To the Graduate Council:

I am submitting herewith a thesis written by Mark H. Wolfe entitled "The Influence of Stemflow on the Distribution of Sulfate-S Around the Base of Two Tree Species." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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The Graduate School

THE INFLUENCE OF STEMFLOW ON THE DISTRIBUTION OF SULFATE-S AROUND THE BASE OF TWO TREE SPECIES

A Thesis

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Master of Science

Degree

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ABSTRACT

Stemflow influence on the distribution of soil (NaH_2PO_4-extractable) sulfate and pH was evaluated over three size classes of red maple (Acer rubrum) and scarlet oak (Quercus coccinea) at two experimental watersheds in Tennessee which receive different yearly inputs of sulfur from atmospheric sources. The soil profile around the base of red maple and scarlet oak was sampled by horizon at 25, 50, 100 and 200 cm from the stem along four transects originating at the stem base which were spaced 90° apart.

Soil extractable SO_4-S and pH were analyzed by horizon to determine the effect of site, tree species, tree size class within species, site by species interaction, sampling transects and distance sampled within transects, on these parameters. Statistical analysis indicated that stemflow was not a factor influencing SO_4-S distribution around the base of red maple and scarlet oak. Species, however, had a strong effect on A1, B22 and B22 soil SO_4-S concentrations than A1 horizons beneath scarlet oak (24.0 $\mu g \cdot g^{-1}$ vs 19.5 $\mu g \cdot ^{-1}$, respectively). The B22 and B23 horizons beneath scarlet oaks had greater SO_4-S concentrations than corresponding horizons beneath red maple (79.0 $\mu g \cdot g^{-1}$ vs. 46.0 $\mu g \cdot g^{-1}$ and 107 $\mu g \cdot g^{-1}$ vs 68.0 $\mu g \cdot g^{-1}$ for scarlet oak and red maple in B22 and B23 horizons, respectively). Reasons for the greater SO_4-S concentration of B22 and B23 horizons are unclear but may relate to 1) the effect of canopy area on throughfall SO_4-S content, 2) differences in above-ground biomass S content of red maple and scarlet oak, 3) the

nature and extent of stemflow movement along root surfaces and old root channels or 4) subtle variations in properties of soils beneath red maple vs scarlet oak.

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I. INTRODUCTION

Precipitation which reaches the forest floor is chemically enriched through the leaching of bark and leaf tissues and by the rinsing of scavenged pollutants from leaf and bark surfaces. Expressed as a percentage of total rainfall, stemflow accounts for between 1 and 15% of the precipitation which reaches the forest floor. The intensity and amount of precipitation, along with bark and canopy characteristics of a tree species, can serve to regulate the amount of stemflow yielded by a tree. Given the same amount of precipitation, smooth bark tree species will yield greater quantities of stemflow than would rough bark species having a similar canopy position and branch habit.

Stemflow and its contained chemical constituents can effect soil chemical, physical and morphological properties over time. Nutrients contained in stemflow can accumulate or be leached from the soil near the base of a tree resulting in a concentration gradient with distance from the stem. In forest nutrient cycling schemes, stemflow represents an important but often overlooked flux of nutrients to the forest floor. This, combined with the fact that stemflow can alter soil properties near tree stems, give a added importance to stemflow and its role in nutrient cycling.

Increasing concerns over the role of acid precipitation in the acidification and leaching of forest soils has led to expanded study of sulfate-S cycling in forest systems. Sulfate-S carried to the forest floor by stemflow at two forested watersheds on the

Cumberland Plateau of Tennessee, represents a significant input of sulfate-S to these sites. Knowledge of the ability of stemflow to alter soil chemistry near the stem of trees raises the question as to the fate of sulfate-S carried by stemflow to the forest floor. Previous work has to a large extent assessed the influence of stemflow on soil cation distribution in soils near tree stems. The objective of this study is to evaluate the extent of stemflow influence on the distribution of soil sulfate-S around the base of two tree species. It is hoped that knowledge gained from this study will be useful to future work in this area.

II. LITERATURE REVIEW

Nature of Stemflow

Precipitation entering a forest system may reach the forest floor by two pathways: throughfall and stemflow. Leonard (1961) defines throughfall as that portion of incident precipitation that reaches the forest floor directly through the canopy, and stemflow as that portion of the rainfall, that having been intercepted by the forest canopy, reaches the forest floor by flowing down the tree stems. In a study conducted on rainfall interception in a northern hardwood forest, Leonard (1961) noted that throughfall and stemflow accounted for 82% and 5% of the total rainfall, respectively, with the remainder being evaporated from or absorbed by leaves, stems and branches.

Stemflow as a percentage of total rainfall has been reported to range between 1 and 15% depending on storm characteristics, species and canopy characteristics (Voight, 1960). Kitterage (1948) noted that for smooth bark species such as American beech (*Fagus grandifolia*), stemflow may begin at rains of 0.025 cm, but for rough bark species stemflow may not occur until 1.7 cm of rainfall has occurred. Kitterage also stated that stemflow has been found to increase with the amount of rainfall per storm. Voight (1960) listed branching habit, form and texture of leaves, and bark texture as factors which can regulate stemflow. Acutely ascending branches (i.e., branches forming an ascending angle of less than 90° with the main tree stem) were observed to enhance stemflow by directing intercepted water to the main tree stem (Hoover, 1958). Branches which are perpendicular to or descend from the main tree stem, reduce stemflow by directing intercepted water away from the stem (Voight, 1960).

Gersper (1971) found that the amount of precipitation which reaches the ground as stemflow is related principally to bark characteristics. Leonard (1961) observed that American beech (smooth-bark) ranked above sugar maple (Acer saccharum) and yellow birch (Betula lutea) (both rough-barked) in the volume of stemflow yielded for equal amounts of total rainfall. Sugar maple yielded only two-thirds as much stemflow as beech. Stemflow yield from yellow birch was half the volume yielded by beech of similar size. Similarly, Voight (196) observed that beech yielded more stemflow than did the rough-barked species eastern hemlock (Tsuga candadensis) and red pine (Pinus resinosa). Voight noted that the greater water storage capacity of hemlock and red pine bark was responsible for the lower stemflow yield, and that the effect of bark water storage capacity would be greatest in storms of low intensity and short duration. Patterson (1975) recognized the influence of bark water storage capacity on stemflow yield and observed that hard dense bark such as that of hickory (Carya spp.) absorbed little water, and that furrowed surface of the bark was the primary bark characteristic effecting stemflow yield.

The canopy position of a tree crown is an additional factor which can influence stemflow yield. Leonard (1961) observed that a tree whose canopy was in a dominant position could yield 30 to 50%

more stemflow than a tree of the same species and diameter, but whose canopy position was co-dominant or intermediate. When stemflow is viewed as being spread uniformly over the crown projection area it amounts to between 1 and 15% of total rainfall; stemflow, however, is absorbed by the soil usually within 30.0 cm of the tree stem and failure to recognize this can lead to an underestimation of the significance of stemflow (Voight, 1960). Leonard (1961) found that stemflow collected from a 24.5 cm d.b.h. beech during a 2.5 cm rainfall was 113.5L. If this amount of water were absorbed within 30.0 cm from the tree stem as Voight (1960) suggests, it would be equivalent to 17.8 cm of total rainfall entering the soil within 30.0 cm of the tree stem. Similarly, Gersper and Holowaychuk (1971) determined that the volume of stemflow from American beech, resulting from 18.6 cm of total precipitation, would be equivalent to 96.0 cm of rainfall entering the soil within 30.0 cm of the tree stem. Both Hoover (1950) and Leonard (1961) found that this concentrated application of water is important to tree growth. Voight (1960) observed that stemflow entering the soil around the base of a tree stem penetrated the soil to a greater depth than would throughfall and consequently can serve as a mechanism for subsoil moisture recharge.

Stemflow Chemistry

As precipitation moves through the canopy of a forest it becomes enriched with nutrients; nutrient enrichment arises from nutrients which are leached or washed from the leaf and bark surfaces and those which are present in the incident precipitation (Eaton et al., 1973). The quality of nutrients removed from the forest cover by precipitation is dependent on tree species and the amount and intensity of precipitation (Mina, 1964). Mina concluded tree species with a rough bark texture had more enriched stemflows than smooth bark species, while Mahendrappa (1974) found that the chemistry of stemflow was not dependent on the bark texture of coniferous species.

Mina (1964) noted that the leaching of calcium and magnesium from leaf tissue of birch increased after prolonged wetting of the leaf, perhaps because the prolonged wetting increased the permeability of epidermal tissues, he therefore noted the concentrations of potassium, Ca and Mg to be greatest in throughfall from low intensity as compared to high intensity rainfall events. Attiwill (1966) also showed that the leaching of nutrients was highest in rainfall of low intensity, and that most of the leaching of nutrients occurred during the first hours of wetting.

The leaching potential of nutrients from tree leaves has been reported to increase with the maturity of the tree (Lutz and Chandler, 1946). Nutrients are less susceptible to leaching in young leaves where they are quickly metabolized, than in old leaves where nutrients are in exchangeable forms and more susceptible to leaching (Tukey et al., 1965).

The leaching of nutrients from tree species may also vary with the nature of the tree. Madwich and Ovington (1959) noted that deciduous trees lose more nutrients than conifers through canopy leaching, but conifers continue to lose nutrients through the winter season. Potassium was found by Mina (1964) to be the most leached nutrient from spruce (Picea spp.), however, Ca was leached in the greatest amounts from birch cover.

Eaton et al. (1973) suggested that the leaching of nutrients from the forest canopy may be a result of hydrogen ion exchange. These researchers observed that 75% of the cationic input from precipitation was from hydrogen 48.5 mmol $(H^+) \cdot m^{-2}$ and that 4.6 mmol $(H^+) \cdot m^{-2}$ was carried to the forest floor by stemflow and throughfall. The net cation loss from the canopy for the same period was 168.5 mmol $(+) \cdot m^{-2}$. The authors concluded that 27% of the leached cations could be accounted for by hydrogen ion exchange.

As nutrients are leached from the forest canopy, they are carried to the forest floor by throughfall and stemflow. Stemflow is much more chemically enriched than throughfall, but total returns to the forest floor are greater in throughfall than in stemflow because of the much greater volume of throughfall (Patterson, 1975). The initial composition of stemflow was found by Eaton et al. (1973) to be difficult to determine. The chemical content of stemflow is somewhere between the chemistry of the rainfall and that of throughfall, and will vary in its chemistry depending on how far the throughfall has penetrated the canopy before becoming stemflow. Carlisle et al. (1966) observed a close correlation between mean monthly throughfall composition and mean monthly stemflow composition for nitrogen, phosphorus, sodium, K, Ca, and Mg. This close correlation suggested to Carlisle that throughfall chemistry was effecting the chemistry of stemflow. Eaton et al. (1973) also observed that stemflow chemistry closely paralleled the chemistry of throughfall in a northern hardwood forest. Thomas (1969) found that Ca^{45} contained in stemflow was much lower after leaf abscission as compared to Ca^{45} levels in stemflow before leaf abscission. This occurrence was thought to indicate that leaching of bark was less important to stemflow chemistry than leaching of nutrients from tree leaf tissues. Carlisle et al. (1966), however, found that the leaching of bark of sessile oak (Quercus petraea) is an important source of nutrients in stemflow of this species. Atmospheric dry fallout may add significantly to the chemistry of stemflow and throughfall (Eaton et al., 1973). The chemistry of stemflow may also be affected by the interaction of microflora (lichens, mosses, etc.) with stemflow water (Carlisle et al., 1966; Eaton et al., 1973; Mina, 1964).

Potassium, Ca, Mg, and Na have been found by most workers to be the dominant cations in stemflow from a variety of tree species from many regions of the world. Eaton et al., (1973), found the rank of cations in stemflow from a northern hardwood forest in New Hampshire to be, in descending order of concentration: K > Ca > Mg > Na. The inputs of K, Ca, Mg, and Na by stemflow to the hardwood forest floor were 3.51 $kg \cdot ha^{-1}$ K, 0.64 $kg \cdot ha^{-1}$ Ca, 0.19 $kg \cdot ha^{-1}$ Mg, and 0.05 $kg \cdot ha^{-1}$ Na. Mina (1964), working in the Moscow region of the U.S.S.R., found that Ca followed by K, Mg, and ammonium-ion were the most common nutrients in stemflow. This order of concentration was independent of tree species considered (Quercus spp., Fraxinus spp., *Corylus* spp., *Tilia* spp., *Betula* spp., and *Pinus* spp.). Potassium and Ca in stemflows from hardwood and softwood species in eastern Canada were found in larger concentrations than Mg, Na, and iron (Mahendrappa, 1974). Several other authors have found K and Ca to be the most dominant cations in stemflow (George, 1979; Gersper and Holowaychuk, 1971: Kaul and Billings, 1965; Kelly, 1980; Patterson, 1975). The order of cation concentration in stemflow from beech, eastern red oak (*Quercus borealis*) and sugar maple was found to be K=Ca > Na=Mg (Gersper and Holowaychuk, 1971). Stemflow from beech contained an average of 0.34 $mmol \cdot l^{-1}$ K, 0.25 $mmol \cdot l^{-1}$ Ca, 0.095 $mmol \cdot ^{-1}$ Na, and 0.74 $mmol \cdot l^{-1}$ Mg, while stemflow from eastern red oak averaged 0.49 $mmol \cdot l^{-1}$ K, 0.15 $mmol \cdot l^{-1}$ Ca, 0.10 $mmol \cdot l^{-1}$ Na, and 0.078 $mmol \cdot l^{-1}$ Mg. The cations in stemflow from a eucalyptus hybrid (*Eucalyptus* spp.) plantation in India were reported by George (1979) to decrease in concentration in the order: K > Ca > Mg. The return of these cations to the soil by stemflow was found to be 3.9 $kg \cdot ha^{-1} \cdot yr^{-1}$ N. Patterson (1975) found that K and Ca were returned by stemflow to the soil in the largest quantities followed by Mg and manganese. Kelly (1984a) reported Ca, followed by K and Mg, were the dominant cations in stemflow from hardwoods of the Cumberland Plateau physiographic region of Tennessee.

Inputs of N and P by stemflow are much less than stemflow inputs of nutrients such as K, Ca, or Mg. The annual input of inorganic N was found by Carlisle (1966) to be 0.02 $kg \cdot ha^{-1} \cdot yr^{-1}$ and for P, the annual input was 0.01 $kg \cdot ha^{-1} \cdot yr^{-1}$. The input of P to the soil in a eucalyptus forest was 0.1 $kg \cdot ha^{-1} \cdot yr^{-1}$ and 0.02 $kg \cdot ha^{-1} \cdot yr^{-1}$ for N (George, 1979). The relatively low content of N and P in stemflow may be due to the fact that N and P are associated with organic molecules and are the most difficultly leached nutrients from the forest canopy (Eaton et al., 1973). Likens et al. (1977) noted that N and P were cycled primarily through litterfall, with stemflow being mostly responsible for K and sulfur cycling in northern hardwood forest. The input of sulfate-S to a northern hardwood site in New Hampshire was found by Eaton et al. (1973) to be second only to K input by stemflow. The input of SO_4-S to this northern hardwood site was 1.87 $kg \cdot ha^{-1} \cdot yr^{-1}$. Kelly (1984a) reports that stemflow accounted for 12 and 17% (8 and 16.0 $kg \cdot ha^{-1} \cdot yr^{-1}$, respectively) of the sulfate which reached the forest floor of Camp Branch and Cross Creek watersheds in Tennessee. These watersheds are 99 km and 19 km from a 1959 megawatt coal-fired power plant and this may account for the difference in SO_4-4 input.

The pH of stemflow varies from species to species. Mina (1964) found the pH of spruce (Picea spp.) stemflow to range from 2.7 to 3.4, while birch (Betula spp.) stemflow ranged from 3.7 to 5.0. Patterson (1974) studying stemflow and through fall in the Piedmont region of North Carolina, observed that stemflow from shortleaf pine (Pinus echinata) and loblolly pine (Pinus taeda) were in the range pH 3.2 to 3.9. Hickories (Carya spp.) and white oak (Quercus alba) ranged from pH 6.3 to 6.8. Stemflow from beech and tulip poplar (Liriodendron tulipifera) ranged from pH 4.4 to 4.7 and pH 6.8 and 6.4, respectively.

In addition to the inorganic constituents of stemflow, stemflow can also carry a considerable amount of organic material to the forest floor (Carlisle et al., 1966; Eaton et al., 1973; Gersper and Holowaychuk, 1971; Mahendrappa, 1974; Mina, 1964). Mahendrappa (1974) found that aspen (Populus gradnidentata) returned 3.03 $kg \cdot ha^{-1}$ of carbohydrates to the forest floor, balsam fir (Abies balsamea) contributed 7.90 $kg \cdot ha^{-1}$, and red maple (Acer rubrum) returned 1.78 $kg \cdot ha^{-1}$ of carbohydrates to the forest floor for the period May through November 1973. Stemflow for some northern hardwoods contributed 11.50 $kg \cdot ha^{-1}$ of organic matter to the forest floor during a period from 1 June 1965 to 28 October 1969 (Eaton, et al., 1973).

Effect of Stemflow on Soil Properties

Stemflow is deposited over a small area, usually 30 cm or less radially around the bole of trees. Since trees are static, stemflow and its contained organic and inorganic constituents effect soil properties over time (Franklin et al., 1967; Gersper and Holowaychuk, 1971; Gersper and Holowaychuck, 1970a, 1970b; Mina, 1967; Patterson, 1975). The effect of stemflow on soil properties of surface soils in forest systems. The variations in soil properties as a result of stemflow influence, may persist for many decades after the death or removal of the tree (Mina, 1967).

Stemflow water entering the soil around the base of a tree can influence morphological, physical, and chemical properties of soils (Gersper and Holowaychuk, 1970a; 1970b; 1971). Gersper and

Holowaychuk (1970) investigated a soil profile 0 to 200 cm from the stem of an American beech to determine the effect of stemflow on soil properties near the beech stem as influenced by progressively less stemflow on soil morphology was increased thickening of the E2 horizon with decreasing distance from the stem. In addition, there was a considerable amount of mottling of B2 horizons at 0 cm from the stem, in contrast to no mottling of B2 horizons at 200 cm from the stem. Bulk densities of A1 horizons were found to decrease towards the stem, while clay content of A horizons increased with decreasing distance from the stem. The clay content of B2 horizons decreased with decreasing distance from the stem.

The effect of beech stemflow on various soil chemical properties was also investigated (Gersper and Holowaychuk, 1970b). The effect of stemflow on soil pH, total N, exchangeable acidity, exchangeable Ca, Mg, and K, cation exchange capacity, base saturation, carbon/nitrogen ratio, organic C and free iron oxides was determined. The authors observed increased levels of exchangeable acidity, C. E. C., organic C, total N, free Fe oxides and exchangeable K with decreasing distance from the stem.

The effect of stemflow from beech, sugar maple, eastern red oak, white oak and pignut hickory (Carya glabra) on the chemical properties of two soils in Ohio showed that soil organic C and exchangeable K accumulated near the stem of species which produced large amounts of stemflow. In addition, soil pH was found to decrease inward toward the stem for the same species. The effect of stemflow on pH, exchangeable K and organic C was more pronounced in the soil near the stems of beech and eastern red oak (i.e., high stemflow volume) than under hickory, sugar maple and white oak (low stemflow volume) (Gersper and Holowaychuk, 1971).

Patterson (1975), working with hardwood and softwood species of the Piedmont region of North Carolina, compared the concentrations of cations in the surface soil (0-10 cm depth) of the stemflow zone (0-30 cm from the tree stem) with that of surface soil at the crown edge, and found that soil K was higher in the stemflow zone than at the crown edge for all species studied. The concentrations of Ca, Mg and Mn in the stemflow zone, however, were not as consistent as K distribution, but varied with the tree species. Calcium and Mn concentrations were greatest in the stemflow zone of white oak and hickory, and were lowest in the stemflow zone of beech, yellow poplar and shortleaf pine relative to Ca and Mn concentrations at the crown edge for the same species. Magnesium concentrations were greatest in the stemflow zone of hickory, but were lowest in the stemflow zone of beech, yellow poplar, shortleaf pine and white oak relative to soil Mg concentrations at the crown edge of these species. The pH of stemflow zone soil of hickory and white oak was found to be higher than soil pH under the crown edge. Soil pH was much lower in the stemflow zone than at the crown edge for beech and shortleaf pine. Patterson (1975) observed that soil pH levels in the stemflow zone of individual species correlated with stemflow pH of that species.

Mina (1967) studying the influence of stemflow on soil properties noted that the pH of A1 horizons decreased with decreasing distance from the stem of a 120-year-old pine. A similar trend in pH was also observed for a 20-year-old birch. For oak, soil pH did not vary with distance from the stem. Stemflow was also found by Mina to effect the mobility of Fe and aluminum in the soil around the base of trees in his study. Mina noted that the high acidity of stemflow coupled with polyphenols (which are leached from leaf tissues and from organo-mineral complexes with Fe and Al) were responsible for increased solubility and mobility of soil Fe and Al.

Stemflow is not always uniformly distributed around the base of a tree but may be greater on the acute angle sides of leaning trees (Gersper and Holowaychuk, 1971). Unevenly distributed stemflow effected soil properties in that on the high stemflow side of the tree, the soil contained a higher percentage of organic C, was more acid, and contained lower exchangeable bases. The authors noted that unequal distribution of stemflow water could have implications with regard to obtaining a representative sample from around the base of a tree.

Bark and leaf litter may also cause variation in soil properties with respect to distance from the stem (Barth, 1980; Gersper and Holowaychuk, 1971; Patterson, 1975; Zinke, 1967). Fission products such as ^{137}Cs can be used to substantiate the area around the base of a tree stem which is effected by stemflow since fallout of long half-life fission products when intercepted by the canopy can be carried to the soil by stemflow (Franklin et al., 1967). Franklin observed that the concentration of ^{137}Cs was highest near the stem of trees which yielded large quantities of stemflow and lowest near the stem of species which yielded little stemflow. In both cases, however, the concentration of ^{137}Cs decreased with increasing distance from the stem, reflecting the input of ^{137}Cs to the soil nearest the stem by stemflow. Accumulation of ^{137}Cs was most evident in the soil near the stem of species, such as beech, which yield large quantities of stemflow and was less evident with species, such as white oak, which yield little stemflow.

Sulfate Retention in Soils

The study of sulfate-ion (to be subsequently abbreviated as SO_4) retention by soils has been given much attention, primarily because of concerns over S deficiencies in soils and the role of acid precipitation in acidification and leaching of soils in agricultural and forest systems. Soil SO_4 retention is generally considered to depend on the presence of Fe and Al hydrous oxides as well as by soil pH, clay mineralogy, organic matter content and competing anions (mainly phosphate). This review considers how these factors may interact to control SO_4 retention in natural soil systems.

Role of Iron and Aluminum Oxides

Subsoils generally retain more SO_4 than do surface soils. Subsoils tend to accumulate Fe and Al oxides which are primarily responsible for SO_4 retention (Brady, 1974). The importance of Fe and Al oxides to SO_4 retention by soils has been reported by many workers (Barrow, 1967; Bornemisza, 1963; Couto, 1979; Ensminger, 1954; Hague, 1973; Harward, 1966; Rajan, 1979). Chao et al. (1962) found that the removal of Fe and Al oxides from SO_4-retentive soils significantly decreased the ability of some Oregon soils to retain SO_4. Work by Johnson (1983) concerning the relationship between SO_4 retention of some forest soils and soil Al and Fe demonstrated that citrate-dithionate extractable Fe was significantly correlated with absorbed water-insoluble SO_4. The relative importance of Fe and Al oxides to the SO_4 retention of a given soil can vary. For example, Ensminger (1954) noted that dehydrated Al_2O_3 retained more SO_4 from a SO_4 solution than did Fe oxides such as hematite, geothite, or limonite. Similarly, Hague (1973) reported a significant correlation between free Al_2O_3 and adsorbed SO_4 in some West Indies soils. Chao et al. (1962), however, considered Fe oxides to be more important than Al oxides in effecting SO_4 retention by a soil.

Harward (1966) noted that SO_4 adsorption can occur on the surface of Fe and Al oxides or by penetraton of SO_4 into the oxide surface with replacement of aquo(-M-OH_2), or hydroxo(-M-OH) groups. A simplified mechanism for SO_4 adsorption by hydrous metal oxides as proposed by Rajan (1978) involves the exchange of SO_4 for the OH ligand of aquo or hydroxo groups of Fe and Al oxides. Rajan further noted that ligand exchange can occur on sites whose initial charge was either positive or neutral. Bonn et al. (1979) indicated that lignand exchange can also occur on negative sites.

The formation of aluminite [$KAL_3(OH)_6(SO_4)_2$] or basaluminite [$AL_4(OH)_{10}SO_4$] has been suggested as an alternative means by which

SO_4 can be retained in acid soils (Adams and Rawajfih, 1977). Basic Al and Fe hydroxy sulfates are capable of being formed in acid soils and their formation is enhanced by the presence of clay minerals (Singh and Miles, 1978). Wolt (1980) investigated the formation of alumite and basaluminite as a possible mechanism for the retention of SO_4 in acid, sulfate-polluted soils of the Copper Basin area of Tennessee and observed that sulfate retention was not clearly expressed as a pH dependent mechanism because of variation in the amount of composition of soil clay. The stability of alunite was advanced as a alternate mechanism for S retention by these soils as evidenced by the close agreement between the Ksp of alunite and soil solution composition, expressed as the ion activity product $(K)(Al)^3(OH)^6(SO_4)^2$.

<u>Soil pH</u>

The exchange between SO_4 and OH of Al and Fe oxides is a pH-dependent mechanism (Ensminger, 1954; Harward, et al., 1966; Kamprath, et al., 1956). In soils with significant amounts of Fe or Al oxides, retention of anions, such as SO_4, can occur due to an increase in positive charge at soil pH below the zero point of charge (Harward et al., 1966). The retention of sulfate by some North Carolina soils was observed by Kamprath (1956) to be greatest at pH 4 and to decrease markedly with increased soil pH. Increased soil pH, as a consequence of liming, will result in the release of "adsorbed" SO_4 (Elkins et al., 1971). Kamprath (1956) noted that the desorption of SO_4 as a result of increasing soil pH may be attributed to the hydroxyl ion being stronger coordinator with aluminum than is sulfate. Decreased SO_4 retention with decreased soil acidity can also be explained as a consequence of increased solubility of Fe and Al hydroxy sulfates as soil pH is decreased (Adams and Rawajih, 1977; Wolt and Adams, 1979).

Clay (Amount and Type)

Increased clay content of soils as well as type of clay mineral can increase the retention of SO_4 by a soil. If SO_4 retention is considered as a surface adsorption mechanism, the exchange of SO_4 for OH occurring on the edges of silicate clay minerals may explain increased SO_4 retention with increased soil clay content (Harward, 1966). The 1:1 clay minerals are known to retain more sulfate than 2:1 types (Chao et al., 1962; Harward, 1966; Meton, 1979), but SO_4 retention by Al and Fe oxides found in association with clay minerals present (Harward, 1966). The effect of clay minerals on sulfate retention in soils may also be partly due to Al hydroxy-sulfate precipitation. Singh and Brydon (1967; 1969) noted that a basic aluminum sulfate was formed when Al was precipitated by calcium hydroxide ($Ca(OH)_2$) in the presence of clay and SO_4 ions.

Organic Matter

The presence of organic matter in soils can effect sulfate retention. In the Ap horizon of some tropical soils, Couto et al. (1979) observed that organic matter reduced SO_4 retention. These researchers hypothesized blocking of adsorption sites by adsorbed organic anions or coating of oxide surfaces by organic matter to be responsible for decreased SO_4 retention. Removal of organic matter from some Oregon soils was found by Chao et al. (1962) to reduce their abilities to adsorb SO_4 from solution. The treatment to remove organic matter, however, may have altered properties of these soils reducing their ability to adsorb SO_4 or the nature of the organic matter may have been such that it had appreciable SO_4 retention capacity. Hague (1973) found that initially adsorbed SO_4 (i.e., natural soil SO_4) was significantly correlated with organic matter in some West Indies soils.

Effect of Phosphate on Sulfate Retention

Kamprath et al. (1956) observed that increasing phosphate concentration decreased sulfate retention in four North Carolina soils possibly because clay minerals have a greater affinity for phosphate than sulfate and that phosphate is effective in reducing the amount of sulfate retained by soils. The competitive advantage which phosphate has over sulfate has been exploited in using phosphate as an extractant for "adsorbed" sulfate in soils (Metson, 1979).

III. MATERIALS AND METHODS

Sites

This study was conducted at two established experimental watersheds--Cross Creek and Camp Branch--which are located on the Cumberland Plateau in Tennessee. Cross Creek is located in Marion County, Tennessee, 19 km northwest of a 1958-megawatt coal-fired power plant and has been subjected to fairly high inputs of atmospheric S. Camp Branch, located in Bledsoe County, Tennessee, is 80 km northwest of the Cross Creek site and receives lower levels of atmospheric S input (Kelly, 1979; 1984a). Vegetation at both sites is primarily second growth oak forest which comprises approximately 70% of the base area at both locations (Kelly, 1984a).

The climate at both sites is very similar. Average annual precipitation at Camp Branch and Cross Creek is 144 cm and 155 cm, respectively. The majority of precipitation occurs as rain and falls in the winter months. Average monthly temperatures are slightly less at Camp Branch than at Cross Creek (Kelly, 1979).

Study Trees and Soils

Three size classes of red maple (*Acer rubrum*) and scarlet oak (*Quercus coccinea*) were selected as the subject trees at both study sites. These species were selected on the basis of bark texture (smooth vs. rough) for red maple and scarlet oak, respectively, which is the primary factor affecting stemflow yield of these species. Difficulty in locating suitable red maples at Camp Branch necessitated the use of red maples having bark rougher than desired.

Diameter at breast height (DBH) and crown area were determined on all study trees. Diameter at breast height was determined with a DBH measuring tape. Crown area was estimated by measuring the distance from the tree stem to the edge of the canopy along eight transects which were spaced at approximately 45° with respect to each other. These distances were then transferred to a scale grid and the canopy circumference reproduced on the grid. Estimated crown area was determined from the area enclosed by the canopy circumference on the scale grid. (Description of subject trees are given in Tables 1 and 2 and in photographs of trees in Figures 1 and 2.)

All size classes of both species at both study areas were located on similar upland soils. In addition, all size classes of a species were located near each other so that soil variation would be minimal between the classes. This grouping resulted in one study unit each for the two species at both study sites. (Brief descriptions of these study units and the surrounding area are given in Table 3.)

Upland soils at both study areas have formed in residuum weathered mainly from Pennsylvanian-aged sandstone and interbedded sandstone and shale. These soils are well drained, highly weathered and leached. This results in soils which are acid, relatively infertile and low in organic matter (Kelly, 1979). Most upland

Table 1. Tree Descriptions for Camp Branch (CB) Watershed.

Species	Tree number	Size class	DBH (cm)	Crown area (m^2)	Canopy position	Bark characteristics
Acer rubrum Red maple	CB1RM	1	28.1	30.0	Co-dominant	Bark rough, deeply furrowed and ridged. Upper trunk and limbs also rough.
	CB2RM	2	17.2	15.0	Co-dominant	Bark rough and shallowly furrowed on lower 2 m of trunk, upper trunk and limbs smooth.
	CB3RM	3	13.2	15.5	Intermediate	Bark somewhat rough on lower 1 m of trunk, upper trunk, and limbs smooth.
Quercus coccinea Scarlet oak	CB1SO	1	40.8	40.0	Dominant	Bark rough and cracked on lower 2 m of trunk. Upper trunk and branches much smoother.
	CB2SO	2	30.8	30.5	Co-dominant	Same as CB1SO.
	CB3SO	3	17.2	9.0	Intermediate	Lower 1 m of trunk rough and shallowly furrowed. Upper trunk and limbs nearly smooth.

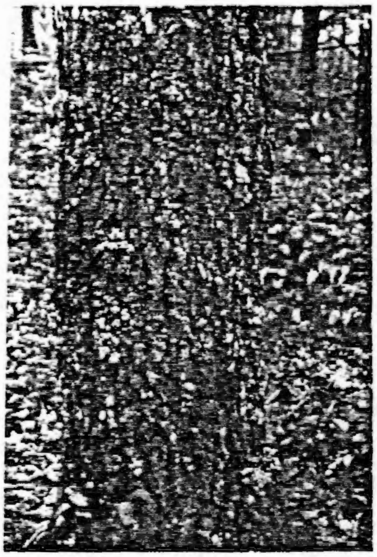
Table 2. Tree Descriptions for Cross Creek (CC) Watershed.

Species	Tree number	Size class	DBH (cm)	Crown area (m^2)	Canopy position	Bark characteristics
Acer rubrum Red maple	CC1RM	1	23.4	31.5	Co-dominant	Bark very smooth over entire tree.
	CC2RM	2	16.4	13.5	Intermediate	Bark very smooth over entire tree.
	CC3RM	3	12.5	11.5	Intermediate	Bark very smooth over entire tree.
Quercus coccinea Scarlet oak	CC1SO	1	41.7	48.5	Dominant	Bark rough and furrowed on lower 2 m of trunk. Upper trunk and branches much smoother.
	CC2SO	2	22.6	21.5	Co-dominant	Bark rough on lower 1.5 m of trunk. Upper trunk and limbs almost smooth.
	CC3SO	3	17.2	19.75	Intermediate	Bark rough ontlower 1 m of trunk. Upper trunk and limbs almost smooth.

CB1RM

CB2RM

CB3RM



CB1SO

CB2SO

CB3SO

Figure 1. Photographs of Red Maple (CB1RM, CB2RM and CB3RM) and Scarlet Oak (CB1SO, CB2SO and CB3SO) Study Trees at Camp Branch.

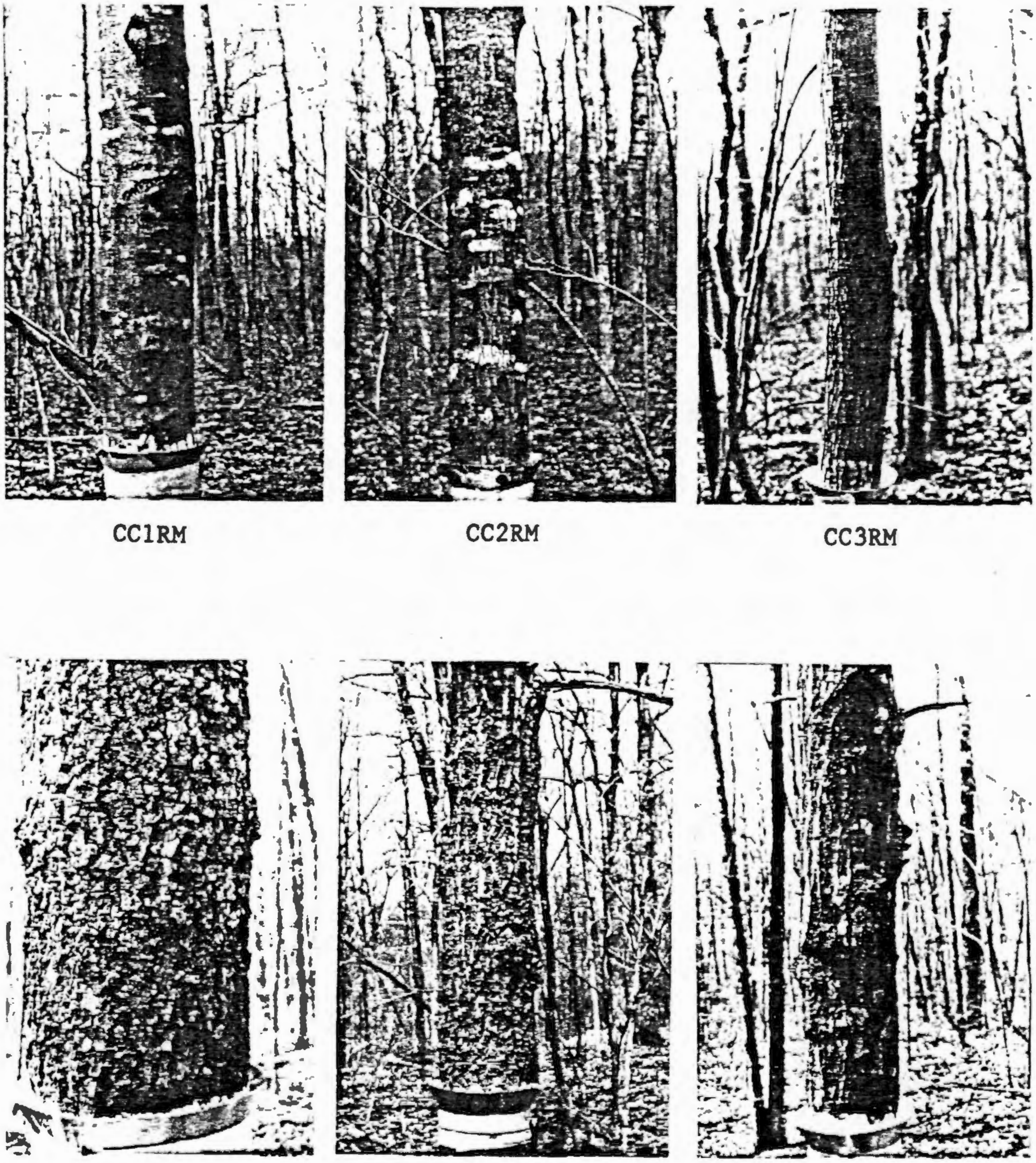


Figure 2. Photographs of Red Maple (CC1RM, CC2RM and CC3RM) and Scarlet Oak (CC1SO, CC2SO and CC3SO) Study Trees at Cross Creek.

Table 3. Study Unit Descriptions for Cross Creek and Camp Branch.

Study unit	Camp Branch	Study unit	Cross Creek
Red maple	Possibly old field at one time. Unit mostly red maple with some dogwood (Cornus florida) and sourwood (Oxydendrum arboreum) (Pinus virginiana) and scarlet oak (Quercus coccinea) also present. Slope 0-3% south aspect.	Red maple	Upland oak mixed hardwood forest dominated by scarlet oak, white oak oak and red oak, with some red oak, with some red maples present. maples present. Slope 0-3% west aspect.
Scarlet oak	Upland oak mixed hardwood forests. Oaks present in plot area includes white oak (Quercus alba), scarlet oak, post oak (Quercus stellata) and red oak (Quercus rubra). Slope 2-5% east aspect.	Scarlet oak	Upland oak mixed hardwood forest. Unit dominated by scarlet oak. Slope 3-5% west aspect.

soils of both study areas are classified as Typic Hapludults although some minor areas of Fragiudults are present.

In order to assess variation in soil types within the study units, an auger description was made of the soil profile at approximately 2 m from the stem of each study tree in each study area. A composite soil profile description was then developed from the individual soil profile descriptions of all size classes of a species. These descriptions are given in Appendix A. All soil profile descriptions in Appendix A have new profile designations (far right hand column) as revised by the Soil Survey Staff (Guthrie and Witty, 1982), along with old profile designations. All references to soil horizonation in this study will refer to old designations. All study trees with exception of CC3RM were found on Typic Hapludults of the fine-loamy, thermic family. A series name for these soils is not currently recognized. CC3RM was located on a Clarkrange silt loam (fine-silty, thermic, family of Typic Fragiudults).

Soil and Stemflow Sampling

Soils were sampled for chemical analysis using 7.5 cm bucket auger and a 2 cm back saver probe. Soils were sampled at 25, 50, 100, and 200 cm from the stem of study trees along with transects which originated at the stem base and were spaced 90° apart. Two transects were oriented in a upslope and downslope direction with the two remaining transects being perpendicular to the upslope downslope transects (Figure 3). Soils were sampled by horizon at all sampling points. At the 25 cm sampling point, roots often

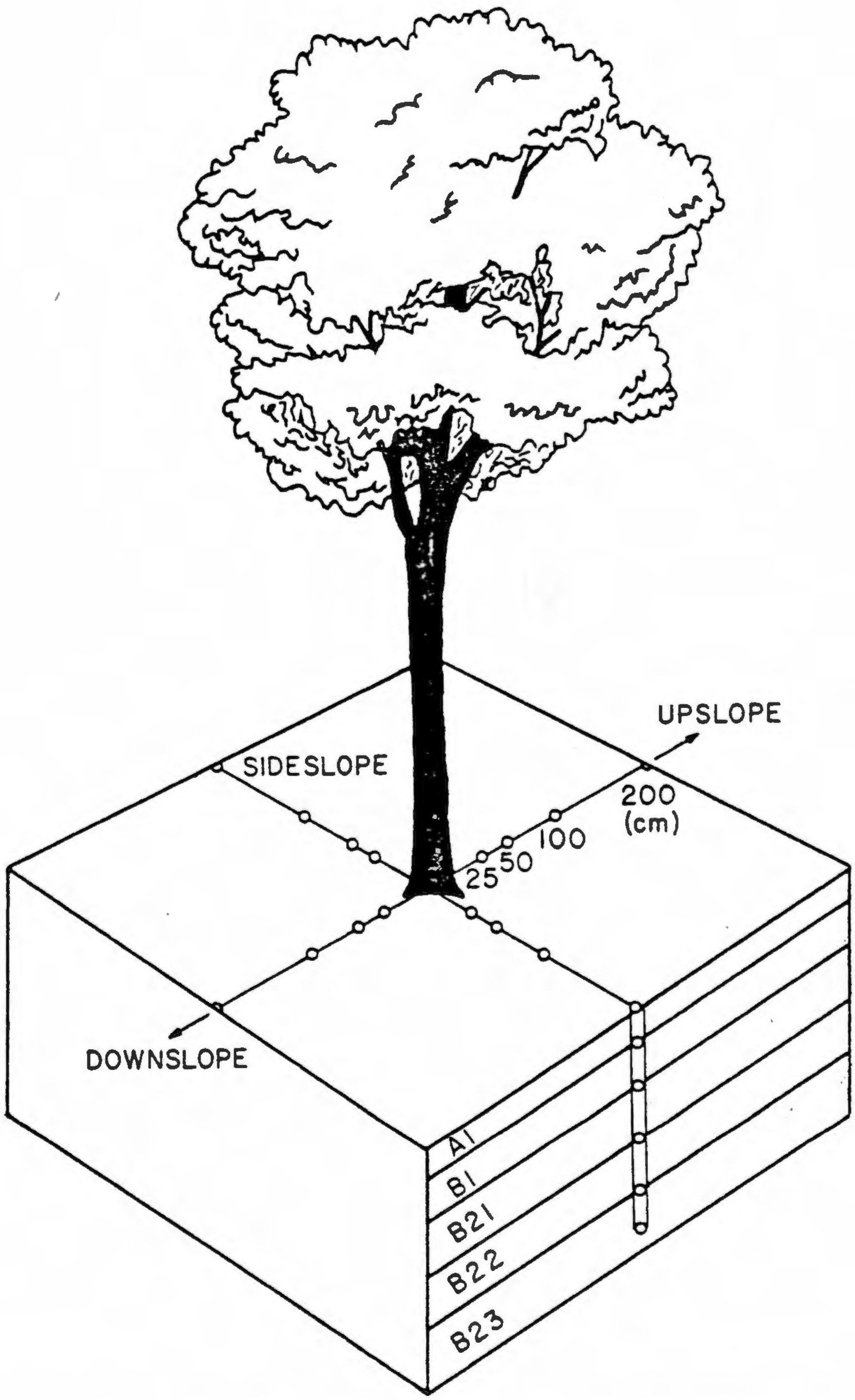


Figure 3. Soil Sampling Scheme for all Study Trees.

prohibited sampling below the B1 horizon in some transects. No 25 cm samples were obtained below the B22 horizon. Soil samples were oven-dried at 80°C for 24 hours and ground to pass a 2 mm sieve and stored in plastic containers until analyzed.

Stemflow was collected for 23 weeks from all study trees with the exception of CB2SO which died soon after soil sampling. Stemflow was sampled using a circular aluminum collar (Voight, 1960) which was sealed to the stem using a silicone sealant to provide a watertight seal. Stemflow water was delivered to 24 L carboys or 100 L plastic trash containers by a length of tygon tubing. Volume of stemflow was measured using a gauged staff for 24 L containers and by direct reading of a gauge marked on the interior of the trash containers. Stemflow was sampled weekly when measurable quantities of stemflow were present. Stemflow samples were stored at 4.5°C until analyzed. Four wedge-type raingauges located in open areas in each watershed were read weekly and weekly rainfall was reported as the mean of these raingauges.

Soil and Stemflow Chemical Analysis

Soil S was extracted by shaking 10 g of dry soil for 30 minutes with 50 ml of NaH_2PO_4 (16.14 mmol $P \cdot L^{-1}$) (Johnson, 1979). The extracts from A1 horizons were filtered through Whatman No. 42 filter paper, while B horizon soils were centrifuged at a relative centrifical force of 4630 g's for 10 minutes then filtered through Whatman No. 1 filter paper to remove organic debris. Sulfate in the filtered extracts was determined colorimetrically by the barium chloranilate procedure (Bertolancini and Barney, 1957). Organic color in A1 and B1 horizon extracts was measured at the analytical wavelength (530 nm) after the addition of all reagents except barium chloranilate. These values were then subtracted from the barium chloranilate developed color of corresponding samples. Sodium phosphate blanks treated the same as samples were used for zeroing the spectrophotometer. All measurements were made in 530 nm using a Bausch and Lomb Spectronic 70 spectrophotometer.

Soil and Stemflow pH

Soil pH was determined on a 1:1 soil-water slurry using a glass electrode. Stemflow pH was also determined by glass electrode.

Statistical Analysis

Data was subjected to analysis of variance as a nested design with six classification levels: site, species within site, size class within species, transect within size class, sampling distance within transect and soil horizon within sampling distance. In addition the site species interaction was also considered. Sulfate and pH data as a function of site, species and size class were evaluated through an analysis of 12 means which represent the means (either SO_4 or pH) of all study trees at both sites for a given horizon. Evaluation of transect within size class and distance within transect was accomplished by pooling the analysis of all 16 observations for A1 horizon soil (12 observations only on B1, B21, B22, and B23 horizons) for each individual tree. In order to have sufficient degrees of freedom left over for testing the effects of transect within the class and distance within transect, a simplifying assumption was made. This assumption considered the two transects which were perpendicular to the upslope-downslope transects as replicates and was reasonable since the primary moment of stemflow would be determined by the upslope-downslope gradient rather than the perpendicular slope gradient. This simplication also made it possible to test for significant transect and distance effects. Although the lack of replication makes it difficult to associate site differences with any particular factor such as SO_4-S input which differerd between the two sites, the results of this analysis will be helpful in designing future studies (Wolfe, et al., 1983).

IV. RESULTS

Soil pH

Soil pH and NaH_2PO_4 extractable SO_4-S were anlayzed by horizon to determine the effects of site, tree species, tree size class within species [size (species)], site by species interaction, sampling transects and sampling distance within transects [distance (transect)] (Table 4). (Anova tables for pH and SO_4-S data are in Appendix B along with summaries of effects by individual trees in Appendix C.)

Although the effect of site on soil pH was significantly different only in the B1 horizon, soil pH in B2 horizons appeared consistently lower at Cross Creek. Soil pH tended to increase with sampling depth at both sites with the most pronounced increases occurring from the A1 to B1 horizons (Figure 4).

The distribution of soil pH as a function of distance from the stem by site and soil horizon which represents the combined mean of all study trees and both species (Figure 5). Soil pH at 25 cm from the stem of red maple and scarlet oak at Camp Branch tended to be higher in the A1, B1 and B21 horizons relative to soil pH at 50, 100, and 200 cm from the stem. The average soil pH beneath both species was pH 4.1, 4.5, and 4.8 in the A1, B1 and B21 horizons, respectively, at 25 cm from the stem. Values of soil pH at 50, 100 and 200 cm from the stem beneath trees at Camp Branch were nearly constant in all horizons. In contrast to the observed trend at Camp Branch, soil at 25 cm from the stem of Cross Creek trees tended to

Table 4. Soil pH and Extractable SO_4-S as Influenced by Various Effects in the Experimental Model.

		Experimental Effects					
	Horizon	Site	Species	Size (Species)	Site * Species	Transect	Distance (Transect)
pH	A1	NS[1]	NS	NS	NS	NS	*
	B1	+	NS	NS	NS	NS	NS
	B21	NS	NS	NS	NS	NS	NS
	B22	NS	NS	NS	NS	NS	NS
	B23	NS	NS	NS	NS	**	NS
SO_4-S	A1	NS	NS	NS	NS	NS	NS
	B1	*	NS	NS	NS	NS	NS
	B21	NS	NS	NS	NS	NS	NS
	B22	NS	NS	NS	NS	NS	NS
	B23	**	NS	NS	NS	NS	NS

[1]Experimental effects are not significant (NS) or are significant at the .01 (**), .05 (*) or .10 (+) % levels.

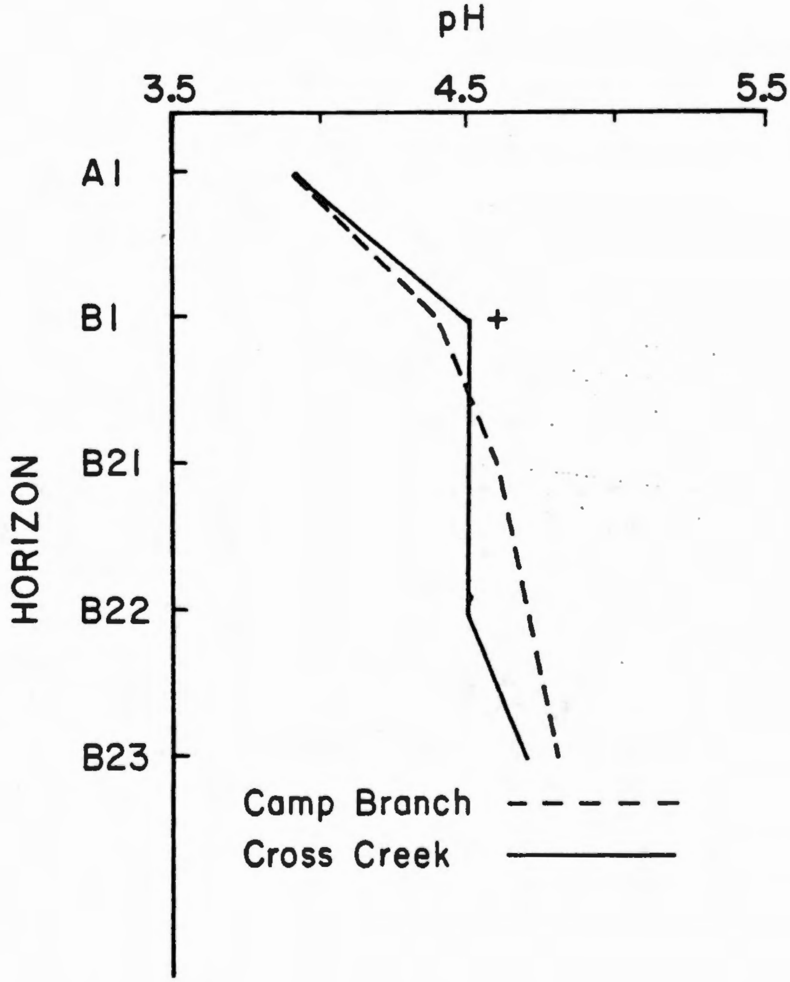


Figure 4. Distribution in Soil pH for Camp Branch and Cross Creek Soil Profiles (+, Significant pH Effect by Horizon at the α = .10 Level).

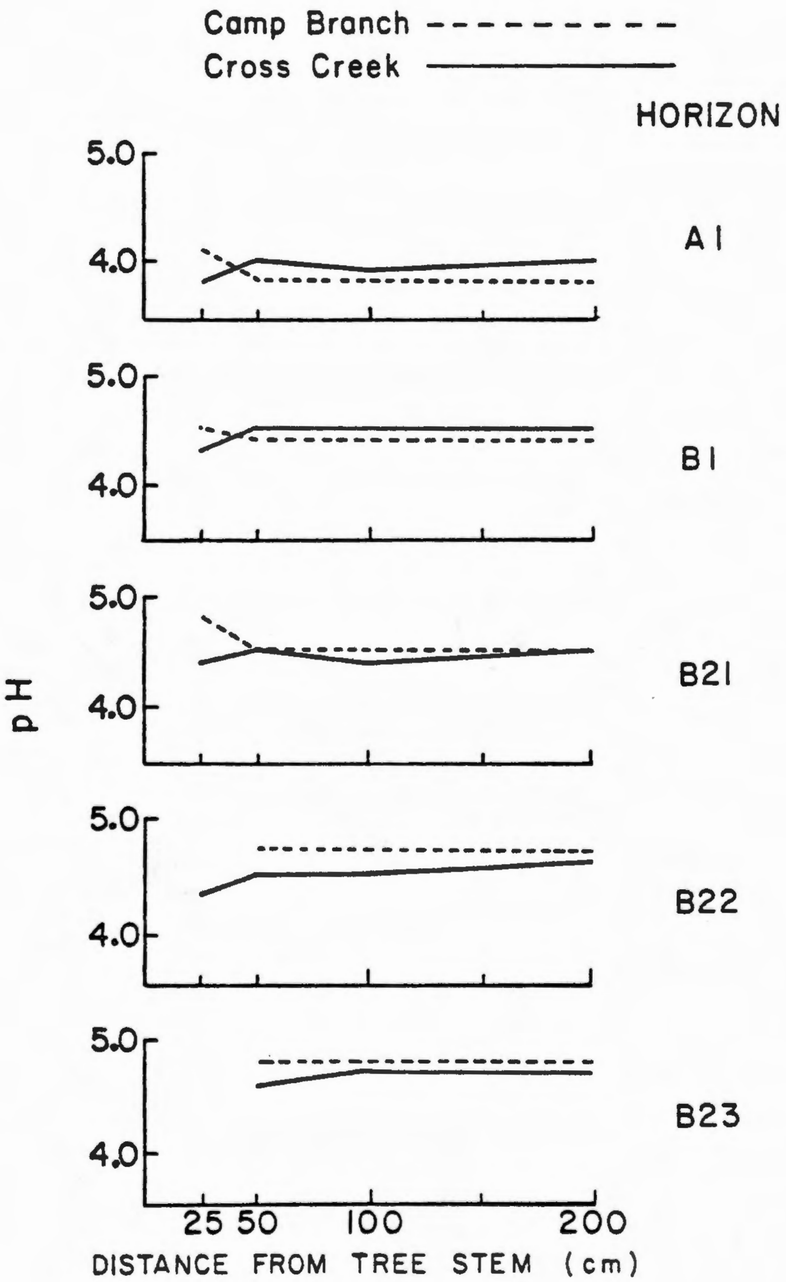


Figure 5. The Effect of Sampling Distance from the Stem of Scarlet Oak and Red Maple on Soil pH by Horizon at Camp Branch and Cross Creek.

be more acidic than soil at 50, 100 and 200 cm from the stem. At Cross Creek, soils at 25 cm from the stem beneath red maples and scarlet oaks had a combined average soil pH of pH 3.8, 4.3, 4.4 and 4.3 in the A1, B1, B21 and B22 horizons, respectively. Values of soil pH at 50, 100 and 200 cm from the stems of trees at Cross Creek varied not more than 0.1 pH unit in any horizon.

The effect of distance from the stem on soil pH in the A1 horizon was significant at the $\alpha = 0.5$ level at both study sites. The trend in soil pH in subsurface horizons was consistent with that observed in the A1 horizon at both Camp Branch and Cross Creek. These trends, however, was not analyzed statistically because roots interfered with the sampling of some horizon-transect combinations which resulted in unequal sample sizes.

Soil Sulfate

Size within species, site*species interaction, distance (transect) and transect did not affect extractable soil SO_4-S in any horizon; site and species, however, were found to significantly affect soil SO_4-S concentrations (Table 4). The extractable SO_4-S distribution for study sites (Figure 6) indicated Camp Branch B1 horizons to have a higher SO_4-S concentration than did Cross Creek B1 horizons (35.5 $\mu g \cdot g^{-1}$ vs 23.2 $\mu g \cdot g^{-1}$, respectively); while B23 horizons at Camp Branch averaged 77.5 $\mu g \cdot g^{-1}$ SO_4-S as compared to 97.0 $\mu g \cdot g^{-1}$ SO_4-S in Cross Creek B23 horizons.

The extractable SO_4-S concentration in soils beneath red maple and scarlet oak were found to be different in the A1 horizon

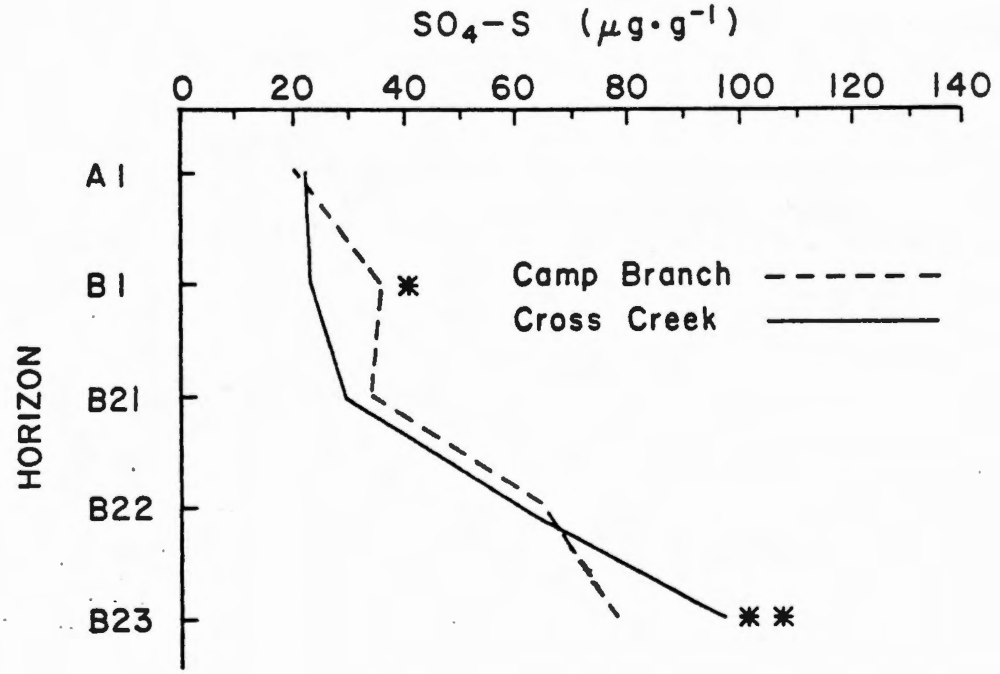


Figure 6. Average Extractable SO_4-S Distribution in Camp Branch and Cross Creek Soil Profiles. Values of SO_4-S by Horizon are either Not Significant or are Significant at the .01 (**) or .05 (*) Levels.

(α = .10) and in the B22 and B23 horizons (α = .01) at both Camp Branch and Cross Creek (Figure 7). The average SO_4-S concentration in the A1 horizon beneath the canopies of red maples from both sites was 24 $\mu g \cdot g^{-1}$ SO_4-S. Scarlet oaks from both study sites, however, averaged 19.5 $\mu g \cdot g^{-1}$ SO_4-S in the A1 horizons beneath their canopies. B22 and B23 horizons beneath red maples averaged 46.0 $\mu g \cdot g^{-1}$ SO_4-S and 68.0 $\mu g \cdot g^{-1}$ SO_4-S, respectively. B22 and B23 horizons, however, averaged 79.0 $\mu g \cdot g^{-1}$ SO_4-S and 107.0 $\mu g \cdot g^{-1}$ SO_4-S, respectively, under scarlet oak canopies.

Stemflow

Stemflow results indicate that the very smooth-barked red maples of Cross Creek collected a much greater quantity of stemflow (2597.3 L) than did the rough-barked red maples at Camp Branch (641.8 L) (Tables 5 and 6, respectively). Individually, Cross Creek red maples ranked in the order of CC1RM > CC2RM CC3RM in terms of stemflow yield while Camp Branch red maples ranked CB2RM > CB3RM > CB1RM in stemflow yield. Cross Creek scarlet oaks CC1SO and CC3SO had a stemflow yield of 960.7 L, while at Camp Branch, scarlet oaks of similar size yielded 1204.6 L of stemflow during the sampling period. (Stemflow collections are not reported for CB2SO which died during the course of this study.)

Stemflow pH tended to be more acidic from Cross Creek red maples (Table 6). The average stemflow pH from Cross Creek red maples was pH 4.0 for CC1RM and pH 3.9 for CC2RM and CC3RM. Stemflow from Camp Branch red maples was much less acidic over the

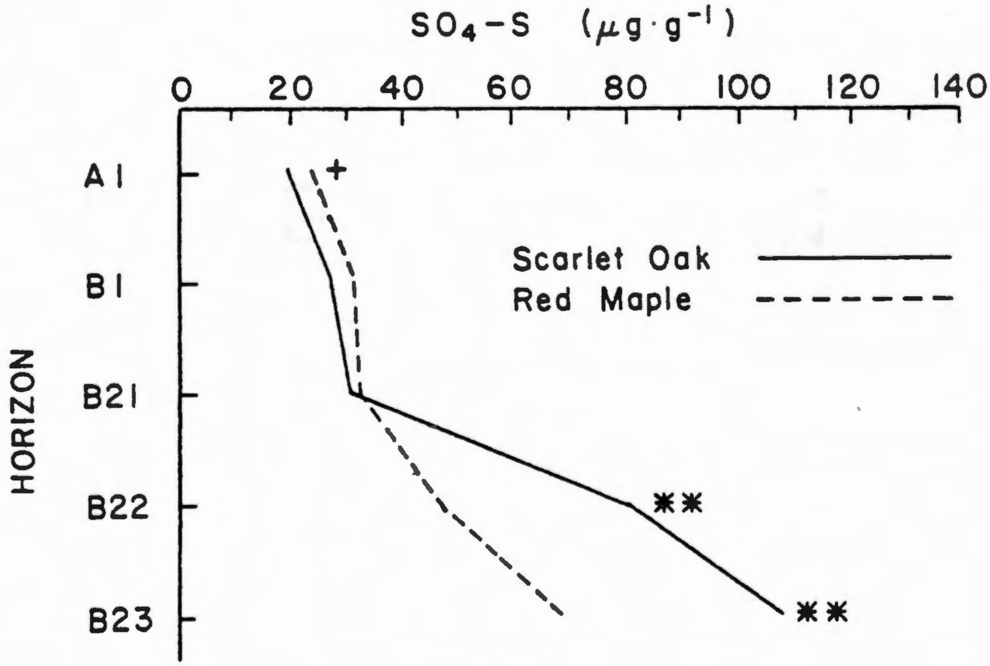


Figure 7. Average Extractable SO_4-S Distribution Beneath the Canopies of Red Maple and Scarlet Oak for both Camp Branch and Cross Creek. Values of SO_4-S by Horizon are either Not Significant or are Significant at the .01 (**) or the .10 (+) Levels.

Table 5. Rainfall, Stemflow Volume, Stemflow (Liters per cm of Rainfall) and pH for Red Maple (RM) and Scarlet Oak (SO) at Camp Branch.

			Species					
			Stemflow Volume (L)		Stemflow ($L \cdot cm^{-1}$ Rainfall)		Stemflow pH	
Date	Total Rainfall (cm)	Size Class	RM	SO	RM	SO	RM	SO
1/83	3.3	1	12.7	49.0	3.74	14.40	6.0	4.2
		2	10.5	-	3.10	-	4.7	-
		3	22.0	31.0	6.50	9.11	4.4	3.9
2/83	14.8	1	52.4	273.0	3.54	18.44	5.8	4.1
		2	58.1	-	3.93	-	4.5	-
		3	70.0	53.0	4.73	3.60	4.3	3.9
3/83	2.4	1	18.9	39.0	7.87	16.25	5.9	4.2
		2	20.9	-	8.70	-	4.4	-
		3	24.6	25.0	10.25	10.41	4.4	3.7
4/83	1.8	1	10.4	100.0	5.77	55.55	5.7	4.4
		2	20.8	-	11.55	-	4.8	-
		3	22.6	24.5	12.55	13.61	4.3	4.1
5/83	13.0	1	50.1	304.0	3.85	23.38	5.5	4.4
		2	85.0	-	6.53	-	4.7	-
		3	82.4	140.0	6.34	10.77	4.3	4.1
6/83	1.7	1	12.3	72.0	7.24	42.40	5.4	4.6
		2	25.8	-	15.18	-	4.7	-
		3	82.4	42.0	22.52	24.70	4.5	4.2
7/1/83-7/6/83	0.8	1	.15	X	.189	X	5.4	X
		2	.30	-	.375	-	4.4	-
		3	3.4	2.8	4.25	3.50	4.3	4.1
			TOTAL		$\bar{X}$		$\bar{X}$	
1/83-7/6/83	37.9	1	157.0	886.0	4.14	23.37	5.7	4.3
		2	221.4	-	5.84	-	4.6	-
		3	263.4	315.8	6.94	8.33	4.4	4.0
	OVERALL		641.8	1204.8	16.93	31.78	4.9	4.2

— Dead stem

X Lost sample

Table 6. Rainfall, Stemflow Volume, Stemflow (Liters per cm of Rainfall) and pH for Red Maple (RM) and Scarlet Oak (SO) at Cross Creek.

			Species					
			Stemflow Volume (L)		Stemflow ($L \cdot cm^{-1}$ Rainfall)		Stemflow pH	
Date	Total Rainfall (cm)	Size Class	RM	SO	RM	SO	RM	SO
1/83	4.6	1	135.0	43.7	29.34	9.50	3.6	4.0
		2	32.0	35.8	6.95	7.78	3.6	3.9
		3	33.0	32.0	7.17	6.95	3.5	3.8
2/83	13.4	1	359.0	120.0	26.79	8.95	3.7	4.0
		2	91.0	90.9	6.79	6.78	3.7	4.0
		3	89.1	95.0	6.64	7.10	3.7	3.8
3/83	4.4	1	169.0	124.0	38.40	28.18	3.7	4.2
		2	47.4	48.0	10.77	10.90	3.7	4.1
		3	40.4	46.0	9.18	10.45	3.8	4.0
4/83	2.7	1	133.0	3.0	49.25	1.11	3.8	4.3
		2	42.0	75.0	15.55	27.77	3.8	4.2
		3	37.0	50.0	13.70	18.51	3.7	4.2
5/83	20.1	1	380.0	142.0	18.90	7.06	4.0	4.5
		2	180.0	181.0	8.95	9.00	4.0	4.1
		3	160.0	144.0	7.96	7167	4.0	4.0
6/83	3.2	1	207.0	30.0	64.68	9.37	4.7	4.5
		2	66.0	69.0	20.62	21.56	4.5	4.5
		3	63.0	51.0	19.68	15.93	4.1	4.4
7/1/83-7/6/83	3.3	1	200.0	9.0	60.60	2.72	4.7	4.5
		2	83.0	58.0	25.15	17.57	4.4	4.4
		3	50.0	71.0	15.15	21.51	4.3	4.3
			TOTAL		$\bar{X}$		$\bar{X}$	
1/83-7/6/83	51.7	1	1583.0	471.7	30.61	9.12	4.0	4.3
		2	541.8	557.7	10.47	10.78	4.0	4.2
		3	472.8	489.0	9.14	9.45	3.9	4.1
	OVERALL		2597.3	960.7	50.23	18.58	4.0	4.2

same sampling period (Table 5). The average stemflow pH from Camp Branch red maples was pH 5.7 for CB1RM and pH 4.6 for both CB2RM and CB3RM. Values of stemflow pH from scarlet oak from both study sites were similar. Both CC1SO and CB1SO averaged pH 4.3 during the sampling period while CC3SO and CB3SO stemflow averaged 4.1 and 4.0, respectively. The stemflow of CC2SO averaged pH 4.2 during the sampling period.

The pH of stemflow of all size classes of both Camp Branch and Cross Creek scarlet oak and Cross Creek red maple tended to become progressively less acidic towards the summer months of the sampling period. CB1RM stemflow became slightly more acidic with CB2RM and CB1RM remaining relatively constant in pH towards the summer months of stemflow sampling.

V. DISCUSSION

Stemflow and Its Influence on Soil pH

Total rainfall during the stemflow collection period (January 1983-July 6, 1983) was 51.7 cm and 37.9 cm at Cross Creek and Camp Branch, respectively. Differences in total rainfall and bark texture were the primary factors influencing stemflow yield of both species at both sites during the study period. Relative stemflow yield (liters of stemflow per centimeter of total rainfall) indicated decreasing relative stemflow yield in the order Cross Creek red maples (50.23 $l \cdot cm^{-1}$) > Camp Branch scarlet oaks (31.78 $l \cdot cm^{-1}$) > Cross Creek scarlet oaks (18.58 $l \cdot cm^{-1}$) > Camp Branch red maples (16.93 $l \cdot cm^{-1}$) (Tables 5 and 6, pages 40 and 41). Reasons for the differences in stemflow pH are not clear but may be related to the greater inputs of atmospheric SO_4 (from precipitation and dry deposition) at Cross Creek than at Camp Branch, causing lower stemflow pH at Cross Creek as a result of strong acids (eg. H_2SO_4).

The pH of soils at 25 cm from the stem of red maple and scarlet oak at both study sites appears to reflect the influence of acid stemflow entering the soil at their bases. The average pH of the profile at 25 cm from the stem of Cross Creek red maples and scarlet oaks (where stemflow averaged pH 4.1) ranged from pH 3.8 in A horizons to pH 4.4 in the lower B horizons; at Camp Branch (where stemflow averaged 4.6), the average pH of the profile at 25 cm from the stem ranged from pH 4.1 to pH 4.8 (Figure 5, page 35). The influence of stemflow pH on soil pH near a tree stem has also been observed by Patterson (1975) and Nicholson (1980).

Effect of Site and Stemflow on Soil Sulfate

Although Cross Creek receives greater yearly inputs of SO_4-S than does Camp Branch (19.9 $kg \cdot ha \cdot yr^{-1}$ vs 16.4 $kg \cdot ha \cdot yr^{-1}$; Kelly, 1982) the overall average profile concentration of SO_4-S was very similar for Cross Creek and Camp Branch (46.6 $\mu g \cdot g^{-1}$ and 46.4 $\mu g \cdot g^{-1}$ SO_4-S, respectively). The greater SO_4-S input at Cross Creek is reflected only in the B23 horizon. In the upper B horizons at Camp Branch, particularly in the B1 horizon, the SO_4-S concentration is much greater than at Cross Creek (34.0 $\mu g \cdot g^{-1}$ vs 23.0 $\mu g \cdot g^{-1}$ SO_4-S) (Figure 6, page 37). The higher concentration of SO_4-S in the B23 horizon at Cross Creek may be a result of a higher gibbsite content (P.A. Mays, 1982, personal communication) and lower pH than B23 horizons a Camp Branch. The reasons for greater SO_4-S concentration in the B1 horizon at Camp Branch are not known, although this may be due in part to the slightly lower pH of the B1 horizon at Camp Branch vs Cross Creek.

The values of extractable SO_4-S reported in this study, particularly those of the A1 horizon, may include some mineralized S from organic sources due to oven drying of samples (Peverill et al., 1975). Sulfate-S concentrations, however, are in the range of SO_4-S concentrations reported by Kelly (1984b) for similar soils from

Cross Creek and Camp Branch which were air-dried and in which mineralization was minimal.

The primary objective of this study was to evaluate the extent of stemflow influence on the distribution of SO_4-S around the base of two tree species. Results showed that distance from the stem was not a factor influencing SO_4-S distribution, although pH data did indicate that stemflow appeared to be influencing soil pH at 25 cm from the stem. The lack of stemflow influence on SO_4-S distribution around the base of red maple and scarlet oak may be a consequence of: 1) The inability of sampling and analytical techniques employed to detect subtle differences in soil S distribution or 2) limited capacity for S retention in the upper solum.

The manner in which samples were obtained in this study may have not been sufficiently sensitive to detect SO_4-S differences especially at 25 cm from the stem. Aurbertin (1971) has noted that water entering the forest floor has a tendency to flow along voids between roots and the soil, old root channels, and channels created by faunal activity. Sulfate-bearing stemflow entering the soil at a tree's base could conceivably flow along the numerous root-soil voids and old root channels and not be concentrated near the stem base, but instead may be concentrated around root-soil voids. Sampling in a vertical manner at various distances would probably not indicate SO_4-S which may have been concentrated in this way.

Sampling interference by roots prevented adequate analysis of samples which were obtained at 25 cm from the stem. This may have masked the trend in SO_4-S distribution in B horizons. Additionally, it is possible that surface soils in this study are saturated with respect to SO_4-S and thus are unable to reflect the influence of stemflow SO_4-S input on surface soil SO_4-S levels. Johnson (1980) notes that SO_4-S in surface horizons of eastern Tennessee forest soils is largely water soluble. Stemflow may leach SO_4-S from the surface horizons near the stem and yet no net difference in soil SO_4-S concentration is observed because SO_4-S in stemflow may be replacing that lost through leaching. Soil SO_4-S concentrations of surface horizons near a tree may periodically reflect higher or lower SO_4-S concentrations of SO_4-S but would not accumulate SO_4-S because of its water soluble nature and frequent flushing of soils near the stem by stemflow.

Effect of Species on Soil Sulfate

Although distance from the stem had no apparent effect on extractable SO_4-S there was, however, a significant species influence on SO_4-S concentrations of the A1, B22 and B23 horizons. The B22 and B23 horizons beneath scarlet oak were found to have higher SO_4-S concentrations than the same horizons beneath red maples. Sulfate-S concentrations of the A1 horizon were slightly lower beneath scarlet oaks (Figure 7, page 39). The greater concentration of SO_4-S in A1 horizons under red maple canopies would suggest that either throughfall and/or litter from red maple have higher SO_4-S concentrations than scarlet oak. No data concerning the SO_4-S content of throughfall or litter beneath red maple or scarlet oak was collected in this study, but there is little difference between the total-S content of red maple and scarlet oak leaf tissue in these watersheds (38.0 $\mu mol \cdot g^{-1}$ and 38.30 $\mu mol \cdot g^{-1}$, respectively, personal communication, J.M. Kelly, 1982). If red maple litter had a more rapid rate of decay than scarlet oak litterfall as indicated by Kelly (1973), then a greater turnover of litterfall-S from red maple might result in slightly higher SO_4-S concentrations under red maple canopies.

The reasons for differences in B22 and B23 soil SO_4-S concentrations beneath red maple an scarlet oak are not clearly understood. It does appear, however, that the same factor or factors are responsible for the differing SO_4-S concentrations beneath these species at both sites. This is based on the observation of lower SO_4-S concentrations in B22 and B23 horizons beneath red maples of all size classes relative to SO_4-S concentrations of the same horizons beneath scarlet oaks of all size classes at both Camp Branch and Cross Creek. A contributing factor could be the influence of crown area on the dry deposition of aerosol SO_4-S. As total crown area increased in the order Cross Creek red maples (56.5 m^2) < Camp Branch red maples (60.5 m^2) < Camp Branch scarlet oak (79.5 m^2) < Cross Creek scarlet oak (89.8 m^2), the concentration of extractable SO_4-S in the B22 and B23 horizons beneath their collective canopies also increased (Figure 8). Nicholson (1980) observed that throughfall SO_4-S increased with increasing canopy cover, presumably because of greater dry deposition washoff. This hypothesis, however, does not fully explain the differences in B22 and B23 horizon SO_4-S concentrations

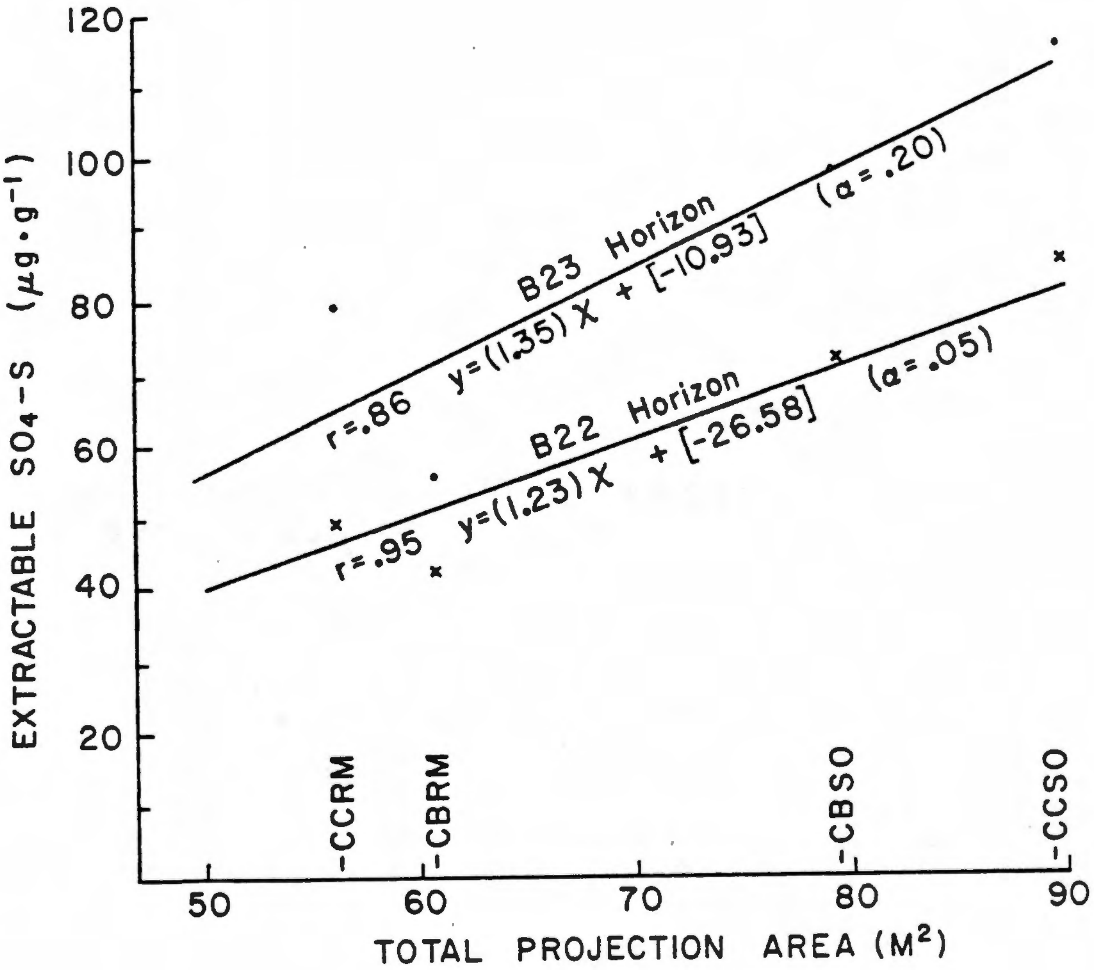


Figure 8. Relationship Between Total Crown Projection Area and Extractable SO_4-S in the B22 and B23 Horizons Beneath Cross Creek Red Maples (CCRM), Camp Branch Red Maples (CBRM), Camp Branch Scarlet Oaks (CBSO) and Cross Creek Scarlet Oaks (CCSO).

beneath scarlet oak and red maple, since individual size classes of a species did not show consistent trends of increasing SO_4-S concentrations in lower B horizons with increasing crown area as did the total crown area of a species.

The difference in the above-ground biomass S content may be an additional factor contributing to greater SO_4-S concentrations in lower B horizons beneath scarlet oaks. Regression of DBH on total-S content of whole tree data of Kelly (1979) indicates that scarlet oak tends to have greater total-S content than does red maple (Figure 9). Scarlet oaks in this study had stem diameters (DBH) of 40.8, 30.8, 17.2, 41.7, 22.6 and 17.2 in. (Tables 1 and 2, pages 22 and 23). Based on data extrapolated from Figure 8, trees with these diameters would have above ground total-S contents of 105.0, 75.0, 33.0, 107.0, 50.0 and 33.0 grams S (combined total-S content of .403 kg). Red maples with DBH's of 28.1, 17.2, 13.2, 23.4, 16.4 and 12.5 cm (Tables 1 and 2, pages 22 and 23) would have an above ground total-S content of 35.0, 19.0, 13.0, 27.0, 17.0 and 12.0 grams S with an overall total-S content of .123 kg. Using, (1) an average soil bulk density (1500 $kg \cdot m^{-3}$) and (2) the combined weighted average of B22 and B23 SO_4-S concentrations and the total area encompassed by sampling transects beneath scarlet oak and red maple 96 m^2), the amount of extractable SO_4-S in the B22 and B23 horizons below scarlet oak and red maple was calculated to be .103 $kg \cdot m^{-3}$ and .045 $kg \cdot m^{-3}$, respectively. In above ground biomass, scarlet oak contained a more than three-fold greater total-S content than red maple. It is not known whether the differences in B22 and B23

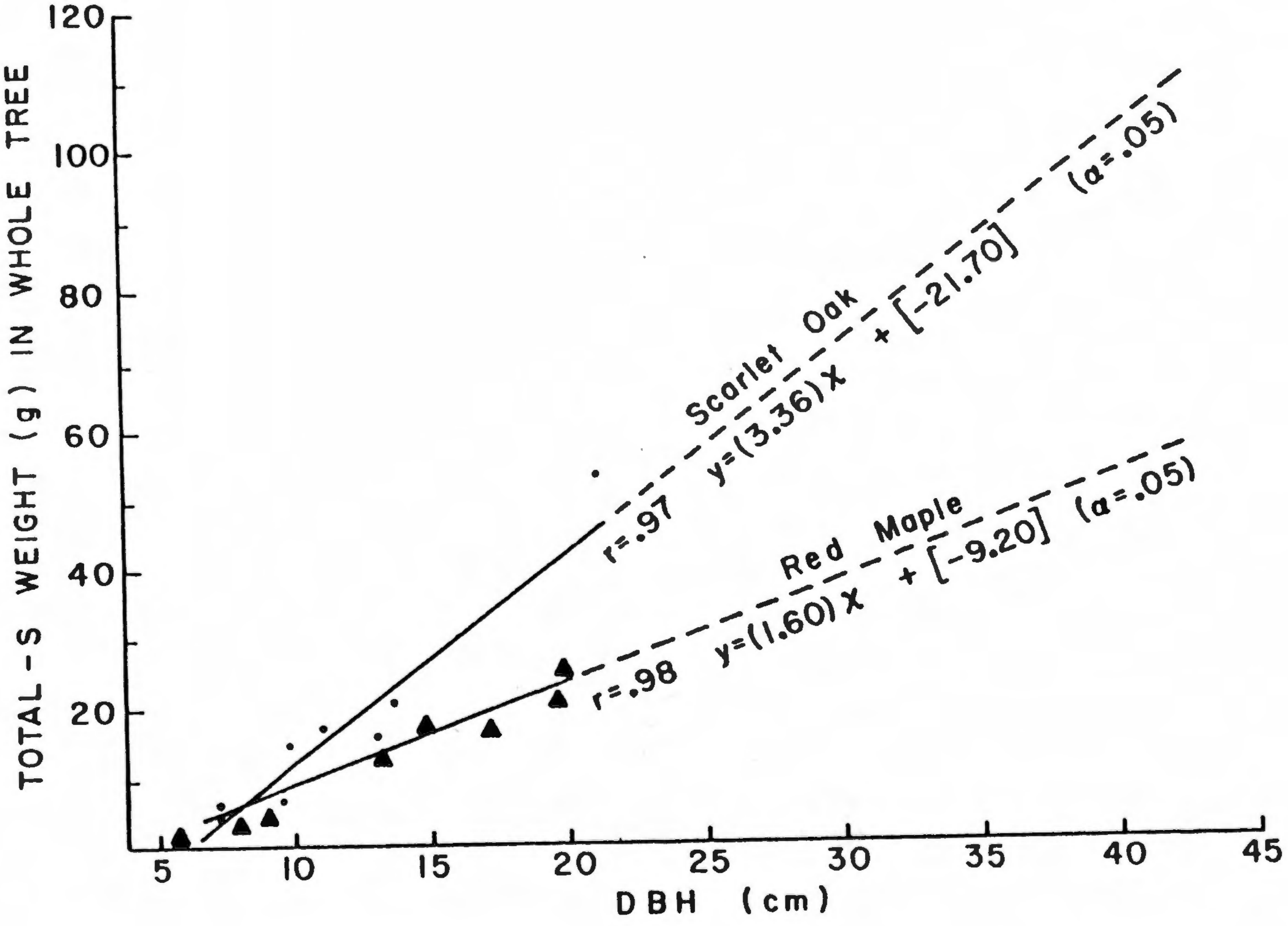


Figure 9. Relationship between Stem Diameter of Scarlet Oak (●) and Red Maple (▲) and the Weight of S Contained in the Whole Tree.

horizon SO_4-S concentrations are a result of the differing total-S contents of these species, although this could be a contributing factor. Turnover of S contained in woody tissue is very slow and could not account for the difference in SO_4-S content in soils beneath these species except over long periods of time. It is interesting, however, that the greater quantity of total-S in scarlet oak biomass is reflected in the greater concentration of SO_4-S in the B22 and B23 horizons beneath the canopy of this species.

Another factor which may have influenced the observed soil SO_4-S distribution is the density and nature of the root network of red maple and scarlet oak, which could be important to the redistribution of stemflow-borne SO_4-S. If scarlet oaks in this study have root systems which extend to a depth greater than that of red maple (i.e., deeper into subsoil) then it is feasible that stemflow water could be channeled into the lower subsoil along root-soil voids. The distribution of SO_4-S carried in this manner will depend on root density (number of roots per unit of area) and extent of the soil-void network in the subsoil so that differences in SO_4-S with distance from the stem may be confounded. Higher SO_4-S concentration in the subsoil beneath scarlet oak, however, might result as a consequence of direct channeling of stemflow-borne SO_4-S into the subsoil along root-soil voids.

The difference exhibited in the SO_4-S concentration of B22 and B23 horizons beneath scarlet oak and red maple may be a result of soil variability (Stone, 1975). Although soils beneath both species at both sites were found to be morphologically similar with the exception of CC3RM, little is known of the physiochemical variability of these soils. There is however, a weak tendency for soil color to have redder hues in the B23 horizons beneath scarlet oak which may indicate a greater Fe and Al oxide content which is important to the SO_4 retention capacity of a soil (Couto, 1979). The pH of the soil profile beneath red maple and scarlet oak are very similar with the soil pH being slightly higher in the B21, B22 and B23 horizons beneath scarlet oak. This would rule out the possibility that more acidic conditions beneath scarlet oak could result in enhanced SO_4-S retention. The clay content of horizons sampled in this study were not analytically determined, but based on field determined textures, there does appear to be a small but inconsistent increase in clay content of B23 horizons beneath scarlet oak. This combined with the redder ues of B23 horizons may partly explain the higher concentrations of SO_4-S in the lower subsoil beneath scarlet oak. It is possible, although unusual, that red maples at both study sites could, by chance, be located on soils with inherently lower SO_4-S retention capacity than scarlet oaks and their associated soils.

VI. SUMMARY

The soil profile around the base of scarlet oak and red maple was sampled at four distances from the stem. Samples were analyzed to determine the influence of site, species, tree size class, transect and distance from the stem on soil pH and SO_4-S distribution. Size class, transect and site did not effect SO_4-S of pH. Distance from the stem and stemflow did appear to influence soil pH at 25 cm from the stem of red maple and scarlet oak.

No positive evidence was found in this study to suggest that stemflow influenced soil SO_4-S distribution despite the observation that stemflow appeared to influence soil pH of A1 horizons near the stem of red mapole and scarlet oak. Because of root interference some horizon-transect combinations were not sampled below the A horizon which prevented adequate assessment of trends of SO_4-S distribution with distance from the stem in the lower soil profile. Sampling along fixed transects does not allow flexibility when roots are encountered. By increasing the number of sampling transects or by sampling in concentric rings of increasing distances from the stem it may be possible to obtain a greater number of samples, offsetting the loss of some samples due to root interference.

The effect of species on SO_4-S concentration in the B22 and B23 horizons is an interesting observation. From data available in this study no conclusions could be made concerning the reasons for the observed differences. Several possible factors have been set forth, which alone or in combination with other factors may be responsible for the higher SO_4-S concentration of B22 and B23 horizons beneath scarlet oak. These factors are 1) the effect of increasing canopy area on throughfall SO_4-S fluxes, 2) differences in above ground biomass S content of red maple and scarlet oak, 3) the nature and extent of stemflow movement along root surfaces and old root channels, and 4) subtle variation in soil properties beneath red maple and scarlet oak.

Although stemflow could not be shown to have an effet on the distribution of SO_4-S in this study there was observed (1) an apparent influence of acid stemflow on soil pH near the tree stem of both red maple and scarlet oak and (2) a higher concentration of SO_4-S in B22 and B23 horizons beneath the canopies of scarlet oaks than beneath the canopies of red maples. Several hypotheses have been set forth, but data supporting these are tenuous at best, and would warrant further study to confirm or refute their significance and to possibly identify other influencing factors.

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APPENDIXES

APPENDIX A

SOIL PROFILE DESCRIPTIONS

COMPOSITE SOIL PROFILE DESCRIPTION

SCARLET OAK PLOT CAMP BRANCH

New Profile Designations	Old Profile Designations	
E	A1	0-6 cm. Pale brown to brown (10 YR 6/3-5/3) loam; file granular structure; friable; many fine roots; abrupt boundary.
BE	B1	6-30 cm. Light yellowish brown to yellowish brown (10 YR 6/4-5/4) silt loam; fine subangular blocky structure; friable; many fine roots; clear boundary.
Bt1	B21t	30-56 cm. Brownish yellow to yellowish brown (10 YR 6/6-5/6) silt loam; medium subangular blocky structure; firm; common medium roots; gradual boundary.
2Bt2	B22t	50-65 cm. Yellowish brown (10 YR 5/6-5/8) sandy clay loam; medium subangular blocky structure; firm; few medium roots; gradual boundary.
2Bt3	B23t	65-100 cm. Strong brown (7.5 YR 5/6) sandy clay loam; medium subangular blocky structure; firm; few roots; gradual boundry.
Cr	Cr	100 cm. Weathered sandstone.

Auger Description

COMPOSITE SOIL PROFILE DESCRIPTION

SCARLET OAK PLOT CROSS CREEK

New Profile Designations	Old Profile Designations	
A	A1	0-3 cm. Dark brown (10 YR 4/3) sandy loam; fine granular structure; friable; many fine roots; abrupt boundary.
BE	B1	3-20 cm. Yellowish brown (10 YR 5/4) sandy loam; fine subangular blocky structure; friable; many fine roots; clear boundary.
Bt1	B21t	20-50 cm. Yellowish brown (10 YR 5/6) loam; medium subangular blocky structure; friable; common medium roots; gradual boundary.
Bt2	B22t	50-90 cm. Yellowish brown (10 YR 5/8) with some (7.5 YR 7/6) mottles; clay loam; medium subangular blocky structure; firm; few medium roots; gradual boundary.
Bt3	B23t	90-135 cm. Strong brown (7.5 YR 5/8) with some red (2.5 YR 5/8) mottles; clay loam; medium subangular blocky structure; firm; few roots; clear boundary.
Cr	Cr	135 cm. Weathered shale.

Auger Description

SOIL PROFILE DESCRIPTION

RED MAPLE PLOT (CC3RM ONLY)

New Profile Designations	Old Profile Designations	
E	A1	0-5 cm. Brown (10 YR 5/3) silt loam; fine granular structure; friable; many fine roots; abrupt boundary.
Bw	B1	5-60 cm. Yellowish brown (10 YR 5/6) silt loam; friable; fine subangular blocky structure; many fine roots; gradual boundary.
2Btx	IIB21x	60-120 cm. Very pale brown (10 YR 8/3) with some strong brown (7.5 YR 5/8) mottles; silt loam; brittle; medium pristmatic structure; few roots; gradual boundary.
2Bt1	IIB22t	120-150 cm. Yellowish red (5 YR 5/8) silt loam; firm; medium subangular blocky structure; few roots; gradual boundary.
2Bt2	IIB23t	150 cm. Yellowish red (5 YR 5/8) loam; firm; medium subangular blocky structure; no roots; gradual boundary.

Auger Description

COMPOSITE SOIL PROFILE DESCRIPTION

RED MAPLE PLOT (CC1RM AND CC2RM)

ONLY

New Profile Designations	Old Profile Designations	
E	A1	0-3 cm. Light brown (10 YR 6/3-5/3) loam; fine granular structure; friable; many fine roots; abrupt boundary.
EB	B1	3-33 cm. Light yellowish brown to brown (10 YR 6/4-5/4) sandy loam; fine granular structure; friable; many fine roots; clear boundary.
Bt1	B21t	33-53 cm. Brownish yellow to yellowish brown (10 YR 6/6-5/6) sandy loam; medium subangular blocky structure; firm; common medium roots; gradual boundary.
Bt2	B22t	53-95 cm. Brownish yellow to yellowish brown (10 YR 6/6-5/8) sandy clay loam; medium subangular blocky structure; firm; common medium roots; gradual boundary.
Bt3	B23t	95-110 cm. Yellowish brown (10 YR 5/8) sandy clay loam; medium subangular blocky structure; firm few roots; gradual boundary.
Cr	Cr	110 cm.

Auger Description

COMPOSITE SOIL PROFILE DESCRIPTION

RED MAPLE PLOT CAMP BRANCH

New Profile Designations	Old Profile Designations	
E1	A1	0-3 cm. Brown (10 YR 5/3) silt loam; fine granular structure; friable; many fine roots; abrupt boundary.
E2	B1	3-28 cm. Pale brown to brown (10 YR 6/3-5/3) silt loam; medium granular structure; friable; many fine roots; clear boundary.
Bt1	B21t	28-68 cm. Light yellow brown to brownish yellow (10 YR 6/4-6/6) silt loam; medium subangular blocky structure; friable; common medium roots; gradual boundary.
2Btx	B22t	68-92 cm. Yellowish brown (10 YR 5/6-5/8) with some pale brown (10 YR 6/3) and strong brown (7.5 YR 5/6) mottles; sandy clay loam; medium subangular blocky structure; firm; few medium roots; gradual boundary.
2Bt3	B23t	92-114 cm. Strong brown (7.5 YR 5/8) with some red (2.5 YR 4/6) and reddish yellow (5 YR 6/6) mottles; sandy clay loam; medium subangular blocky structure; firm; few medium roots; clear boundary.
Cr	Cr	92-125 cm.

Auger Description

APPENDIX B

ANOVA TABLES OF pH AND SULFATE DATA

Table B-1. Anova Table for A1 Horizon pH Data.

Source	DF	SS	MS	F	Significance
Site	1	0.0025	0.0025	0.15	NS
Species	1	0.0300	0.0300	1.81	NS
Size (Species)	4	0.0408	0.0102	0.62	NS
Error	5	0.0830	0.0160		
Transect[1]	24	1.0210	0.0425	1.45	NS
Distance (Transect)[1]	108	4.98	0.0461	1.54	*
Error[1]	48	1.44	0.0300		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant

*Significant at (α = .05)

Table B-2. Anova Table for B1 Horizon pH Data.

Source	DF	SS	MS	F	Significance
Site	1	0.0366	0.0366	4.47	+
Species	1	0.02005	0.02005	2.51	NS
Size (Species)	4	0.0518	0.0129	1.58	NS
Error	5	0.0409	0.0082		
Transect[1]	24	1.5348	0.0222	1.16	NS
Distance (Transect)[1]	72	0.9583	0.0133	0.70	NS
Error[1]	36	0.6900	0.0191		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant

[+]Significant at (α = .10

Table B-3. Anova Table for B21 Horizon pH Data.

Source	DF	SS	MS	F	Significance
Site	1	0.0163	0.0163	0.53	NS
Species	1	0.0215	0.0215	0.70	NS
Size (Species)	4	0.0246	0.0062	0.20	NS
Error	5	0.1530	0.0305		
Transect[1]	24	0.6708	0.0280	1.33	NS
Distance (Transect)[1]	72	1.3733	0.0190	0.90	NS
Error[1]	36	0.7550	0.0210		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant

Table B-4. Anova Table for B22 Horizon pH Data.

Source	DF	SS	MS	F	Significance
Site	1	0.0500	0.500	0.75	NS
Species	1	0.0567	0.0567	0.85	NS
Size (Species)	4	0.0502	0.0126	0.19	NS
Error	5	0.3317	0.0663		
Transect[1]	24	0.5825	0.0243	1.36	NS
Distance (Transect)[1]	72	1.7367	0.0241	1.36	NS
Error[1]	36	0.6450	0.0179		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant

Table B-5. Anova Table for B23 Horizon pH Data.

Source	DF	SS	MS	F	Significance
Site	1	0.0472	0.0472	1.12	NS
Species	1	0.0057	0.0057	0.14	NS
Size (Species)	4	0.0240	0.0060	0.14	NS
Error	5	0.1683	0.0420		
Transect[1]	22	0.8597	0.0390	2.93	**
Distance (Transect)[1]	66	1.0183	0.0154	1.16	NS
Error[1]	33	0.4400	0.0133		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

**Significant at (α = .01).

Table B-6. Anova Table for A1 Horizon SO_4-S Data.

Source	DF	SS	MS	F	Significance
Site	1	2.3796	2.3796	0.20	NS
Species	1	54.3203	54.3203	4.47	+
Size (Species)	4	87.5335	21.8834	1.80	NS
Error	5	60.7165	12.1433		
Transect[1]	24	1063.2025	44.3001	1.15	NS
Distance (Transect)[1]	108	5954.1900	55.1313	1.43	NS
Error[1]	48	1854.7500	38.6406		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

[+]Significant at (α = .10).

Table B-7. Anova Table for B1 Horizon SO_4-S Data.

Source	DF	SS	MS	F	Significance
Site	1	503.4117	503.4117	6.74	*
Species	1	67.1667	67.1667	0.90	NS
Size (Species)	4	176.1734	44.0433	0.59	NS
Error	5	373.6517	74.1433		
Transect[1]	24	1558.4686	64.9361	1.56	NS
Distance (Transect)[1]	108	4647.6663	64.5509	1.55	NS
Error[1]	48	1498.8750	41.6354		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

*Significant at (α = .05).

Table B-8. Anova Table for B21 Horizon SO_4-S Data.

Source	DF	SS	MS	F	Significance
Site	1	47.1703	47.1703	1.12	NS
Species	1	0.3196	0.3196	0.008	NS
Size (Species)	4	239.9594	59.9898	1.43	NS
Error	5	209.8219	41.9644		
Transect[1]	24	2331.5278	97.1470	1.06	NS
Distance (Transect)[1]	72	9802.0815	136.1400	1.50	NS
Error[1]	36	3297.7500	91.6041		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

Table B-9. Anova Table for B22 Horizon SO_4-S Data.

Source	DF	SS	MS	F	Significance
Site	1	86.8960	86.8960	0.83	NS
Species	1	3466.5835	3466.5835	33.22	**
Size (Species)	4	1420.7575	355.1893	3.40	NS
Error	5	521.7403	104.3480		
Transect[1]	24	18139.0200	755.7925	0.55	NS
Distance (Transect)[1]	72	53644.5830	745.0636	0.54	NS
Error[1]	36	49854.5000	1384.8472		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

**Significant at (α = .01).

Table B-10. Anova Table for B23 Horizon SO_4-S Data.

Source	DF	SS	MS	F	Significance
Site	1	1909.0027	1909.0027	14.23	**
Species	1	6632.8301	6632.8301	49.44	**
Size (Species)	3	179.7337	59.9112	0.32	NS
Error	4	759.2891	189.8222		
Transect[1]	24	30670.6750	1277.9448	1.26	NS
Distance (Transect)[1]	72	35163.2080	488.3778	0.48	NS
Error[1]	36	36622.5000	1017.2917		

[1]Values pooled from all species and size classes at both Camp Branch and Cross Creek.

[NS]Not Significant.

**Significant at (α = .01).

APPENDIX C

SUMMARY OF EFFECTS BY INDIVIDUAL TREES

Table C-1. Summary of Effects of Individual Scarlet Oaks and Red Maples on SO_4-S and pH at Cross Creek.

		Experimental Effects[1]			
		Distance (Transect)		Transect	
Tree	Horizon	pH	SO_4-S	pH	SO_4-S
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	NS
CC1SO	B21	*	NS	*	NS
	B22	*	NS	NS	NS
	B23	+	NS	NS	NS
	A1	NS	NS	*	NS
	B1	NS	*	NS	+
CC2SO	B21	*	NS	**	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	+
	A1	NS	NS	+	+
	B1	NS	*	NS	*
CC3SO	B21	NS	NS	NS	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	NS	NS	+	NS
	B1	NS	NS	NS	NS
CC1RM	B21	NS	NS	NS	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	NS
CC2RM	B21	NS	NS	NS	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	+
	A1	NS	NS	NS	*
	B1	NS	NS	NS	NS
CC3RM	B21	NS	NS	+	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	*	NS

[1]Experiment effects either not significant (NS) or are significant at the .01 (**), .05 (*) or .10 (+) % level.

Table C-2. Summary of Effects of Individual Scarlet Oaks and Red Maples on SO_4-S and pH at Camp Branch.

		Experimental Effects[1]			
		Distance (Transect)		Transect	
Tree	Horizon	pH	SO_4-S	pH	SO_4-S
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	NS
CB1SO	B21	NS	*	NS	*
	B22	NS	NS	NS	NS
	B23	-	-	-	-
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	+
CB2SO	B21	NS	NS	+	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	*	NS	NS	NS
	B1	+	+	NS	NS
CB3SO	B21	NS	+	NS	+
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	*	NS	+	NS
	B1	NS	*	NS	**
CB1RM	B21	NS	NS	NS	+
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	NS
CB2RM	B21	NS	+	NS	NS
	B22	+	NS	NS	NS
	B23	NS	NS	NS	NS
	A1	NS	NS	NS	NS
	B1	NS	NS	NS	NS
CB3RM	B21	NS	NS	NS	NS
	B22	NS	NS	NS	NS
	B23	NS	NS	NS	NS

[1]Experiment effects either not significant (NS) or are significant at the .01 (**), .05 (*) or .10 (+) % level.

VITA

Mark Hilton Wolfe was born in Noblesville, Indiana on August 14, 1957, the son of Mr. and Mrs. R.B. Wolfe. He attended elementary schools in Knoxville, Tennessee and was graduated from Bearden High School in June 1975. The following September he entered Hiawassee College in Madisonville, Tennessee, and in June 1977 received a Associate of Arts degree in Agriculture. In the fall of 1977 he entered The University of Tennessee, Knoxville, and received a Bachelor of Science degree in Agriculture in June 1980. He began study towards a Master's degree in Plant and Soil Science at The University of Tennessee in the fall of 1980, while working with the Tennessee Valley Authority. This degree was awarded in March 1984.

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