the eastern U.S.? Does the highly mobile nitrate nitrogen leave the area *en masse* in streamflow? Will the anticipated growth response of the vegetation reduce the amount of streamflow yielded from the fertilized area? How much of the applied nitrogen is incorporated in the biomass? Many questions remain unanswered.

This project was designed to attempt to answer several of the above posed questions. Specifically, *the primary objective was to measure and evaluate the effects of nitrogen fertilization (ammonium nitrate) on the quality and quantity of streamflow from an eastern hardwood watershed.*

CHAPTER II

RESEARCH PROCEDURES

The paired (calibrated) watershed approach was used in this study to evaluate the effects of nitrogen fertilization on the quality and quantity of streamflow (Wilm, 1949; Kovner and Evans, 1954). Plot measurements were also employed to better define processes operating within the watersheds and to supplement the data obtained between watersheds. The study utilized three relatively small experimental watersheds lying entirely within the boundaries of Robinson Forest, a 6,075 ha facility of the University of Kentucky, located in eastern Kentucky. The paired watersheds were Falling Rock (93.76 ha), the control, and Field Branch (40.68 ha), which was the treated area. A third experimental watershed, which was not treated, Little Millseat (81.75 ha), was used to obtain additional comparisons for the evaluation of treatment effects. Robinson Forest and the experimental watersheds are located in the Buckhorn watershed, which is within the drainage basin of the North Fork of the Kentucky River (Fig. 1).

Description of Study Area

Physiography and Geology

Robinson Forest, located in Breathitt and Knott Counties of eastern Kentucky, is within the Cumberland Plateau physiographic province and more specifically, in the Mountains and Eastern Coalfields physiographic region. This extensive plateau is naturally dissected with varying relief of narrow winding ridges, steep valley walls and narrow bottoms, which are expressions of variations in rock outcrop and textures. Elevation generally ranges between 260-460 m. above sea level with local relief approximately 200 m. The Cumberland Plateau is generally underlain with rocks of the Pennsylvanian geologic period. The Breathitt Formation (middle Pannsylvanian) which dominates the study area is composed of alternating layers of sandstones, siltstones, and shales (Welch, 1958). This formation has weathered to form a dendritic drainage pattern. Sideslopes in the study area are quite steep, ranging between 35-60 percent and averaging approximately 45 percent.

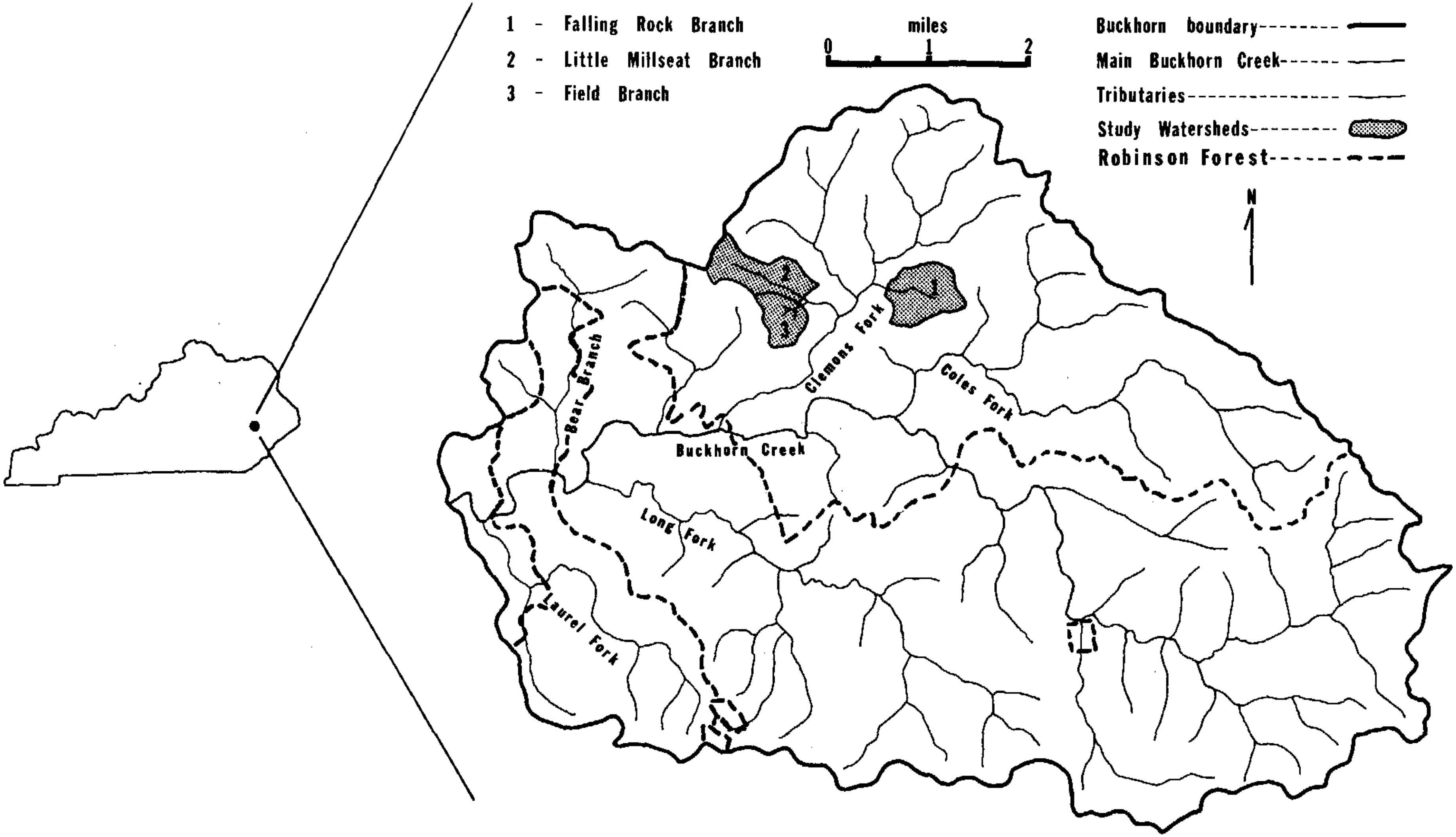


Figure 1. Buckhorn Watershed (Approximately 44 sq. mi.)

Soils

Most soils on the sideslopes have developed in colluvium of variable thickness overlying alternating layers of resistant and nonresistant rocks. This has resulted in complex, benchy, and/or dissected sideslopes. The soils are quite variable in depth, ranging from very shallow near rock outcrops to several meters or more near the uphill sides of benches, though generally averaging less than one meter. The predominant soils on the area are the Shelocta and Rigley series, comprising 31 and 45 percent, respectively, of the soils found on Robinson Forest (Hutchins et al, 1976). The Shelocta is a Typic Hapludult, fine-loamy, mixed, mesic, and the Rigley a Typic Hapludult, coarse-loamy, mixed, mesic. Rigley soils, which are sandier than the Shelocta, occur more frequently on south-facing slopes and on upper slope positions of northerly aspects. The finer-textured Shelocta soils occur on north aspects and in concave "cove" positions.

Several other less dominant soils occur on the area. These include Gilpin, Steinsburg, and Pope. The Gilpin series is found on drier upper slopes, while the Steinsburg series occurs on upper slopes and ridges exhibiting rock outcrops. The Pope series are alluvial soils found in some of the wider bottoms.

Some mean values of selected properties of the three most prominent soils on the study area are listed in Table 1. From the standpoint of water storage capacity, the soils of the study area are hydrologically shallow. Vertical internal drainage is generally restricted by impermeable or slowly permeable strata resulting in rather rapid lateral subsurface drainage during storm events (Springer and Coltharp, 1978).

Vegetation

The vegetation is typical of the mixed hardwood forests indigenous to this area. Oaks (*Quercus* spp.), hickories (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera* L.) are the principal hardwood species, with Virginia pine (*Pinus virginiana* Mill.), shortleaf pine (*Pinus echinata* Mill.), and pitch pine (*Pinus rigida* Mill.) common near cliffs and on narrow, droughty ridges. Past logging practices, scattered agricultural uses, and fires have altered the native vegetation somewhat, but several distinct cover types can

Table 1. Mean values for selected soil parameters of principal soils found on Robinson Forest (after Hutchins et al., 1976).

	Particle Size Distribution			pH	CEC[1]		Base Saturation		Organic Matter	
Series	Sand	Silt	Clay		Surf.[2]	Sub.[3]	Surf.	Sub.	Surf.	Sub.
		(%)			(me/100 g)		(%)		(%)	
Rigley (Jefferson)	61[4]	27	12	6	15	5	44	27	8	2
Shelocta	32	44	24	6	16	9	83	46	10	3
Gilpin	34	48	18	5	6	6	9	6	2	1

[1] cation exchange capacity

[2] surface, 0-2.5 cm

[3] subsurface, 2.5-46 cm

[4] all values are rounded off

be delineated.

The *pine-oak* type occurs primarily on the narrow, droughty ridges and upper side slopes with southerly aspects. The *oak-hickory* type occupies steep side slopes with southern exposure. The *oak* type is similar to the oak-hickory type but is found on more moist sites. Frequently the oak type is represented by a nearly pure stand of white oak (*Quercus alba* L.), possibly due to past land use practices. The *oak-yellow poplar* type is found on steep north-facing side slopes. Steep coves and slopes below cliffs on northerly exposures represent sites on which the *cove hardwood* type is found. A specific cover type that has resulted from past land use practices is the "yellow-poplar field." These nearly pure stands developed on small abandoned fields located on benches in the headwaters of numerous 1st order streams.

A more complete listing of trees and shrubs found on Robinson Forest has been published by Carpenter and Rumsey (1976).

Climate

The climate of the area is best described as temperate (Hill, 1976). Mean annual temperature is approximately 14°C, with a growing season of 170 days. Mean annual precipitation is approximately 114 cm for the general area, with a rather uniform distribution throughout the year. During the period 1972 - 1976, precipitation averaged 136 cm for Robinson Forest. Low intensity, long duration rain storms predominate during the winter months and short duration, high intensity convectional storms occur during the summer months. Potential ET (evapotranspiration) is approximately 70 cm per year. Snow does not usually represent a significant form of precipitation, at least from a hydrologic standpoint.

Pretreatment Sampling

Precipitation

Gross incoming precipitation was measured by a system of weighing-type recording precipitation gages located in forest openings on or adjacent to the experimental watersheds. This precipitation sampling system was established in August, 1971.

A network of precipitation quality samplers was also located on the treatment watershed (Field Branch) in August, 1975 (Shearer et al, 1976). The samplers consisted of a polyethelene funnel 20.32 cm in diameter, set in a 4 liter glass bottle. These samplers were double rinsed with distilled water and set out immediately prior to a storm event and collected immediately after the event was over. Thus only precipitation water was sampled, not bulk precipitation, which includes dry fallout. After each storm the precipitation sample was collected, frozen and transported to the laboratory for analysis of NO_3-N, Ca, Mg, Na, K, SO_4, and pH. The samplers were located at six forested sites and two open sites primarily on Field Branch watershed (Fig. 2). Five of the forested sites were under hardwood trees and one under pine, which roughly corresponds to the amount of area covered by each type of cover.

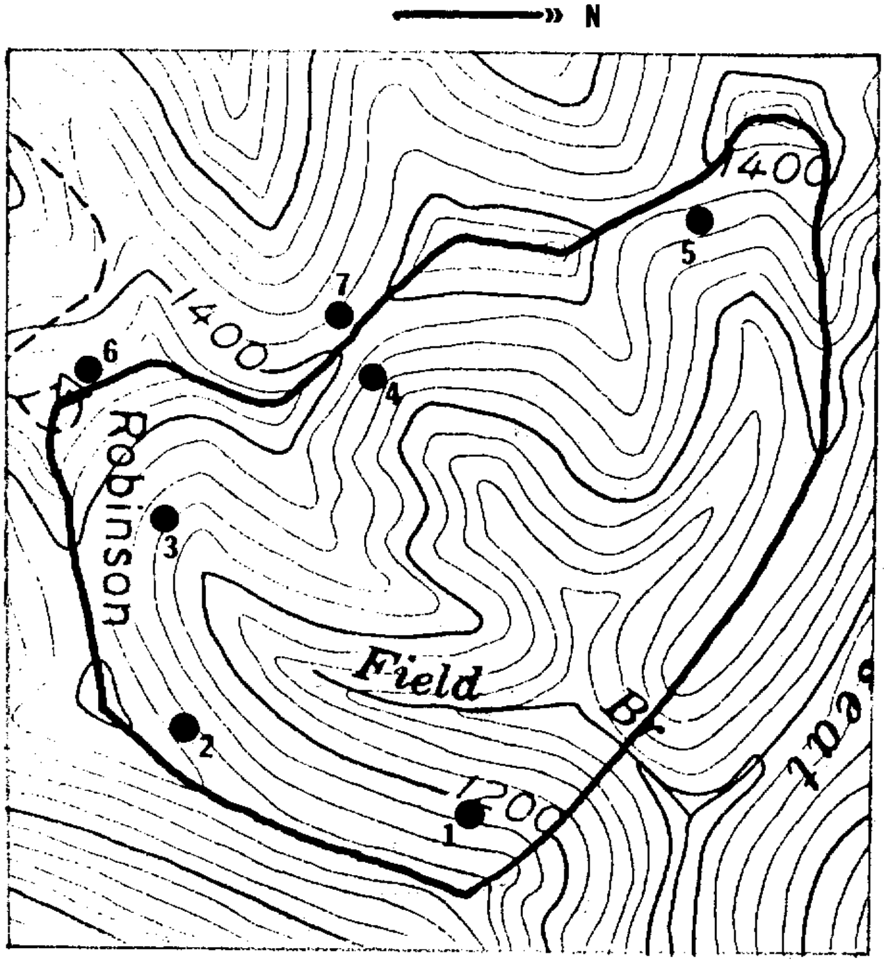
Soils

Soil samples were obtained at 42 locations on the treatment watershed and six locations on an adjacent untreated area (Fig. 3). These samples, obtained for nitrate nitrogen analysis, were obtained during the period March 17 - 20, 1975 shortly before the application of fertilizer. Samples were taken from the mineral soil at depths of 0 - 5 cm, 15 - 20 cm, and 41 - 46 cm. At each sample location a pit was excavated and samples obtained from the uphill face of the pit.

Soil samples to be analyzed for nitrate nitrogen were allowed to air dry, then ground to pass through a two mm sieve. Fifty gram aliquots of this soil were then placed in 500 ml Erhlenmayer flasks, mixed with 250 ml of distilled water and 0.5 gm of $CaSO_4$, shaken for 10 minutes and allowed to settle. The supernatent was filtered through Whatman No. 40 filter paper and frozen to await nitrate nitrogen analysis as previously described. The above procedure is an adaptation of a method detailed by Bremner (1965).

Soil Water

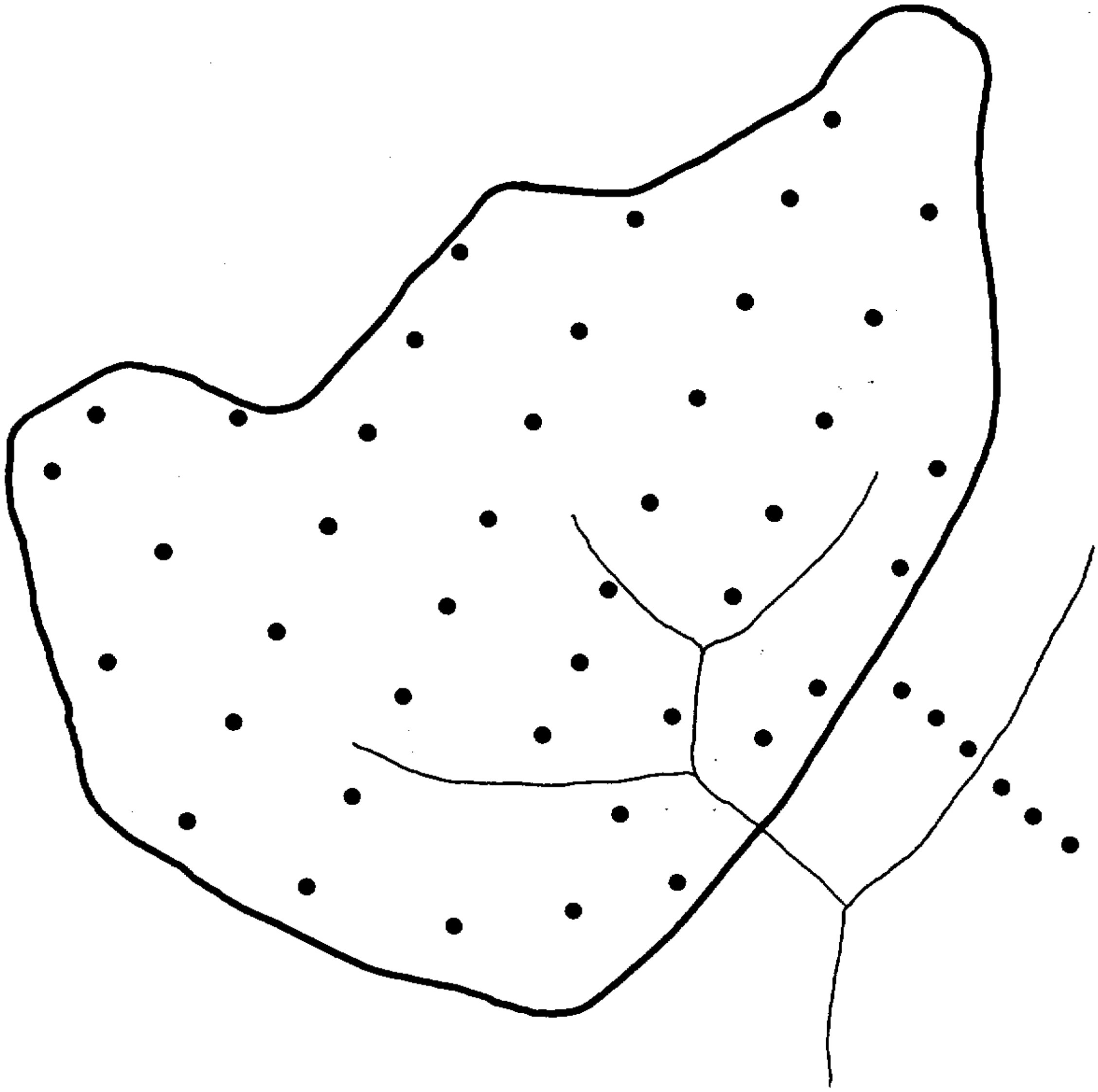
Initial study plans called for installation of suction lysimeters to be located throughout the watersheds to sample soil water at several depths. Since these devices were not obtained prior to treatment, percolating soil water forced to the soil surface at rock outcrops or seeps was sampled at



● precipitation sample point

1 - 5	hardwood
6	pine
7	open

Figure 2. Location of precipitation sample stations - Field Branch



● soil sample points

Figure 3. Location of soil sample plots in Field Branch and Little Millseat Branch.

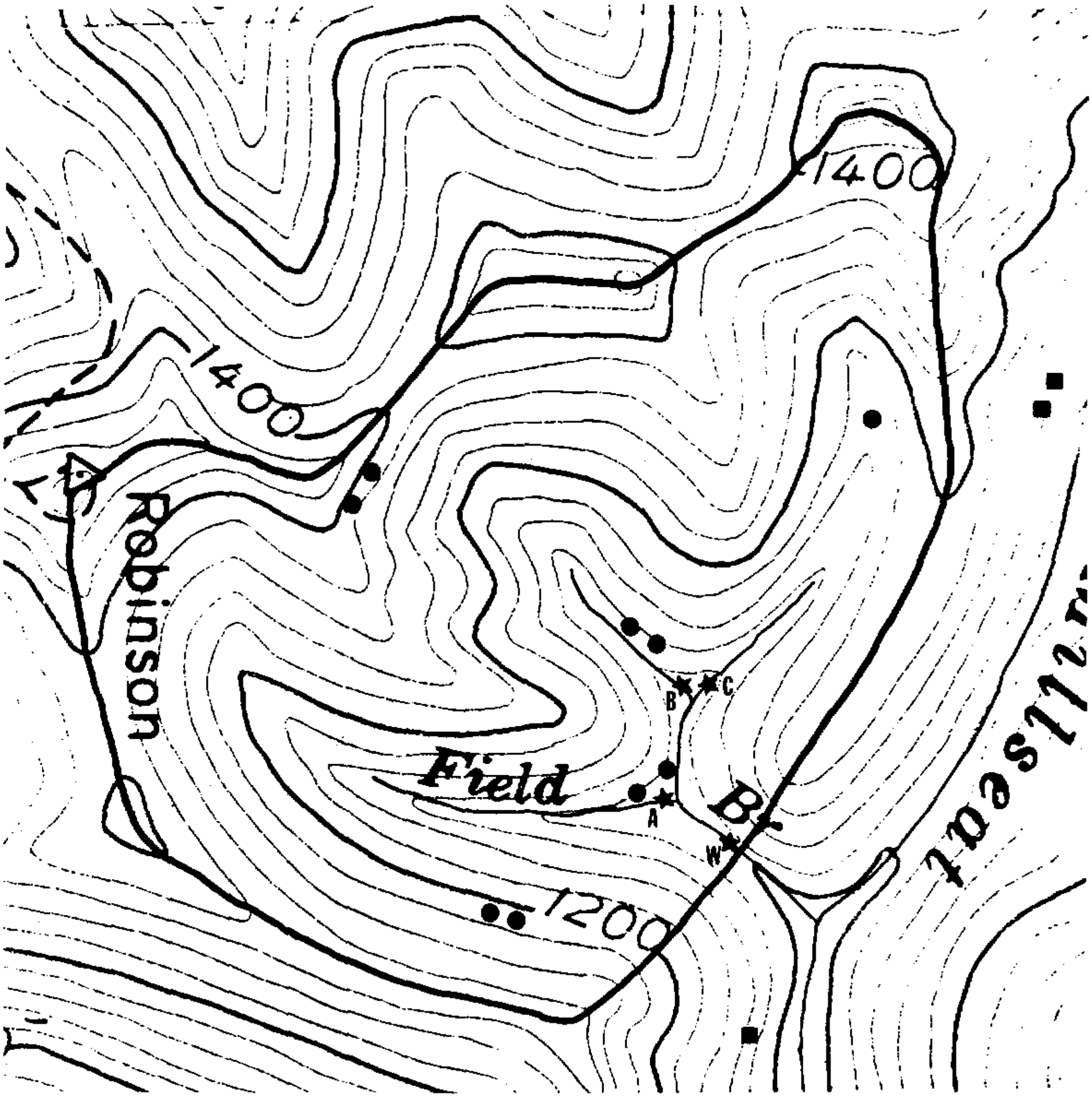
eight locations on the treated watershed and one on an adjacent untreated area (Fig. 4). These samples were also frozen until they were analyzed for nitrate nitrogen.

Streamflow

Both the quantity and quality of streamflow eminating from the three experimental watersheds have been monitored, in conjunction with another study, since August, 1971. Continuous quantitative measurements were obtained by means of concrete v-notch broadcrested weirs, with 3:1 sideslopes (143° notch), located at the mouth of each watershed. An analogue record of streamflow was produced by means of an FW-1 waterstage recorder. Data were reduced and computer processed using the Coweeta streamflow program (Hibbert and Cunningham, 1967). The output of the program includes: 1) mean daily flow in liters per second per square mile, with monthly and annual volumes of flow in centimeters of depth; 2) flow frequency by minutes; 3) stormflow information; and 4) stormflow summaries by months, season, and year.

The quality of streamflow has also been monitored since August, 1971 by means of weekly grab samples obtained immediately above the weir on each watershed. The parameters monitored include: temperature, dissolved oxygen, suspended sediment, turbidity, specific conductivity, alkalinity, pH, NO_3-N, Ca, Mg, K, Na, and SO_4. Temperature and dissolved oxygen were measured *in situ* with a polarographic O_2 probe and a thermister. Water samples for the remainder of the parameters were refrigerated and/or frozen (nitrate nitrogen) until analyzed in the laboratories on the main campus of the University. The analysis techniques employed are listed in Table 2. Standard methodology (American Public Health Association, 1976) was followed in most analyses used. The analysis for nitrate nitrogen was a modified nitrate reductase procedure utilizing *Eschericia coli* as the reducing agent (Lowe and Gillespie, 1975).

Since the principal thrust of this investigation is concerned with the effects of nitrogen fertilization on the quality and quantity of streamflow, primary emphasis has been devoted to monitoring nitrate nitrogen movement and storage on the involved watersheds. The other water quality parameters mentioned above were only secondarily examined in this study for possible related effects of treatment.



● seep sample points in Field Branch

■ seep sample points in Little Millseat Branch

★ water sample points in Field Branch

W - weir

A, B, C - subdrainages

Figure 4. Seep and streamflow sample points - Field Branch and Little Millseat

Table 2. Analysis techniques employed for examination of physical and chemical water parameters.

Parameter	Technique
Dissolved Oxygen	Polarographic O_2 probe
Temperature	Thermister probe
Turbidity	Spectrometer
Suspended Sediment	Filtration
Specific Conductivity	Conductivity Meter
Total Alkalinity	Titration
pH	pH meter, combination probe
NO_3-N	Nitrate reductase, auto analyzer[1]
Ca^{++}	Atomic spectroscopy
Mg^{++}	Atomic spectroscopy
Na^+	Atomic spectroscopy
K^+	Atomic spectroscopy
SO_4	Spectrometer

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[1] Lowe and Gillespie, 1975

Treatment Application

Design

Ammonium nitrate was the form of nitrogen fertilizer applied to the treatment watershed. The fertilizer, in prilled form, was applied by helicopter at a prescribed rate of 504 kilograms per hectare or 168 kilograms of nitrogen per hectare.

The fertilizer was distributed over Field Branch watershed on April 27 and 28, 1975. These dates coincided with initial leaf flush for most of the tree species on the watershed, which was judged to be the most opportune time to fertilize deciduous forest stands. This phenological stage would present a minimum amount of fertilizer interception by the tree crowns (lodging) and yet provide a needed input of nutrients, just prior to a period of rapid spring growth.

Because of the mountainous nature of the watershed special effort was needed to guide the pilot to insure adequate distribution of the fertilizer. Conventional flagging methods used on flatter areas could not be used on this terrain. The watershed area was divided into four strips of equal width (Fig. 5). These strips were indicated with helium-filled weather balloons located at the strip terminus on the watershed boundary. The percentage of the total watershed area enclosed by an individual strip determined the amount of fertilizer to be applied per strip. This provided some degree of area control, in the absence of ground flagging of individual flight lines. Additionally, the watershed boundary was marked for identification for the pilot using highly reflective panels placed at intervals along the ridges.

A combination of small payload (136 kg) and a reduced distribution rate from the fertilizer hopper caused an excessive number of passes to be flown over the watershed (approximately 150). This coupled with the uneven terrain and minimal markings for the pilot led to the likelihood of a non-uniform distribution pattern over the area.

Fertilizer Distribution Sampling

A network of fertilizer sample collectors was placed on the watershed to measure application variability. The collectors were cylindrical paperboard cartons 17.15 cm in diameter by 16.50 cm in height. The containers were

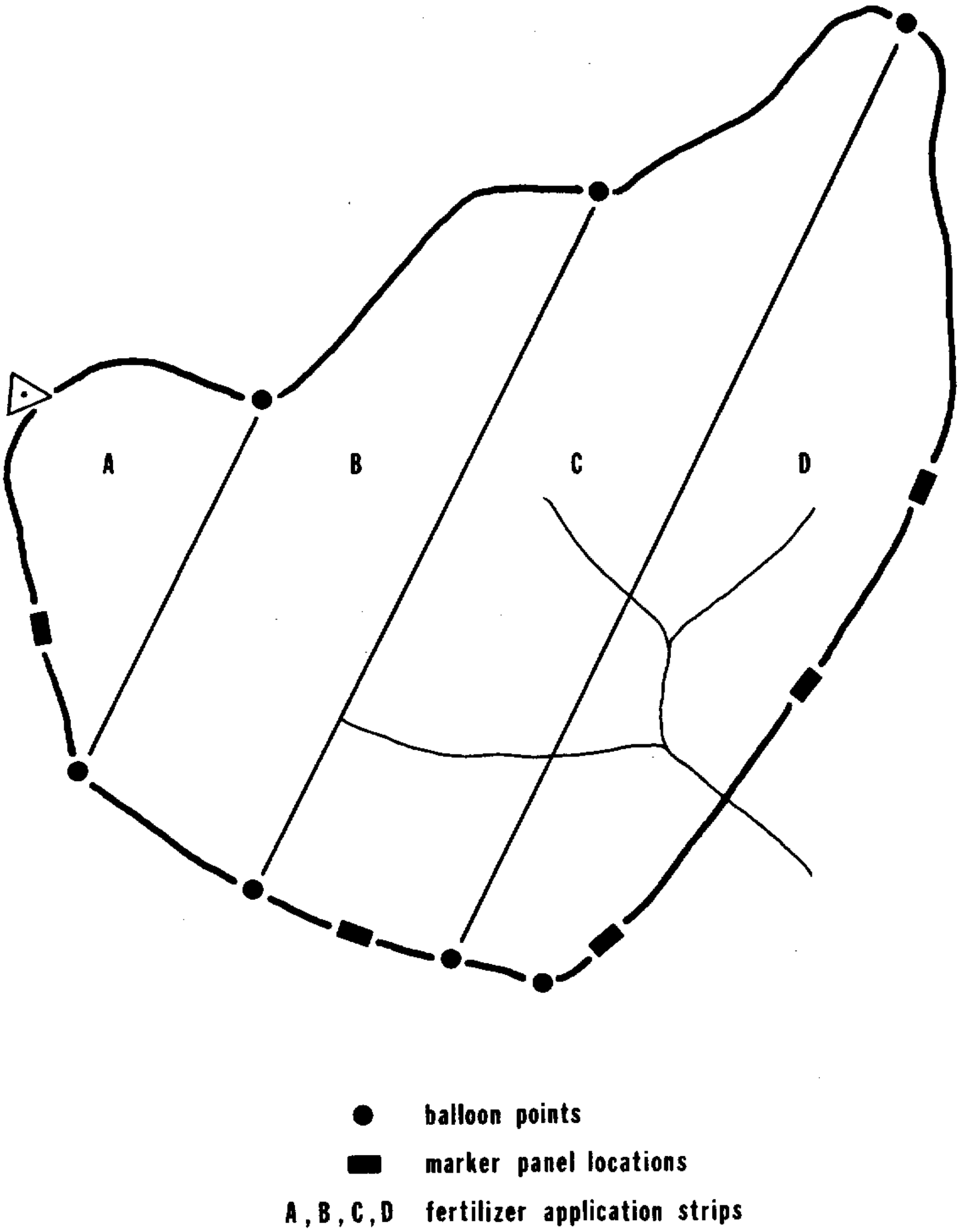


Figure 5. Delineation of the watershed for aerial fertilizer distribution.

lined with polyethylene bags, which facilitated transportation after collection and provided a moisture-proof container for the sampled fertilizer. Three of the collectors were placed in a line across each of the 42 soil sampling locations, 7.6 meters apart and approximately perpendicular to the lines delineating the fertilizer application strips. The center container was immediately adjacent to the plot center. The containers were opened immediately prior to fertilizer application and collected immediately after application on each strip, to limit contamination of the catch or loss of granules due to moisture accumulation.

Post-treatment Sampling

Precipitation

The quality and quantity, as well as the timing, of precipitation continued to be sampled after treatment. The quality component was sampled by the system of collectors previously described and the total incoming amounts and temporal variations measured by the network of recording precipitation gages.

Soils

In order to follow the movement and subsequent distribution of the fertilizer (nitrate nitrogen) in the soil mass, samples were obtained three times during the treatment year and once in early spring during the following two years. The first samples were obtained after a minimum of 2 cm of precipitation was received on the area to move the fertilizer into the soil. This first sampling was conducted from May 12 - 14, 1975, after 5.36 cm of precipitation had fallen. The second sampling period was from July 21 - 23, 1975. A cumulative total of 28.09 cm of precipitation had been received on the area since treatment. The third sample period was October 8 - 10, 1975, after a total of 54.75 cm of precipitation had been received. The fourth sample period was approximately one year after treatment, May 17 - 20, 1976. The fifth and final sampling was during the period March 16 - 17, 1977.

All post-treatment soil sampling was conducted on the same plots as the pre-treatment sampling. A new soil pit was excavated each time, immediately adjacent to the last pit, and the samples secured from the uphill face of the pit.

Soil Water

A limited number of soil water samples were obtained from the previously sampled "seeps". This flow stopped around mid-May and did not resume until mid-November, 1975.

Foliage and Litter

Foliage samples from selected overstory and understory tree species were collected from the treated watershed and an adjacent untreated area during 1975 and 1976. The samples were analyzed for total nitrogen content by means of Kjeldahl distillation.

Samples of the forest floor, primarily leaf litter, were obtained during the October, 1975 soil sampling period from 16 plots selected for intensive measurement, and from plots on an adjacent untreated area. The litter samples represented leaf fall from previous years since leaf fall for 1975 had not begun. The nitrate nitrogen in these samples would then be representative of that caught and held in the forest floor without reaching mineral soil.

Streamflow

Water quality sampling of streamflow at the weir of the treated watershed started immediately prior to fertilizer application and continued at 30 minute intervals throughout the two-day treatment period and for an eight-hour interval following treatment. Samples were then taken at increasing intervals for the next two days, until the first precipitation event. Then, the stream was sampled daily for the next 10 days, except during storm events, when samples were obtained at 15 minute intervals on the rising side of the hydrograph and every two hours on the recession side. After this period of intensive sampling the weekly sampling routine employed prior to treatment was resumed.

In addition to the intensive sampling at the weir of the treated area, samples were also obtained at hourly intervals during treatment from the three subdrainages within the watershed (Fig. 4). The subdrainage sampling continued throughout the application period and for an eight hour post-treatment interval.

Samples were also taken from the weir location of an adjacent untreated watershed (Little Millseat, Fig. 1) at the beginning of fertilizer application on both days. Measurement of the quantity of streamflow continued at the weirs of the three experimental watersheds.

CHAPTER III

DATA AND RESULTS

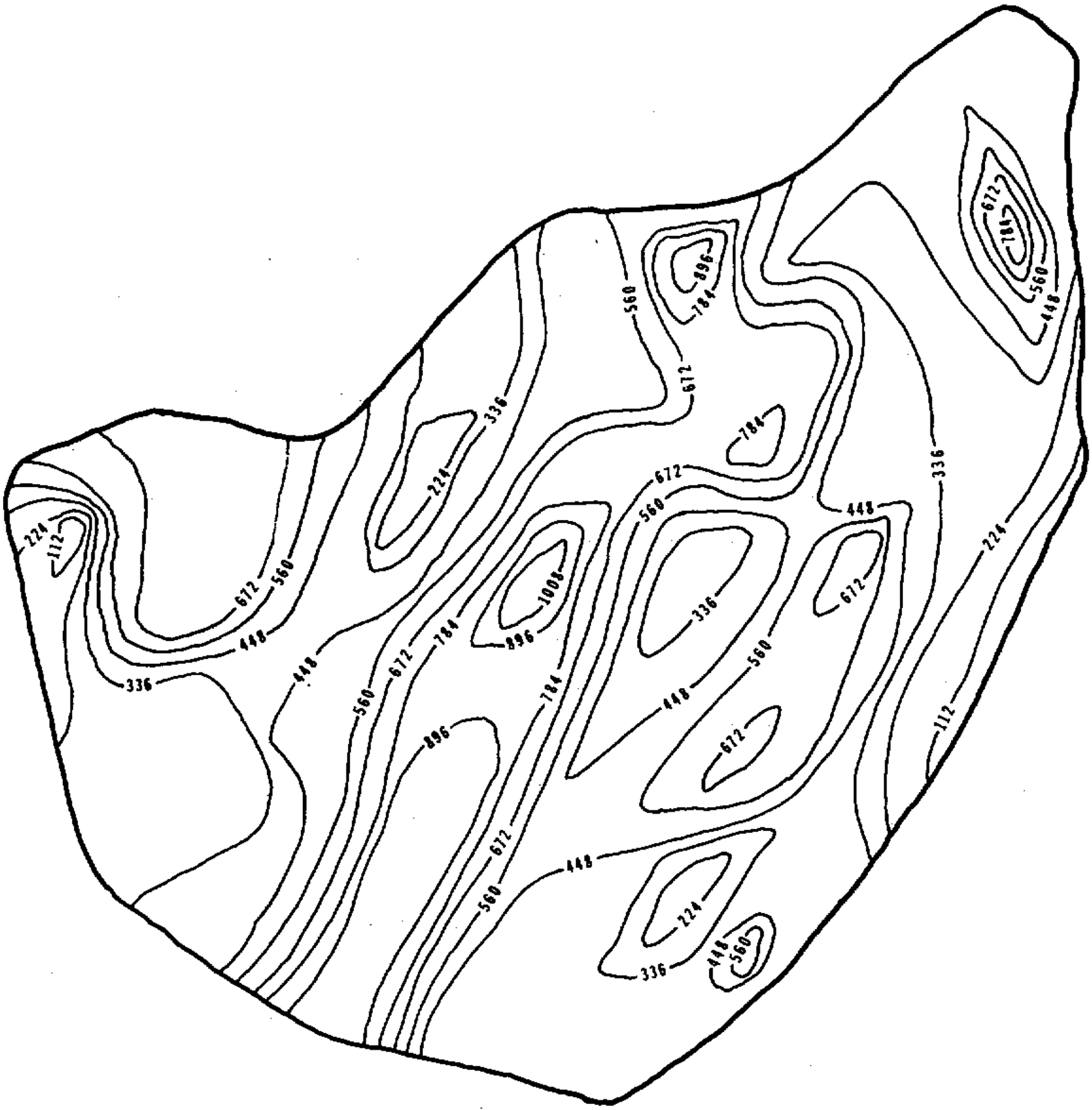
Fertilizer Distribution

A total of 20,430 kg of ammonium nitrate (NH_4NO_3) was applied to the 40.68 ha watershed during the afternoon and evening (2:15 pm - 7:45 pm) of April 27 and the morning (9:00 am - 12:30 pm) of April 28, 1975. The measured mean application rate, as determined by the 126 sample containers, was 516.63 kg/ha, which compares quite well with the target rate of 504.00 kg/ha. Despite the relatively close agreement between the actual overall application rate and the target rate there was considerable variation between the application rates on the various plots. The maximum rate exceeded the minimum rate by a factor of approximately 10 (108.81 kg/ha vs 1039.57 kg/ha). A distribution map with isoquants or lines of equal application rates is shown in Figure 6.

Several different measures of dispersion were used to evaluate the fertilizer distribution (Table 3). The uniformity quotient, which is determined by dividing the total catch on the highest 50 percent of the plots by the total catch on the lowest 50 percent of the plots, should generally be less than 3.00 (Armson, 1972). Our quotient was 2.57, approaching the maximum value.

The "Half-Value" is the percentage of plots which receive less than one-half of the target rate of fertilizer (Ballard and Will, 1971). In our study this value was 19 percent.

The coefficient of variation (C.V.), which is a rather standard measure of variability, was 51.91 percent, again emphasizing the considerable variation in application rates throughout the watershed. There is a strong likelihood that the prilled fertilizer ultimately moved to lower positions on the steep watershed slopes after it was initially deposited, further complicating the final pattern of distribution.



isoquant interval - 112 Kg / Ha

Figure 6. Watershed map showing isoquants of equal fertilizer application.

Table 3. Summary of fertilizer distribution data for Field Branch watershed.

Target Rate	504.00	kg/ha of NH_4NO_3
Observed Rate		
Maximum	1039.57	kg/ha of NH_4NO_3
Minimum	108.81	kg/ha of NH_4NO_3
Mean	516.63	kg/ha of NH_4NO_3
Coefficient of variation (C.V.)	51.91	%
Uniformity quotient	2.57	
Half value	19.00	%

Nitrate Nitrogen in the Soils

Data concerning nitrate nitrogen concentrations in the upper 46 cm of the soils on the study area provide information for the interpretation of fertilizer movement into and through the soil profile during the course of the study. Although the soils of the study area are quite variable, mean values for the entire area can be used to characterize the overall nitrate nitrogen status.

The soils of the study area were sampled six times; once prior to treatment (March, 1975), and five times following treatment (May, July, and October, 1975; May, 1976; March, 1977).

Pre-treatment concentrations of nitrate nitrogen were generally low and highly variable. The values ranged from 0 - 26 mg/l, with coefficients of variation (C.V.'s) ranging from 161 - 191 percent. This obviously high degree of variability, when combined with a highly variable fertilizer application rate, resulted in an extremely variable pattern of nitrate concentrations after treatment. C.V.'s after treatment ranged from a high of 257 percent two months after treatment to a low of 56 percent two years after treatment (Table 4). Even though pretreatment concentrations were highly variable, standard errors and C.V.'s were generally higher after treatment.

Means and standard errors of nitrate concentrations in soils of the treated and control areas for all sample dates are given in Table 5. These values are graphically presented in Figure 7. The most dramatic increase of soil nitrate concentrations appeared in the first sampling after treatment. Some increase was noted at the intermediate depth (15 - 20 cm) during July, but little increase was noted at the lower depth (41 - 46 cm). From the initially high concentrations measured in May, 1975 immediately after treatment, there was a steadily declining concentration of nitrate in the soils of the treated watershed during the remainder of the study.

Precipitation received on the area is the likely mechanism involved in the movement of the nitrate down through the soil profile. From the time of fertilizer application to the first sample date, 5.36 cm of precipitation was received on the area. This was an adequate amount of precipitation to move the applied material into the upper layer of the soil profile, but not necessarily enough to affect the middle or lower sampling depths as indicated in Figure 8. Between the May sampling date and the July sampling date 22.73 cm of additional precipitation was received in the area. Cumulative

Table 4. Coefficients of variation (%) of soil nitrate nitrogen concentrations.

Depth	Sample Date					
	Mar'75	May'75	July'75	Oct'75	May'76	Mar'77
			Field Branch			
0 - 5 cm	190.60[1]	78.98	256.64	136.73	155.06	111.45
15 - 20 cm	161.07	160.18	155.18	164.69	88.31	56.43
41 - 46 cm	161.93	112.26	185.96	197.39	98.43	95.11
			Little Millseat			
0 - 5 cm	159.02[2]	209.06	81.98	199.87	60.86	25.75
15 - 20 cm	153.06	68.93	38.40	91.89	38.45	9.11
41 - 46 cm	129.76	116.45	65.73	78.24	63.24	33.05

[1] each value represents 42 samples

[2] each value represents 6 samples

Table 5. Means and standard errors of concentrations of soil nitrate nitrogen on the experimental watersheds.

Depth	Dates											
	1975								1976		1977	
	March		May		July		October		May		March	
(cm)	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$
	mg/l											
	Field Branch											
0-5	3.41[1]	1.00	75.66	9.22	14.46	5.73	7.54	1.59	2.59	0.62	0.73	0.12
15-20	0.93	0.23	6.34	1.57	5.31	1.27	2.08	0.53	0.78	0.11	0.38	0.03
41-46	0.62	0.15	1.54	0.27	3.55	1.02	1.91	0.58	0.51	0.08	0.50	0.07
	Little Millseat											
0-5	0.31[2]	0.20	2.70	2.30	0.08	0.03	2.41	1.96	0.22	0.06	0.18	0.02
15-20	0.17	0.11	0.29	0.08	0.19	0.03	0.37	0.14	0.21	0.03	0.17	0.01
41-46	0.23	0.12	0.17	0.08	0.12	0.03	0.17	0.06	0.25	0.07	0.20	0.03

[1] Each value represents 42 samples

[2] Each value represents 6 samples

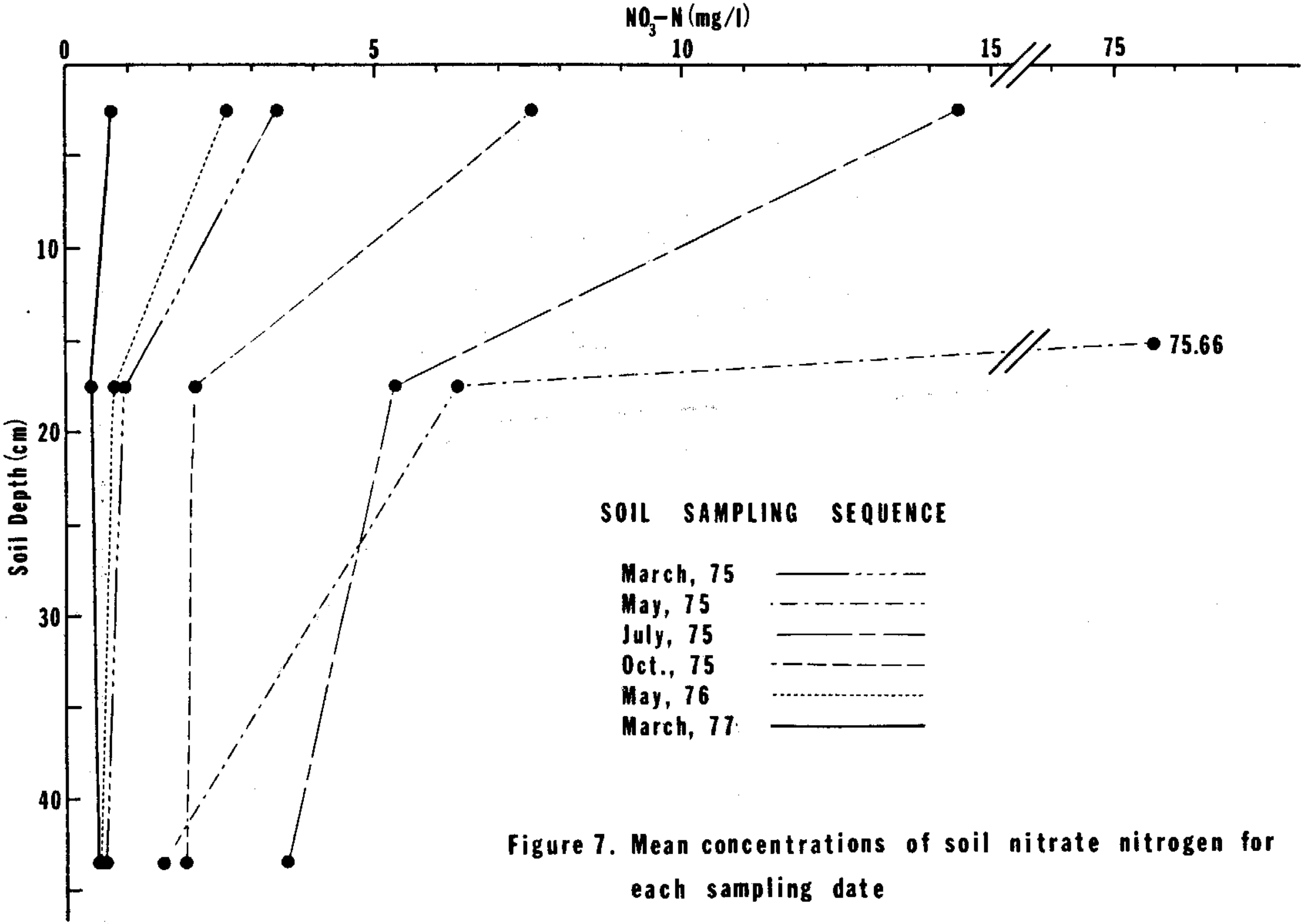


Figure 7. Mean concentrations of soil nitrate nitrogen for each sampling date

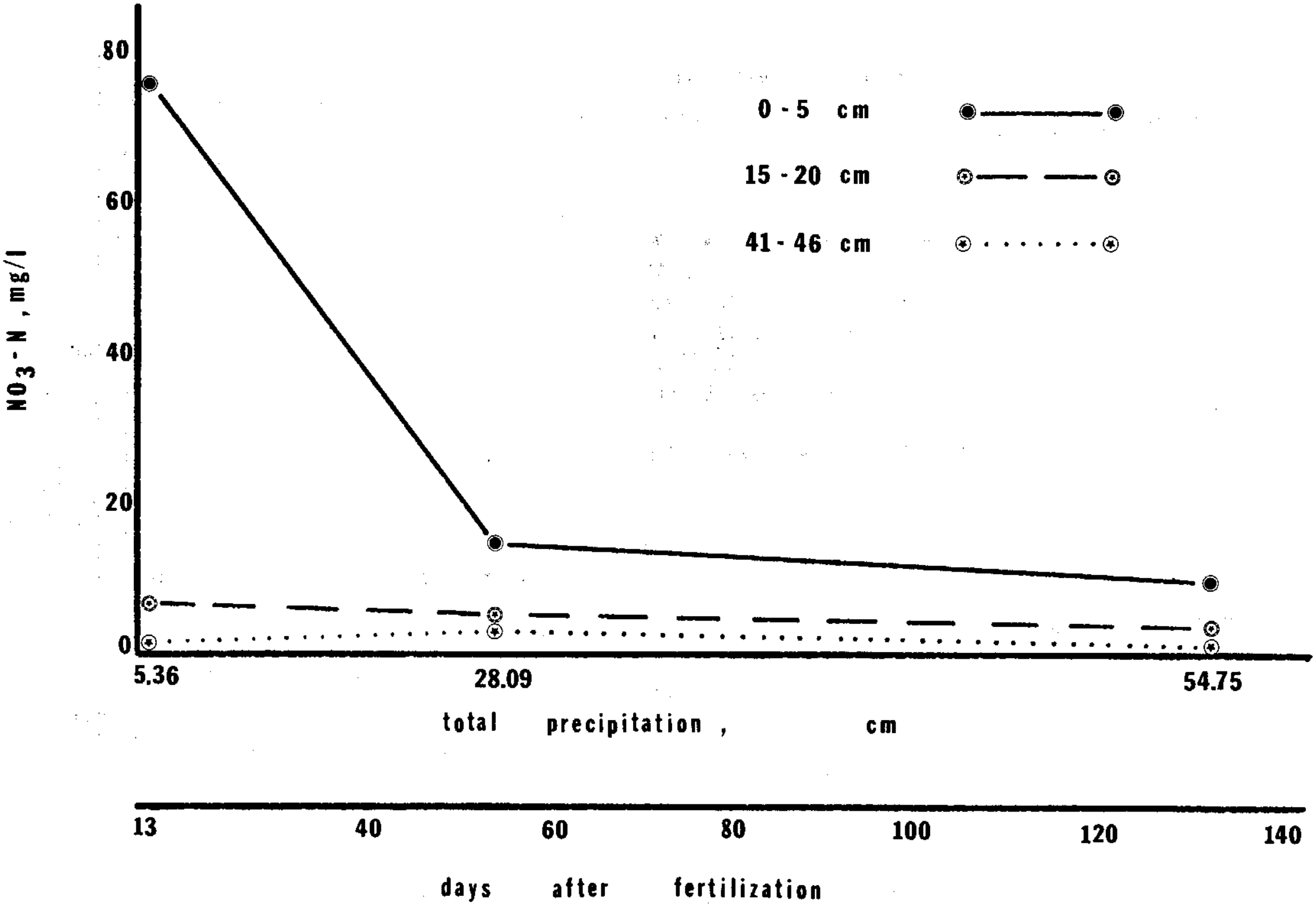


Figure 8. Concentrations of soil nitrate nitrogen related to precipitation and time since treatment

precipitation received thus far was 28.09 cm. Again, the pattern of nitrate distribution (vertically) in the soil was that of high concentrations in the surface layer with decreasing concentrations with depth. Between the July sample date and the October sample date an additional 26.64 cm of precipitation had been received, or a total of 54.75 cm since treatment. This quantity of precipitation was sufficient to move most of the free nitrate ions down through the soil profile as indicated in Table 5 and Figure 8. An expected "bulge" of nitrate moving down through the profile was not detected; either because it did not occur or because the timing of the sampling missed it.

The general nitrate depth distribution pattern throughout the course of the study was that of higher concentrations in the 0 - 5 cm depth, intermediate concentrations at the 15 - 20 cm depth, and lowest concentrations at the lowest depth 41 - 46 cm (Fig. 7). This pattern did not change with time, only the magnitude of the values.

Mean nitrate concentrations one year after treatment (May, 1976) were slightly less than the pre-treatment values, indicating that the treatment effects in the upper 46 cm of the soil lasted less than one year. Two years after treatment (March, 1977) the values were still lower than pre-treatment and even less than those one year after treatment. The much lower concentrations obtained in March, 1977, particularly in the upper 0 - 5 cm of the profile, can perhaps be rationalized by considering temperatures prevailing prior to the sampling dates. The March, 1977 sampling date was preceded by one of the coldest periods on record for the study area, hence little or no breakdown of organic matter would have occurred since the fall of 1976. On the other hand, pretreatment values (March, 1975) were obtained after a relatively mild winter when nitrogenous products could have been produced up to the time of sampling.

The relevance of the nitrate distribution in the soils of the treated watershed after fertilization will be seen in later sections of this report, however several points should be emphasized here. The concentrations of nitrate in the soils of the treated area were highly variable in area distribution, both before and after treatment. Also, vertical distribution of nitrates in the profile was such that the surface 0 - 5 cm consistantly contained the highest concentrations of nitrate, the intermediate depth, 15 - 20 cm, contained intermediate concentrations, and the lowest depth, 41 - 46 cm, contained the lowest concentrations. This relationship persisted before treatment as well as after treatment, only the magnitudes changed. Losses of nitrate in the profile following treatment corresponded rather closely to nitrate concentrations in streamflow leaving the watershed.

A more detailed analysis of the fertilizer-soil response part of this study may be found in a thesis by Shearer (1976).

Foliage and Litter

It is generally assumed that the vegetation on fertilized areas acts as a "sink" for some of the applied nutrients. How much of the applied nitrate nitrogen was incorporated into the forest system biomass is unknown. Foliage samples give, perhaps, some indication of the relative magnitude of nitrogen uptake by the living biomass on the treated watershed. Foliage samples were obtained in late September, 1975 and in July, 1976 from a variety of species represented in the study areas and from a number of locations (slope positions and aspects).

Litter on the forest floor provides additional biomass storage capabilities for applied nutrients. Litter samples were also obtained along with the foliage samples at the above indicated times. All samples were analyzed for total nitrogen content which should be indicative of the relative uptake and storage of the applied fertilizer.

The values acquired in the foliage and litter analyses are presented in Table 6.

Table 6. Mean values of total nitrogen (%) in foliage and litter (forest floor) of treated and control areas.

Location	Total N (%)		
	Fertilized		Control
		1975	
Overstory	2.20 (11)[1]		1.81 (11)
		1976	
Overstory	1.62 (23)		1.43 (17)
Understory	1.55 (8)		1.20 (3)
Litter	0.87 (4)		0.81 (4)

[1] Number of samples.

In all instances the mean values for the fertilized area were greater than from the control area. The differences between mean nitrogen content in the overstory foliage on the treated area vs the control area were less in 1976 than in 1975, indicating, perhaps, a rather short-lived storage function of the vegetation for applied nutrients.

In addition to the above sampling results, the litter layer was sampled for nitrate nitrogen in October, 1975. The litter layer in the fertilized area had a mean nitrate nitrogen concentration of 7.25 mg/l while the untreated area had a concentration of 1.10 mg/l. These values indicate a considerable storage function of the litter layer for nitrate nitrogen, at least through the first fall after treatment. Total nitrogen values obtained during 1976 indicate this storage was probably short-lived.

Precipitation

Both the quantity and quality of precipitation received on the study area were monitored. Monthly and annual quantitative values for the period 1972 - 1977 are presented in Table 7. Annual precipitation received on the control watershed averaged 133.07 cm, with a range of 117.85 cm in 1976 to 156.99 cm in 1974. The average on the treated watershed was 140.24 cm, with a range of 123.14 cm in 1973 to 165.79 cm in 1974. Average monthly values on the treated watershed ranged from a low of 9.24 cm in February to a high of 16.03 cm in March. On the control area the values ranged from a low of 8.44 cm in February to a high of 15.59 cm in March. Except for the high value in March, precipitation is rather uniformly distributed throughout the year.

Precipitation quality monitoring was initiated in August, 1975 and continued on an intermittant basis throughout the study. Average concentrations of nitrate nitrogen for all storms and for the growing season and dormant season were:

	Open	Pine	Hardwood
	- - - - - -	mg/l	- - - - - - - -
All storms	0.33	3.48	0.52
Growing season	0.30	2.53	0.36
Dormant season	0.35	4.91	0.75

Table 7. Precipitation (cm) received on the experimental watersheds, 1972-1977.

Month	1972	1973	1974	1975	1976	1977
			Field Branch			
Jan	21.09	4.42	24.24	10.86	10.10	7.20
Feb	17.92	7.16	4.33	10.91	10.29	4.83
Mar	9.86	11.75	18.82	30.48	16.89	8.38
Apr	22.09	15.23	13.80	10.69	1.40	17.15
May	8.29	15.18	16.27	16.00	7.56	6.07
Jun	7.87	8.86	24.73	9.46	17.78	14.48
Jul	8.51	15.00	7.56	4.19	14.48	17.40
Aug	1.85	4.06	14.77	6.29	10.29	20.83
Sep	8.42	1.84	11.89	19.30	14.86	6.92
Oct	8.03	10.03	5.64	12.38	17.08	10.35
Nov	11.15	18.52	13.02	10.48	3.49	5.33
Dec	17.87	11.19	10.72	10.67	9.91	4.70
∑	142.95	123.14	165.79	151.71	134.13	123.64
			Falling Rock			
Jan	20.70	4.11	22.23	9.17	9.32	5.92
Feb	18.08	7.32	4.83	9.09	8.64	2.67
Mar	10.29	13.46	17.86	28.02	16.33	7.56
Apr	21.64	12.95	11.99	9.25	1.07	14.35
May	7.70	14.66	14.61	17.65	6.83	6.05
Jun	7.75	5.44	24.89	9.25	16.51	11.94
Jul	8.89	15.57	7.24	4.14	12.34	16.75
Aug	0.89	3.76	13.72	7.87	7.75	20.64
Sep	11.43	5.59	9.78	17.02	13.46	7.05
Oct	7.62	9.14	4.95	12.01	15.19	9.78
Nov	10.46	17.58	11.43	10.13	2.79	9.87
Dec	17.02	10.80	13.46	9.07	7.62	5.37
∑	142.47	120.38	156.99	142.67	117.85	117.95

There is a definite influence from type of cover through which the precipitation falls, as well as the time of the year. Average monthly concentrations (mg/l) falling in the open over the period of record are:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.27	0.39	0.31	0.53	0.35	0.16	0.29	0.22	0.14	0.45	0.24	0.71

The above monthly means are used later to develop a gross input/output budget of nitrate nitrogen.

Soil Water

Soil water samples were obtained from "seeps" flowing at eight locations in the treated watershed and at one location in an adjacent untreated area (Fig. 4). Two sets of samples were obtained prior to treatment, and 10 sets after treatment. The results of these samplings are presented in Table 8.

Pre-treatment concentrations at all locations were low or nonexistent. Out of a total of 18 samples obtained prior to treatment only four provided recordable concentrations. After treatment the highest concentrations were detected at the lower locations. Sample locations 1 - 4 were near the upper parts of the watershed, hence they had little contributing area above them from which fertilizer could affect soil water at the sampling points. The lower locations, 5 - 8, showed rather dramatic and persistant increases in nitrate nitrogen after treatment. Samples obtained on the untreated area exhibited very low concentrations throughout the period reported.

All sample locations on the treated area exhibited increased concentrations immediately after fertilization, even prior to the first major precipitation event. After the storm of 5 - 8 - 75 (pm) most locations exhibited rather high concentrations, with the most pronounced values again found at the lower locations. The most persistant elevated concentrations were also obtained at these lower locations. Approximately one year after treatment, samples from locations 5 - 8 were still exhibiting relatively high values, while soil samples exhibited values below pre-treatment levels. This is apperently the result of nitrate nitrogen being leached out of the upper layers of the soil and slowly emerging as seep flow.

Table 8. Nitrate nitrogen concentrations in soil water on Field Branch watershed.

Sample Location No.	Sample Dates											
	1975									1976		
	4-3	4-24[1]	5-8 (am)	5-8 (pm)[2]	5-12	5-14	11-13	12-10	12-16	1-14	2-18	3-12
Control	0	0	0.14	0	trace	0	0.02	0	trace	0	trace	trace
1	0	0	0.15	3.35	0.25	0.16	1.03	0	0.16	0.10	0.37	0.01
2	0	0	0.14	2.42	0.38	0	0.03	0	0	0	0.16	0.01
3	0	0.17	-[3]	-	0	-	0.55	-	0	0.06	0.35	0.01
4	0	0.19	0.17	1.94	trace	0.17	0.60	-	0.64	0.06	0.18	0.01
5	trace	0.20	3.87	23.00	10.50	4.31	9.75	1.45	2.52	0.83	1.91	2.65
6	trace	0.17	3.95	12.00	3.95	7.50	14.10	4.15	0.52	2.75	3.96	3.51
7	trace	0	1.85	4.77	17.50	4.54	6.92	-	0.47	1.70	5.16	0.59
8	trace	0	11.75	5.68	4.15	5.70	5.10	-	0.68	0.64	0.99	0.42

[1] April 3 and 24 samples obtained before treatment.

[2] May 8 pm sample obtained after first storm following treatment.

[3] No flow.

Generally, the values obtained from the "seep" samples are considered to be representative of nitrate nitrogen concentrations in soil water on the treated watershed. These values represent concentrations found in gravitational soil water matriculating downward to contribute to streamflow. They do not necessarily indicate concentrations to be found in retention soil moisture storage.

Nitrate nitrogen concentrations in soil water samples exceeded Drinking Water Standards (U.S. Public Health Service, 1964) on several occasions, mainly within several weeks after fertilization, but as late as eight months after treatment.

Streamflow

Both the quality and quantity of streamflow eminating from a forested watershed may be affected by forest fertilization practices, hence both of these components of streamflow have been analyzed.

Quality

Pre-treatment - Baseline water quality monitoring, during the pre-treatment period of the study, indicated rather low concentrations of nitrate nitrogen in streamflow from Field Branch watershed as well as the control (Falling Rock). Individual weekly pre-treatment concentrations of nitrate nitrogen in streamflow from the treated area ranged from 0 - 0.91 mg/l, with a mean value of 0.14 mg/l (Fig. 9). The pre-treatment range of concentrations on the control watershed were 0 - 0.62 mg/l, with a mean value of 0.13 mg/l. These values are comparable to those reported from a study area in neighboring West Virginia (Aubertin et al, 1973).

Nitrate nitrogen concentrations exhibited definite seasonal variations on the untreated areas as indicated in Table 9.

Table 9. Mean seasonal concentrations of nitrate nitrogen in streamflow.

Watershed	Growing Season (May - Oct.)	Dormant Season (Nov. - Apr.)
	- mg/l -	
Field Branch[1/]	0.21	0.10
Falling Rock	0.18	0.09
Little Millseat	0.16	0.08

[1/] Pre-treatment values for Field Branch

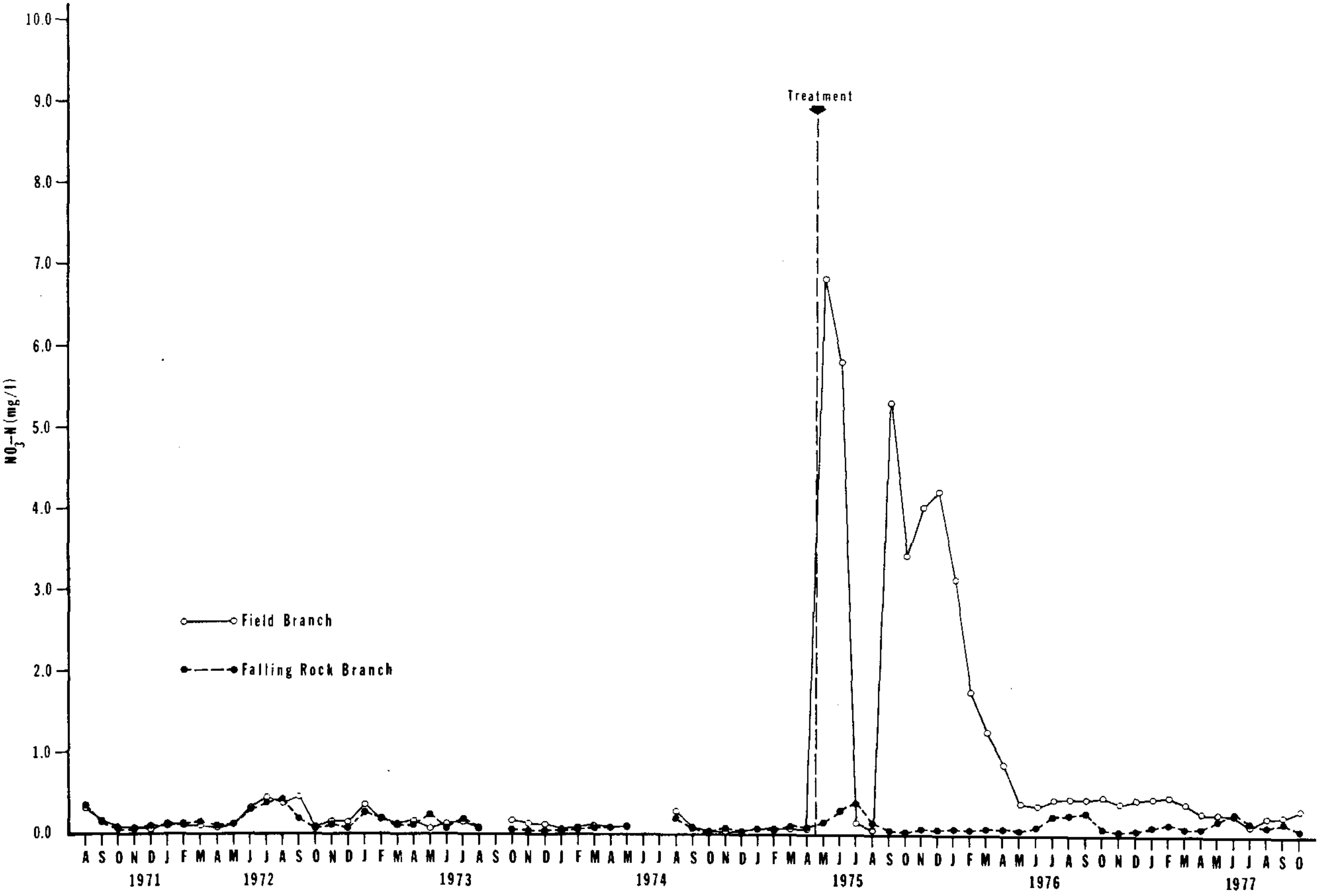


Figure 9. Mean monthly concentrations of nitrate nitrogen in streamflow

The values for each of the three watersheds during the growing season were approximately double the values during the dormant season. Although the concentrations are higher during the growing season, greater amounts of streamflow during the dormant season results in larger loading values.

Several reasons may be advanced as to why the concentrations of nitrate nitrogen in streamflow are greater during the growing season. First, the nitrification process is accelerated by warm temperatures, hence nitrogenous materials accumulated during the previous fall and winter oxidize with the advent of warm weather. Secondly, with increased concentrations of nitrate nitrogen in the soil and decreased quantities of precipitation and streamflow available for dilution, the concentrations leaving the watershed in streamflow are higher.

<u>During Treatment</u> - Stream samples from Field Branch watershed were obtained at the weir and on subdrainages A, B, and C immediately prior to fertilizer application and throughout the application. Samples were obtained at the weir at 30 minute intervals and from the subdrainages at hourly intervals. Sampling times and concentrations for all sample stations are listed in Appendeces A, B, and C. Fertilizer application started at 2:15 pm on 4 - 27 - 75 and by 5:45 pm the first measurable effect of the application was detected at the weir. The 5:15 pm sample contained 0.05 mg/l nitrate nitrogen and the 5:45 pm sample contained 12.50 mg/l. Fertilizer application ceased at 7:45 pm the first day, with application strips A and B completed and C partially completed (Fig. 5). Maximum concentration at the weir, resulting from the first day of application, was 75.00 mg/l. Application on the second day (4 - 28 - 75) started at 9:00 am and ended at 12:30 pm. During this period (10:45 am) a maximum concentration of 120.00 mg/l was recorded at the weir. The high concentrations reported during application in this study differ considerably from values reported in the only other comparable study in the eastern U.S. (Aubertin et al, 1973). In the other, maximum concentrations during application were approximately 1.30 mg/l. This value corresponds to our peak value of 120.00 mg/l at the weir.

The high concentrations reported both days resulted from direct application of the fertilizer into the stream, as no effort was made to avoid it. Because of the relatively small surface area of the stream, approximately 0.06 percent of the watershed area, and the mountainous topography, the pilot was not instructed to avoid the stream channel. Higher maximum values during the second day of application resulted from a carry-over effect of the first days operation and the orientation of the application strips relative to the sub-drainages. The flight paths in application strip D paralleled the stream in subdrainage C resulting in a heavy application directly in that channel. As a result, the maximum concentration measured on the subdrainages occurred on the second day of application and was 640.00 mg/l at 10:23 am on subdrainage D. This very high concentration of nitrate nitrogen exceeded the drinking water standard (10 mg/l) by a factor of 64.

After Treatment - During the period of intensive sampling, from 4 - 27 - 75 through 5 - 9 - 75, a total of 140 samples were obtained at the weir, with 65 of these having concentrations exceeding 10 mg/l. Most of these greater-than-10 mg/l samples were obtained during application or within a 12 hour period following application. Twenty three samples were obtained, at hourly intervals, from each subdrainage during and immediately after application. On subdrainages A and B, 15 out of the 23 samples exceeded the 10 mg/l concentration, while 11 out of 23 samples exceeded this concentration on subdrainage C (Appendeces A, B, and C).

After the initially high concentrations of nitrate nitrogen during the period of 4 - 27 - 75 through 5 - 9 - 75 weekly grab sampling was resumed for the remainder of the study. Out of a total of 108 samples collected during this period none exceeded the 10 mg/l criteria for drinking water. However, approximately seven months after treatment (1 - 2 - 76) a value of 8.55 mg/l was measured. The last value to exceed 1.0 mg/l occurred on 3 - 26 - 76, with a slow but steady decline throughout the rest of the study.

The variations of concentrations of nitrate nitrogen in storm flows were also examined. For a few selected storms immediately after treatment, storm flows were sampled at 15 minute intervals on the rising side of the hydrograph and two hour intervals on the recession side. It was anticipated that a "flushing action" would occur with a rising hydrograph and increased concentrations of nitrate nitrogen would be measured and conversely, lower concentrations would be in evidence on a falling or receding hydrograph. As indicated in Figure 9 this did not happen consistently. In fact, no clearly definable pattern of concentrations emerged for individual storms.

Mean monthly concentrations of nitrate nitrogen, as measured at the weir,

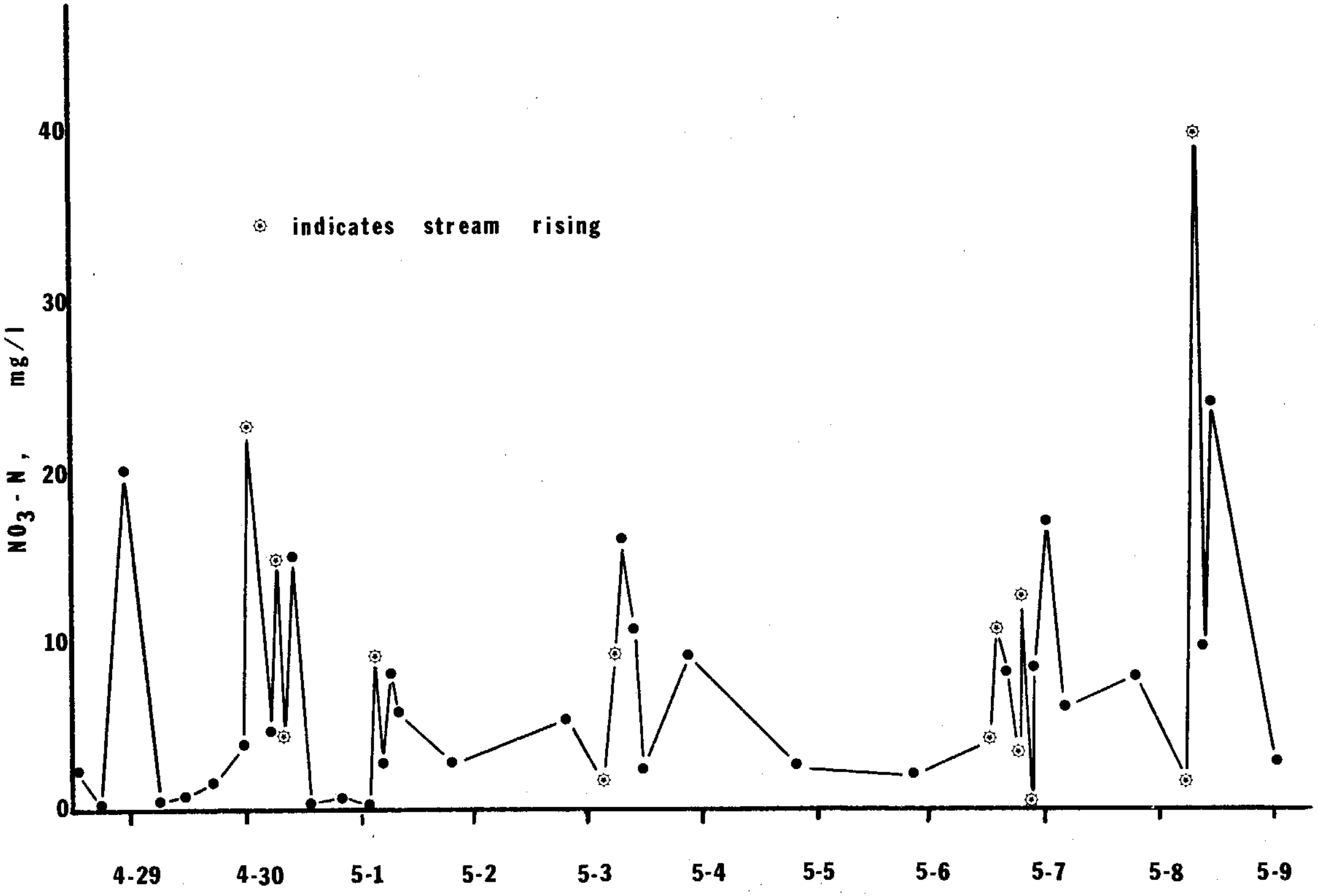


Figure 10. Relationship of nitrate nitrogen concentrations in streamflow to stream stage

responded dramatically and erratically after treatment (Fig.10). The maximum mean monthly concentration occurred in May, followed by a sharp drop in July, which coincided with very little precipitation and streamflow. The concentrations in August represented the low point for the growing season, but with the advent of fall rains, starting in September, another sharp increase in concentrations occurred, this time coinciding with more abundant precipitation and streamflow. Again, the peak mean monthly concentration (6.82 mg/l) occurred in May, followed by sub-peaks in September (5.30 mg/l) and December (4.22 mg/l). After the December sub-peak there was a steady decline until May, 1976, at which time the concentrations leveled off at approximately 0.40 mg/l until April, 1977 when they dropped to approximately 0.27 mg/l. The values from the treated watershed were still slightly elevated over pre-treatment levels and control levels through June, 1977, which was the last month field data were obtained for this study.

To further illustrate the treatment effect on nitrate nitrogen concentrations in Field Branch streamflow, a calibration equation was developed between Field Branch and Falling Rock watersheds using pre-treatment data. The relationship between mean monthly concentrations of nitrate nitrogen from the two watersheds was defined by the following equation:

$$\hat{Y} = .0283 + .7922X \qquad (1)$$

where: $\hat{Y}$ = predicted mean monthly nitrate nitrogen from Field Branch

X = observed mean monthly nitrate nitrogen from Falling Rock

The correlation value was $r = .68$. This relationship is graphically shown in Figure 11. Monthly post-treatment concentrations are also plotted and numbered. The post-treatment values are conspicuously higher than the pre-treatment values and significantly exceed the predicted values at the .05 level in all but two instances, numbers 16 and 24.

Loading values for nitrate nitrogen before, during, and after treatment also reflect the interactions of the treatment with precipitation and streamflow (Fig. 12). Maximum loading values (kg/ha) occurred during December, 1975 as opposed to May, 1975 for maximum concentration. Several sub-peaks are also in evidence, but occur at different times from those of the concentrations.

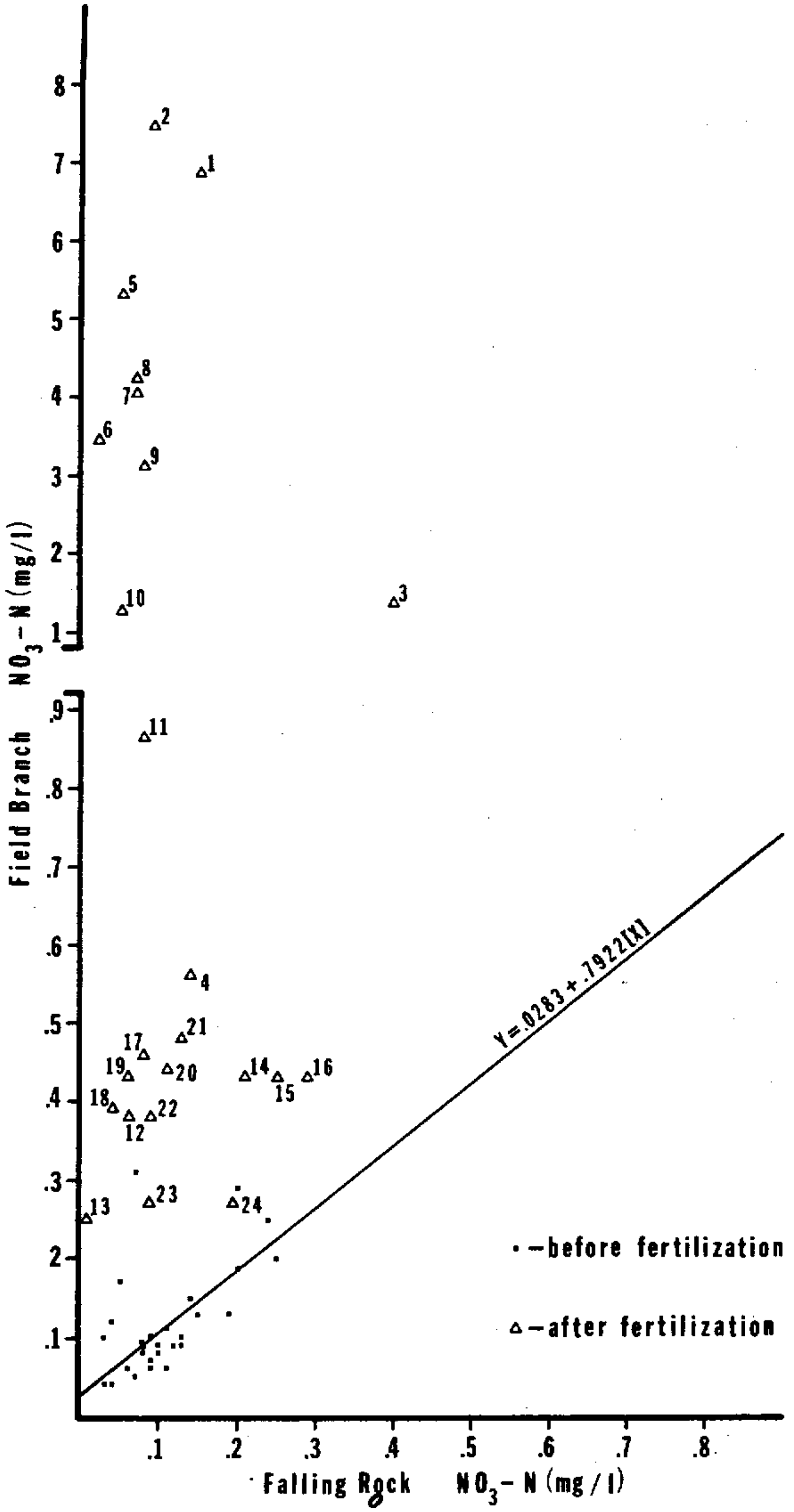


Figure 11. Nitrate nitrogen concentrations in streamflow: predicted vs observed

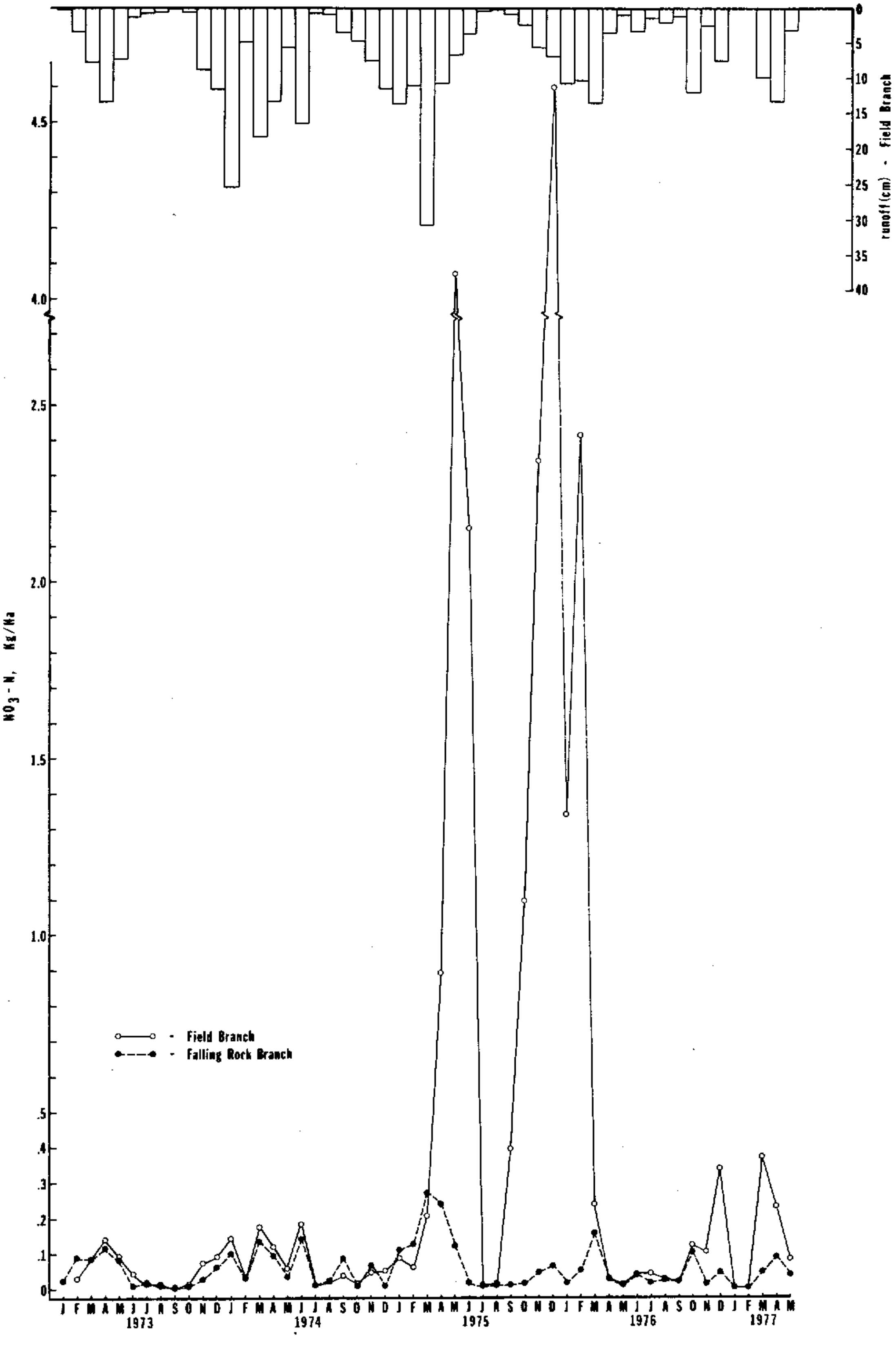


Figure 12. Nitrate nitrogen loadings in streamflow from Field Branch and Falling Rock

Both the concentration and loading values are dependent upon the time since treatment, which is related to the amount of nitrate remaining on the area, and the amount of precipitation and streamflow to move the nitrate out of the area.

Loading values were also used to determine the total transport of applied nitrate nitrogen from the treated watershed. A total of 3368 kg of nitrate nitrogen was applied during the fertilizer application. Of this total, approximately 2 percent fell directly into the stream and was discharged during the application phase. By the end of the first growing season (April, 1975 - October, 1975) following application, approximately 11 percent of the applied nitrate had been discharged from the watershed in streamflow. A total of 19 percent of the applied nitrate had been discharged through December, 1975. During calendar year 1976 an additional 7 percent was discharged. Approximately 28 percent of the total applied nitrate nitrogen left the watershed in streamflow during the treatment period, April, 1975 - June, 1977.

Total amounts of nitrates, discharged in streamflow from the control and treated watersheds, by seasons and years, are listed in Table 10. These values represent net amounts leaving the watersheds. Presumably the remaining 72 percent is either tied-up in the biomass or is located in deep pockets of soil on the watershed and will be discharged at some later time.

Previous forest fertilization-water quality studies have suggested that nitrogen applications may trigger the release of significant quantities of selected cations (Aubertin et al. 1973). Our study also indicates significant (.05 level) increases in several ions, i.e. Ca, Mg, and K, along with an increase in specific conductivity and a decrease in pH (Table 11).

Quantity

The effects of forest fertilization on the quantity of water yielded as streamflow has been subject to speculation but it has not been substantiated in the literature. It has been suggested that a fertilized forest stand will increase its water use efficiency, concomitant to increased biomass production, resulting in a decrease in water yields from the fertilized area (Hilmon and Douglas 1967, Hornbeck and Pierce 1973). This effect has been demonstrated on a grass-covered watershed in the mountains of North Carolina (Hibbert 1969).

Table 10. Total nitrate nitrogen (kg) discharged from the control and treated watersheds, by season and year.

Season	1974		1975		1976	
	Control	Treated	Control	Treated	Control	Treated
Dormant[1/]	16.87	15.60	5.47	296.33	21.08	236.77
Growing[2/]	31.36	17.12	5.78	348.06	18.77	49.67
Total	48.23	32.72	11.25	644.06	39.85	286.67

[1/] Dormant season = November - April

[2/] Growing season = May - October

Table 11. Effects of fertilization on selected water quality parameters.

Month	Parameter					
	Ca	Mg	Na	K	Sp.Cond.	pH
5-75	+*[1]	+*		+*	+*	-*
6	+*	+*		+*	+*	-*
7	+*	+*			+*	
8	+*	+*			+*	
9	+*	+*		+*	+*	-*
10	+*	+*		+*	+*	
11	+*	+*		+*	+*	-*
12	+*	+*		+*	+*	
1-76	+*	+*		+*	+*	
2	+*	+*		+*		
3	+*	+*				
4		+*		+*		
5		+*				
6						
7						
8						
9						
10						

---

[1] Significance at the .05 level
+ or - direction of change

In the study reported here, there is evidence that the fertilization treatment caused a reduction in water yield from the treated watershed. Monthly and annual streamflow amounts for the experimental watersheds are presented in Table 12.

A calibration equation (Fig. 13), based upon pre-treatment water yield values from the treated watershed (Field Branch) and the paired control (Falling Rock), was used to predict water yield after treatment:

$$\hat{Y} = 0.290 + 1.192X \qquad (2)$$

$\hat{Y}$ = predicted monthly water yield on Field Branch

X = observed monthly water yield on Falling Rock

Monthly water yields were predicted for those months when the vegetation was physiologically active (April - October). The values obtained (Table 13) indicated less water yield than predicted during 11 out of 13 post-treatment months tested. A similar comparison using the control watershed and an adjacent untreated watershed (Little Millseat) indicated six months with the same or more yield than predicted and seven months with less than predicted, during the same time span.

Although few of the differences between predicted and observed monthly water yields are statistically significant (0.05 level), there appears to be strong evidence of a reduction in yield due to treatment (Fig. 13). This indicated reduction in yield was most pronounced the first growing season after treatment (-7.04 cm) and less pronounced the second (-2.95 cm), as would be expected, as the effects of the fertilization diminished.

Nitrate Nitrogen Flux

A gross budget for nitrate nitrogen on the study areas was obtained by comparing inputs (in precipitation) with outputs (in streamflow) and the resulting differences (flux) indicating gains or losses from the watershed systems. Average nitrate nitrogen concentrations per month in precipitation (in the open) and streamflow were multiplied by total quantities of respective input-output components to arrive at gross values on a monthly basis. Monthly and annual input, output, and flux values (kg/ha) for 1974 - 1976 are

Table 12. Streamflow (cm) from the experimental watersheds, 1972 - 1977.

Month	1972	1973	1974	1975	1976	1977
	Field Branch					
Jan	18.64	-	25.35	13.64	10.72	-
Feb	17.73	3.25	4.78	10.87	10.21	-
Mar	8.33	7.70	18.21	30.84	13.36	9.78
Apr	32.26	13.28	13.18	10.69	3.45	13.31
May	2.97	7.26	5.59	6.63	0.89	3.18
Jun	0.48	1.27	16.31	3.61	3.33	0.89
Jul	0.51	0.71	0.84	0.25	1.40	3.23
Aug	0.23	0.51	0.91	0.15	2.11	6.38
Sep	-	0.15	3.40	0.81	1.22	0.36
Oct	-	0.46	4.75	2.26	11.99	2.41
Nov	-	8.69	7.52	5.64	2.39	-
Dec	-	11.46	11.40	6.78	7.47	-
$\sum$			112.24	92.17	68.54	
	Falling Rock					
Jan	19.99	1.98	22.81	13.18	3.91	-
Feb	19.46	8.92	4.42	11.71	10.67	-
Mar	9.02	7.67	15.75	31.57	13.49	7.26
Apr	28.09	9.65	10.82	10.57	3.10	11.81
May	3.71	7.75	3.40	10.41	0.86	2.74
Jun	0.53	0.64	12.50	2.46	3.12	0.61
Jul	0.46	0.71	0.81	0.23	1.47	2.44
Aug	0.15	0.38	0.91	0.15	1.65	5.28
Sep	0.56	0.18	2.59	0.74	1.14	0.53
Oct	0.66	0.41	1.73	1.96	9.88	1.70
Nov	2.77	7.37	6.88	5.11	2.24	-
Dec	17.68	6.30	10.24	6.36	7.11	-
$\sum$	103.08	51.96	92.86	94.45	58.64	

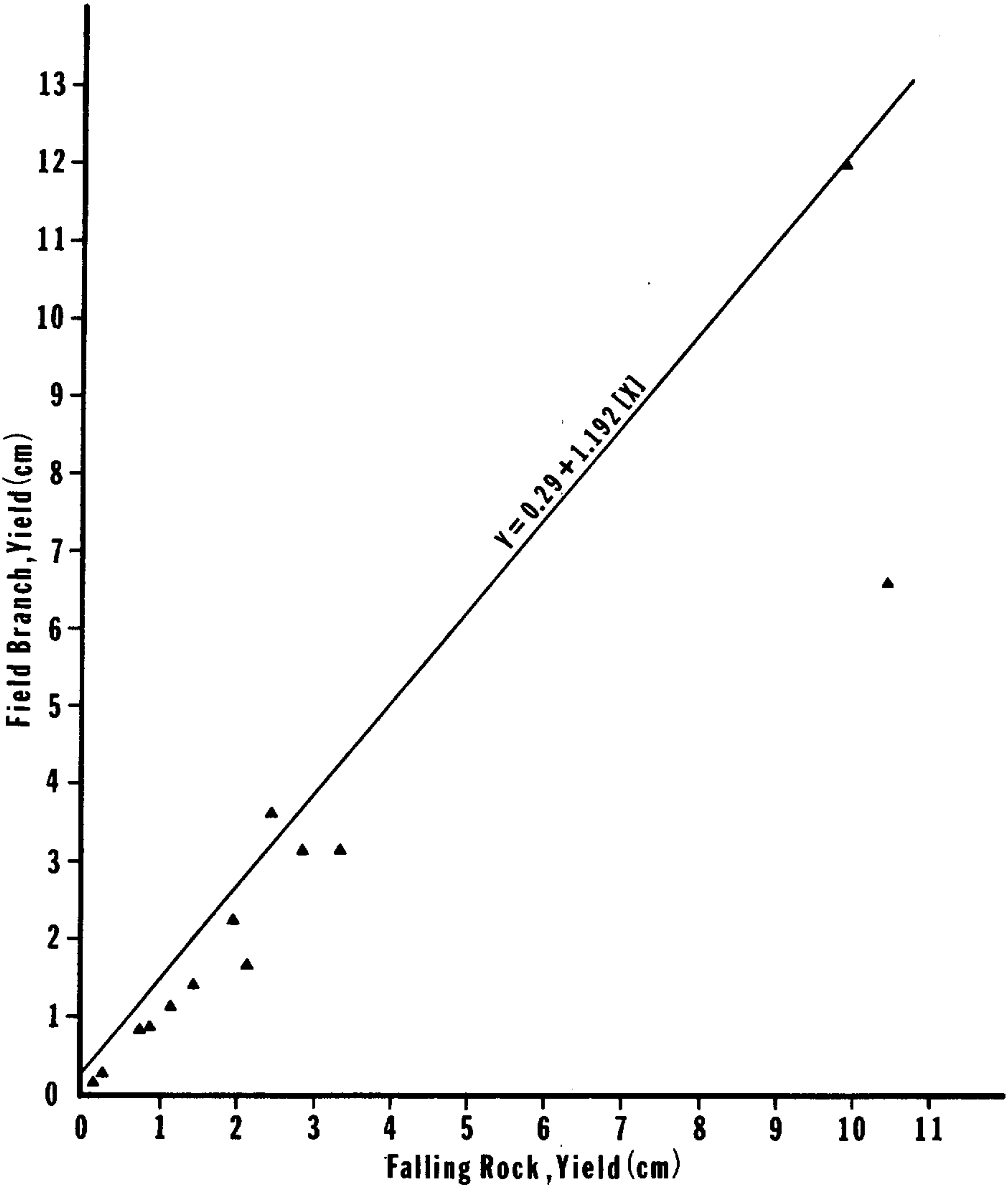


Figure 13. Predicted water yield vs observed yield, 1975 and 1976 growing seasons

Table 13. Comparison of estimated water yield with actual water yield from treated watershed during growing seasons of 1975 and 1976.

Month and Year	Falling Rock	Field Branch		Difference
	(Observed X)	(Observed Y)	(Predicted $\hat{Y}$)[1/]	$(Y - \hat{Y})$
		(cm)		
1975				
May	10.41	6.63	12.70	-6.07
June	2.46	3.61	3.22	0.39
July	0.23	0.25	0.56	-0.31
Aug.	0.15	0.15	0.47	-0.32
Sept.	0.74	0.81	1.17	-0.36
Oct.	1.96	2.26	2.63	-0.37
				-7.04
1976				
Apr.	3.10	3.45	3.99	-0.54
May	0.86	0.89	1.32	-0.43
June	3.12	3.33	4.01	-0.68
July	1.47	1.40	2.04	-0.64
Aug.	1.65	2.11	2.26	-0.15
Sept.	1.14	1.22	1.65	-0.43
Oct.	9.88	11.99	12.07	-0.08
				-2.95

[1/] Predicted water yield values, based on calibration equation

$$\hat{Y} = 0.290 + 1.192X$$

presented in Table 14. Both watersheds were accumulating nitrate nitrogen at a rather substantial rate. The average annual rate for Falling Rock for the period was 4.10 kg/ha and prior to fertilization (1974) Field Branch accumulated 4.34 kg/ha. These rates of accumulation are quite high when compared to results reported from other studies in central and eastern hardwood forests (Likens, et al. 1977, Settergren et al. 1976). One possible explanation may be that the concentrations of nitrate nitrogen in precipitation received in the study area are higher than concentrations reported in several areas of the central and eastern U.S. (Settergren et al. 1976; Swank and Henderson, 1976; Likens et al. 1977). The application of 83.92 kg/ha of nitrate nitrogen during April, 1975 caused a dramatic change in the flux of this nutrient on Field Branch watershed. Assuming an annual output of 0.80 kg/ha, which is approximately the amount for 1974 (0.79 kg/ha), a total of 15.05 kg/ha was discharged during 1975 and 6.26 kg/ha during 1976. The total nitrate nitrogen discharged for those two years, minus the background amount (0.80 kg/ha), would constitute approximately 25 percent of the applied nitrate nitrogen. The quantity discharged the first year constitutes approximately 17.9 percent of the applied nitrate nitrogen, which compares closely with the value of 17.8 percent of applied N discharged the first year in West Virginia (Aubertin et al, 1973). Since the project terminated in mid 1977 we do not have a budget for that year, however with only one month out of the last six in 1976 producing an excess of nitrate nitrogen (negative flux value), the indication is that the budget was returning to pretreatment conditions by the end of calendar year 1976.

The amounts of excess nitrate nitrogen leaving the watershed during 1975 (612 kg) and 1976 (255 kg) could very likely have produced accelerated eutrophication under somewhat different circumstances than those encountered in the study area. Topographic and foliar shading of the affected stream restricted solar input to levels less than necessary for optimum eutrophic activity.

Table 14. Monthly and Yearly Budgets of Nitrate Nitrogen Input, Outputs and Fluxes (kg/ha).

	1974			1975			1976		
Months	Input	Output	Flux	Input	Output	Flux	Input	Output	Flux
	Field Branch								
Jan.	0.65	0.10	0.55	0.29	0.10	0.19	0.27	1.30	-1.03
Feb.	0.17	0.03	0.14	0.43	0.06	0.37	0.40	2.32	-1.92
Mar.	0.58	0.17	0.41	0.94	0.19	0.75	0.52	1.77	-1.25
Apr.	0.73	0.11	0.62	0.57	0.88	-0.31	0.07	0.19	-0.12
May	0.57	0.06	0.51	0.56	4.06	-3.50	0.26	0.03	0.23
June	0.40	0.07	0.33	0.15	2.12	-1.97	0.28	0.18	0.10
July	0.22	0.12	0.10	0.12	0.01	0.11	0.42	0.16	0.26
Aug.	0.32	0.02	0.30	0.14	0.01	0.13	0.23	0.09	0.14
Sept.	0.17	0.03	0.14	0.27	0.39	-0.12	0.21	0.07	0.14
Oct.	0.25	0.01	0.24	0.56	1.09	-0.53	0.77	0.51	0.26
Nov.	0.31	0.04	0.27	0.25	2.34	-2.09	0.08	0.13	-0.05
Dec.	0.76	0.03	0.73	0.76	4.60	-3.84	0.70	0.31	0.39
$\sum$	5.13	0.79	4.34	5.04	15.85	-10.81	4.21	7.06	-2.85
$\bar{x}$	0.43	0.07	0.36	0.42	1.32	-0.90	0.35	0.59	-0.24
	Falling Rock								
Jan.	0.60	0.09	0.51	0.25	0.02	0.23	0.25	0.01	0.24
Feb.	0.19	0.02	0.17	0.35	0.01	0.34	0.34	0.00	0.34
Mar.	0.55	0.06	0.49	0.87	0.02	0.85	0.51	0.16	0.35
Apr.	0.64	0.07	0.57	0.49	0.02	0.47	0.06	0.02	0.04
May	0.51	0.03	0.48	0.62	0.01	0.61	0.24	0.01	0.23
June	0.40	0.14	0.26	0.15	0.01	0.14	0.26	0.02	0.24
July	0.21	0.01	0.20	0.12	0.00	0.12	0.36	0.02	0.34
Aug.	0.30	0.00	0.30	0.17	0.00	0.17	0.17	0.03	0.14
Sept.	0.14	0.08	0.06	0.24	0.01	0.23	0.19	0.01	0.18
Oct.	0.22	0.00	0.22	0.54	0.00	0.54	0.68	0.08	0.60
Nov.	0.27	0.01	0.26	0.24	0.00	0.24	0.07	0.01	0.06
Dec.	0.96	0.00	0.96	0.64	0.00	0.64	0.54	0.05	0.49
$\sum$	4.99	0.51	4.48	4.68	0.10	4.58	3.67	0.42	3.25
$\bar{x}$	0.42	0.04	0.37	0.39	0.01	0.38	0.31	0.03	0.27

CHAPTER IV

CONCLUSIONS

This project was designed and conducted to determine the effects of nitrogen fertilization on the quality and quantity of streamflow eminating from a mature eastern hardwood forest watershed. Since a relatively large part of any applied nitrogen fertilizer ends up in the highly mobile nitrate nitrogen form it is important to know the disposition of this particular anionic nutrient. Concentrations and quantities of nitrate nitrogen were monitored, throughout the study, in precipitation, soils, litter, vegetation, and streamflow. Comparison of gross quantities of nitrate nitrogen in precipitation (inputs) with quantities in streamflow (outputs) permitted the determination of nitrate nitrogen flux for the study area.

Several salient findings have surfaced in this study:

1. It is very difficult to obtain uniform distribution of aerially applied fertilizer to mature hardwood forests in mountainous terrain. Despite strenuous ground control efforts and coaching of the helicopter pilot, the variations in amounts deposited on the ground were quite high. The maximum deposition rate exceeded the minimum rate by a factor of 10.
2. Although initial concentrations and amounts of applied nitrate nitrogen in the 0 - 48 cm depth of the soils may be quite high this condition persisted less than one year. A combination of leaching and uptake by vegetation were the likely processes responsible for the rather short-lived effect.
3. Where no attempt is made to avoid application of fertilizer over live streams, extremely high concentrations of nutrients may be found in the streamflow. During application of the ammonium nitrate, concentrations of nitrate nitrogen were measured in excess of 600 mg/l in subdrainages of the watershed. Levels of nitrate nitrogen potentially toxic to humans and animals persisted in the stream for several days after application.

4. Concentrations of nitrate nitrogen several orders of magnitude greater than pretreatment levels were evident in streamflow two years after application.
5. Fertilization apparently reduced the quantity of streamflow during the two growing seasons following application.

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APPENDIX A

Concentrations of nitrate nitrogen (NO_3-N) in streamflow during period of intensive sampling - Field Branch at weir.

Date	Time	NO_3-N (mg/l)	Stream Condition
4 - 27 - 75	1:53 pm	0.17	
	2:45 pm *	0.05	
	3:15 pm *	0.10	
	3:45 pm *	0.05	
	4:15 pm *	0.05	
	4:45 pm *	0.30	
	5:15 pm *	0.05	
	5:45 pm *	12.50	
	6:15 pm *	8.50	
	6:45 pm *	52.00	
	7:15 pm *	16.00	
	7:45 pm *	36.00	
	8:15 pm	7.50	
	8:45 pm	6.30	
	9:15 pm	8.50	
	9:45 pm	19.00	
	10:15 pm	14.30	
	10:45 pm	35.00	
	11:15 pm	28.50	
	12:10 am	10.00	
	12:15 am	14.30	
4 - 28 - 75	12:45 am	28.00	
	1:15 am	11.00	
	1:45 am	14.00	
	2:15 am	75.00	
	2:45 am	9.50	
	3:15 am	17.50	
	3:45 am	16.00	
	4:15 am	70.00	
	4:45 am	41.50	
	5:15 am	16.00	
	5:45 am	75.00	
	6:15 am	70.00	
	6:45 am	28.50	
	7:15 am	55.00	
	7:45 am	17.50	

APPENDIX A (Continued)

Date	Time	NO_3-N (mg/1)	Stream Condition
	8:15 am	16.50	
	8:45 am	19.30	
	9:15 am *	19.50	
	9:45 am *	65.00	
	10:15 am *	65.00	
	10:45 am *	120.00	
	11:15 am *	52.50	
	11:45 am *	123.00	
	12:15 pm *	10.30	
	12:45 pm	39.20	
	1:15 pm	33.30	
	1:45 pm	52.50	
	2:15 pm	13.50	
	2:45 pm	16.00	
	3:15 pm	61.00	
	3:45 pm	42.00	
	4:15 pm	26.50	
	4:45 pm	33.50	
	5:15 pm	44.20	
	5:45 pm	28.00	
	6:15 pm	11.00	
	6:45 pm	31.00	
	7:15 pm	0.85	
	7:45 pm	0.45	
	8:15 pm	6.00	
	9:00 pm	0.51	
	10:00 pm	32.00	
	11:00 pm	22.00	
4 - 29 - 75	12:00 M	2.35	
	6:00 am	0.30	
	12:00 N	20.00	
	6:00 pm	0.44	
4 - 30 - 75	12:00 M	0.81	
	6:00 am	1.60	
	12:00 N	4.00	
	1:32 pm	22.50	R (Rising)
	1:45 pm	14.30	
	2:00 pm	5.70	
	2:15 pm	14.30	F (Falling)
	4:15 pm	4.80	
	5:45 pm	13.60	R
	6:00 pm	5.70	
	6:15 pm	4.50	
	6:30 pm	8.40	F

APPENDIX A (Continued)

Date	Time	NO_3-N (mg/l)	Stream Condition
	8:30 pm	16.00	
	10:30 pm	12.30	
5 - 1 - 75	12:30 am	0.25	
	8:10 am	0.80	
	12:46 pm	0.45	R
	1:00 pm	1.35	
	1:15 pm	9.00	
	1:30 pm	6.00	
	1:45 pm	2.72	F
	3:45 pm	8.00	
	5:47 pm	6.50	
	7:45 pm	5.70	
5 - 2 - 75	8:00 am	2.75	
5 - 3 - 75	8:05 am	5.50	
	3:15 pm	1.85	R
	3:30 pm	4.93	
	3:45 pm	1.05	
	4:00 pm	5.50	
	4:15 pm	2.50	
	4:30 pm	5.60	
	4:45 pm	9.10	
	5:00 pm	9.00	
	5:15 pm	16.00	F
	7:15 pm	10.70	
	9:15 pm	10.50	
	11:15 pm	2.25	
5 - 4 - 75	8:00 am	9.00	
5 - 5 - 75	8:03 am	2.55	
5 - 6 - 75	8:45 am	2.15	
	12:00 M	4.14	R
5 - 7 - 75	12:15 am	2.96	
	12:30 am	6.50	
	12:45 am	5.80	
	1:00 am	10.70	
	1:15 am	5.80	F
	3:15 am	8.00	
	5:15 am	3.35	R
	5:30 am	12.50	
	5:45 am	5.60	

APPENDIX A (Continued)

Date	Time	NO_3-N (mg/l)	Stream Condition
	6:00 am	5.20	
	6:15 am	0.38	
	6:30 am	7.40	F
	8:31 am	8.30	
	10:30 am	9.60	
	12:33 pm	17.00	
	2:30 pm	9.20	
	4:35 pm	6.00	
	6:45 pm	6.00	
5 - 8 - 75	8:30 am	7.90	
	5:45 pm	1.60	R
	6:00 pm	3.65	
	6:15 pm	5.00	
	6:30 pm	39.50	
	6:45 pm	38.50	
	7:00 pm	19.00	F
	9:00 pm	9.40	
	11:00 pm	24.00	
5 - 9 - 75	1:00 am	7.00	
	11:50 am	2.75	

* Fertilizer application

APPENDIX B

Concentrations of nitrate nitrogen (NO_3-N) in streamflow during period of intensive sampling - Field Branch subdrainages above weir.

Date	Time	NO_3-N (mg/l) Subdrainage		
		A	B	C
4 - 27 - 75	2:00 pm	0.13	0.11	0.11
	3:20 pm *	0.16	0.23	0.28
	4:20 pm *	0.19	0.30	0.20
	5:20 pm *	11.00	0.19	2.35
	6:20 pm *	77.50	7.50	0.88
	7:20 pm *	170.00	103.00	1.40
	8:20 pm	97.50	31.70	0.28
	9:20 pm	287.50	160.00	0.30
	10.20 pm	42.00	65.00	0.25
	11:20 pm	12.00	42.00	0.28
4 - 28 - 75	8:20 am	0.41	23.00	0.15
	9:20 am *	0.26	10.50	0.15
	10:20 am *	125.00	88.00	640.00
	11:20 am *	48.50	137.00	390.00
	12:20 pm *	31.00	45.00	145.00
	1:20 pm	33.50	16.50	64.50
	2:20 pm	51.00	28.00	210.00
	3:20 pm	43.00	40.50	84.00
	4:20 pm	37.50	17.60	46.00
	5:20 pm	8.50	25.00	45.00
	6:20 pm	9.80	31.00	28.50
	7:20 pm	13.20	5.30	29.50
	8:20 pm	9.50	5.96	26.50

* Fertilizer application

APPENDIX C

Concentrations of nitrate nitrogen (NO_3-N) in streamlfow during period of intensive sampling - control areas.

Date	Area	Time	NO_3-N (mg/1)
4 - 27 - 75	Little Millseat	2:15 pm	0.19
	Little Millseat	8:30 pm	0.15
4 - 28 - 75	Little Millseat	8:30 am	0.17
	Little Millseat	1:30 pm	0.12
	Little Millseat	5:30 pm	0.17
5 - 8 - 75	Little Millseat	5:50 pm	0.25
	Little Millseat	6:49 pm	0.25
4 - 24 - 75	Falling Rock		0.58
4 - 28 - 75	Falling Rock		0.24