NUTRIENT DYNAMICS OF THE FOREST FLOOR IN AN APPALACHIAN OAK FOREST STAND FOLLOWING CLEARCUTTING AND WHOLE-TREE REMOVAL

by

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Dissertation submitted to the Graduate Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

in

Forestry

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August, 1981

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ACKNOWLEDGEMENTS

I extend my appreciation to Dr. David Wm. Smith, who served as my major professor and provided encouragement and support throughout the course of the study.

I also thank my committee members, Dr. Harold E. Burkhart, Dr. Terry L. Sharik, Dr. Marcus M. Alley, and Dr. John L. Neal, for their help and advice during my graduate studies.

A special acknowledgement is due for the tremendous help and encouragement provided by Dr. James A. Burger, who continually challenged and inspired me.

Dr. William B. Stuart and the Industrial Forestry Operations Section of the Department of Forestry conducted the whole-tree harvesting operation, without which this study could not have been possible.

Furthermore, the able field and lab assistance provided by and is also appreciated.

Finally, I extend my love and appreciation to my wife and daughter for their countless sacrifices over the course of my graduate program, and to , who arrived in time to give me final inspiration.

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INTRODUCTION

Over the past century the population of the United States has increased three-fold, to over 224 million people in 1981. This population boom has placed a tremendous demand on the nation's natural resources, and the land base upon which to produce essential food, fiber, and energy has become limited in many areas. It is evident that in order to meet this demand, more intensive management of a smaller number of acres is required. The trend of intensive management has been evident in agriculture for a number of years. Increased mechanization, widespread pesticide and fertilizer use, and improved genetic stock have led to substantial increases in crop yields.

The trend of increasing management intensity has also become evident in the forest products industry, particularly within the past ten years. Such practices as forest fertilization, intensive site preparation, and the use of genetically improved planting stock are in common use today. In addition, intensive culture, short rotation, hardwood plantations are being widely established for rapid fiber production (Ribe, 1974). In the Lake States and the southeastern U.S. the trend is toward whole-tree utilization, where all above-ground portions of the tree are harvested and removed from the site (Nelson, 1976).

The use of intensive management in agriculture and forestry is undoubtedly necessary for continued production of food and fiber in sufficient quantities to meet the needs of the nation and the world. Many management practices, however, have received sharp criticism over the years. Pollution caused by excessive use of pesticides and fertilizers on agricultural lands has been well documented, and concern has been expressed over various forestry practices. For example, in 1979 the Environmental Protection Agency banned the commonly used 2,4,5-T herbicide for forestry use on the grounds that it may be a hazard to human health. In addition, intensive silvicultural practices such as some types of site preparation have been questioned as to their possible contribution to non-point source water pollution.

One of the major concerns of intensive forest management relates to whole-tree utilization and nutrient cycling. Foresters have known for a number of years that nutrients are removed from the site through conventional timber harvesting activities (Rennie, 1955; Ovington, 1962). Whole-tree removal results in a much greater nutrient loss from the site through removal of foliage, small branches, and other vegetative parts than in conventional harvesting when only the merchantable bole is removed. This disruption of the nutrient cycle has been addressed by numerous authors (Boyle and Ek, 1972; Weetman and Webber, 1972; Boyle et al., 1973; Malkonen, 1973; White, 1974; Kimmins and Krumlik, 1976; Kimmins, 1977; Wells and Jorgensen, 1979); however, much more specific information needs to be gathered with respect to different forest types, climatic and geographic regions, and soil types.

Whole-tree utilization has been widely advocated by some for a number of years (Young, 1964; Keays, 1971); however, it has only been widely applied in the U.S. since the early 1970's. While high capital investments in equipment, reduced pulp yields, and chip storage problems have been cited as operational disadvantages to whole-tree utilization, a 30 to 50 percent increased fiber yield per acre and substantial reductions in site preparation costs are strong advantages for its continued use (Matics, 1978).

Foresters have long been aware that intensive management practices, no matter how beneficial they may seem in the short run, have long-term utility only if they provide the desired result without causing site degradation. The speculation that whole-tree utilization may result in a depletion of soil nutrients and lead to reduced site quality has been discussed by Boyle (1976), who concluded that it is necessary to develop reliable estimates of nutrient inputs, transformations, and outputs in order to evaluate site impacts of whole-tree harvesting.

The effects of whole-tree removal on the site are many and varied, but the most drastic effects are incurred by the forest floor. Aside from the normal disturbance and mixing of layers caused by logging equipment, the forest floor experiences tremendous changes in terms of reduced nutrient inputs from litterfall, accelerated water movement through the layers, sharply different temperature regimes, and increased microbial decomposition. In addition, the amount of logging slash available for incorporation into the forest floor is only half the quantity that remains after conventional harvesting (Boyle, 1976).

The importance of the presence of a protective organic mat over forest soils has been known since the early 1800's, when the German forester J. C. Hundeshagen pointed out the silvicultural significance of different types of forest humus. Recently, Pierce et al. (1972) summarized the importance of the forest floor of podzol soils in New Hampshire as follows: ". . . the forest (both species diversity and growth) is almost totally dependent for its existence on this thin (2-20 cm), rather fragile, organic layer." The forest floor plays such a critical role in the forest nutrient cycling process that any disturbance could trigger a sequence of events leading to a reduction in site quality.

Clearcutting has its greatest immediate effect in the space closest to the ground surface, i.e., the slash layer, forest floor, and the A_1 soil horizon. It is critical to the development of the new stand that the forest floor continue to provide protective cover and a source of available nutrients to the underlying mineral soil. The present study was designed to analyze the changes in nutrient content in forest floor layers, upper mineral soil, and litterfall for a period of time following clearcutting and whole-tree removal, and to relate these changes to indices for mineralization and decomposition, soil temperature, soil moisture, and precipitation.

In order to adequately study the dynamics of the forest floor following clearcutting and whole-tree removal, it is necessary to carry out a long-term research effort to monitor forest floor changes until a return to pre-cutting conditions occurs. To accomplish this goal a two-phase research project was established. This dissertation reports on Phase I, which consisted of a study of forest floor changes which occurred in the first 16 months following clearcutting and whole-tree removal. Phase II is a continuation of the study with the intent of obtaining extreme values for certain key forest floor characteristics and monitoring changes that occur as the forest floor approaches pre-cutting conditions. Phase I encompassed the measurement period of June, 1979, through April, 1981, while Phase II began in May, 1981, and will proceed through as many years as necessary for the forest floor to return to pre-cutting levels. The specific objectives for Phase I are as follows:

1. To quantify and compare the following forest floor characteristics existing between a clearcut (whole-tree removal) and an uncut portion of an Appalachian oak forest stand: oven-dry weight, depth, and total nutrient content (N, P, K, Ca, Mg) of the L, F, and H layers.
2. To quantify and compare the following A_1 horizon soil characteristics existing between a clearcut (whole-tree removal) and an uncut portion of an Appalachian oak forest stand: total nutrient content, pH, organic matter content, C:N ratio, soil moisture, and soil temperature.
3. To quantify and compare the following litterfall characteristics existing between a clearcut (whole-tree removal) and an uncut portion of an Appalachian oak forest stand: oven-dry weight and total nutrient content.
4. To quantify and compare the following soil solution characteristics existing between a clearcut (whole-tree removal) and an uncut portion of an Appalachian oak forest stand: NO_3-N, NH_4-N, P, K, Ca, Mg, and pH.

LITERATURE REVIEW

Nomenclature and Classification of Forest Floors

The importance of organic matter to such soil properties as fertility, structure, and tilth has been realized since ancient times, and is even referred to in Greek mythology dating from 900 B.C. (Tisdale and Nelson, 1975). Organic matter in forest soils is equally important in determining soil properties affecting tree growth. The forest floor can be viewed as a storehouse of organic matter containing energy and nutrients, which forms a protective mantle over underlying mineral soil. Through natural decomposition processes the forest floor develops a characteristic series of layers described by Hoover and Lunt (1952) as follows:

L Layer - (Litter) the surface layer of the forest floor consisting of freshly fallen leaves, needles, twigs, bark, and fruits. Where decomposition and incorporation are rapid, this layer may be very thin or absent during the growing season. In standardized horizon nomenclature this is the A_{00} horizon.

F Layer - A layer of partially decomposed litter recognizable as to origin. The A_{01} horizon.

H Layer - A layer consisting of well-decomposed organic matter unrecognizable as to origin. The A_{02} horizon.

Early research involving the forest floor focused on the development of a classification scheme for the numerous types of forest floors encountered. Hundeshagen (1830) was perhaps the first to attempt to classify the forest floor based on morphological characteristics. His ideas, however, were not accepted, and 45 years passed before Emeis (1875) distinguished three different types of forest floors roughly corresponding to the more widely known classification proposed by the Danish forester Muller (1879, 1884). Muller was the first to recognize the forest floor as a natural biologic unit, and as a result of discriminating field and lab work he distinguished two main types of forest floors as follows:

mor - organic material distinctly separate from underlying mineral soil.

mull - organic material incorporated into underlying mineral soil.

Ramann (1893) authored the first standard textbook on forest soils, and diverged from Müller's nomenclature when he recognized three forest floor types which he called mull, dry peat or trockentorf, and coarse humus or rohhumus. Ramann's mull and rohhumus corresponded to Muller's mull and mor, respectively; however, Ramann's trockentorf class described a heavier, tougher, more extreme organic mat than Muller's mor. In subsequent editions of his text, Ramann (1905, 1911) only referred to two forest floor types, mull and raw humus (rohhumus).

The confusing array of forest floor terminology continued to plague European foresters during the early 1900's. The term "alpenhumus" was introduced by Ramann (1905) in reference to organic soils, and was later changed to "moder" in the third edition of his text (1911). The use of the term moder has fluctuated throughout the years and has been applied to describe such widely varying conditions as organic soils and unincorporated humus occurring directly beneath the forest litter (Vater, 1928).

The development of European thoughts on forest floor nomenclature was clarified by Romell and Heiberg (1931). In addition, they proposed a classification system for forest floors in the northeastern U.S. After analysis of the physical and chemical properties of a large number of forest floor samples, a classification scheme was developed that employed mull and duff as the basic units, with numerous subdivisions under each, i.e., crumb mull, grain mull, twin mull, detritus mull, root duff, leaf duff, greasy duff, and fibrous duff. Revisions of this system were published by Heiberg (1937) and Heiberg and Chandler (1941), which eventually led to a key for identification and classification of forest floors (Hoover and Lunt, 1952).

Forest floor classification in the U.S. continued at the University of Wisconsin under the influence of Dr. S. A. Wilde. A summary paper was published by Mader (1953) describing morphological features of 35 forest floor types found throughout the U.S. and Canada. Wilde (1971) proposed an all-inclusive classification scheme unlike older attempts which stemmed from the earlier work of Romell and Heiberg. In Wilde's system the organic material comprising the forest floor is characterized by its position relative to the underlying mineral soil. Three broad groups were distinguished as follows:

1. ectorganic layers - consist of organic material which rests on the surface of the mineral soil.
2. endorganic layers - consist of organic material which forms an intimate mixture with the mineral soil.
3. ectendorganic layers - consist of ectorganic layers overlying dark organo-mineral horizons.

Further breakdowns were distinguished within each broad group. For example, vermiol and parvital represent earthworm mulls and microbiotic mulls, respectively; while velor and lentar represent friable or spongy mor and matted mor, respectively.

Nomenclature discrepancies concerning forest floor layers have also commonly occurred throughout the years. For example, the symbols F and H were introduced by Hesselman (1926) as abbreviations for Swedish words. Romell and Heiberg (1931) suggested their adoption for international use and indicated that F could represent a "fermentation horizon" or a first layer of decomposition, and H could represent a "humified horizon" or a layer of extreme decomposition. This nomenclature, due to its simplicity and symbolism for natural conditions, quickly became accepted and is still commonly used by foresters today.

The most recent soil taxonomy scheme departs from the traditional L, F, and H layer designations for the forest floor (U.S.D.A., 1975). The Soil Taxonomy System recognizes two subdivisions as follows:

01 - Organic horizons in which essentially the original form of most vegetative matter is visible to the naked eye (corresponds to the L and F layers, and the old A_{00} horizon).

02 - Organic horizons in which the original form of most plant or animal matter cannot be recognized with the naked eye (corresponds to the H layer and the old A_0 horizon).

The 01 and 02 designations are in common usage today by soil scientists, and thus a discrepancy still exists as foresters prefer the more traditional and descriptive L, F, and H labels.

Discrepancies in the literature also exist as to the proper designation for the forest floor. The term "humus layer" has been commonly used, and Wilde (1971) still prefers its usage. In soil science terminology, however, humus refers to the "more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed" (Brady, 1974). Obviously the organic mat overlying mineral soils in forests differs considerably from the soil scientist's conception of humus. The Society of American Foresters (1971) recognized the term "humus layer" as "a general term for the surface layers composed of or dominated by organic material, whether unincorporated or incorporated with mineral soil, or at some intermediate stage" and the term "forest floor" as "the surface layer of a soil supporting forest vegetation." The current Soil Taxonomy System (U.S.D.A., 1975) referred to the forest floor simply as an organic horizon, designated by the letter O, and further divided into O1 and O2 subhorizons. In this dissertation the organic mat surface overlying mineral soil will be referred to as the forest floor, and will be divided into L, F (O1), and H (O2) layers.

Early Forest Floor Studies in the U.S.

Early American studies involving the forest floor focused on quantifying the size and nutrient content, and in developing relationships to measurable stand characteristics. Kittredge (1948), in the chapter entitled "Litter and the Forest Floor," summarized the older literature. Several early studies were carried out in the Lake States (Alway and Kittredge, 1933; Alway et al., 1933a; Alway et al., 1933b) in various forest types. From this research it was established that forest floors under hardwood stands have higher pH's and higher nitrogen contents than forest floors developed under coniferous stands. In addition, nutrient contents (N, P, K, and Ca) in the forest floor were found to be higher under later successional species. In this case the successional progression from jack pine to red pine to eastern white pine to sugar maple-American basswood was considered.

In addition to Alway's work in the Lake States, Sims (1932) reported on a project undertaken in the Appalachian Mountains of North Carolina to determine the protective value of the forest floor in the oak-pine type. Several study sites were established and different treatments imposed on the forest floor. Burning was found to have a detrimental effect on the forest floor, as it took at least three years to build the forest floor back to preburning levels. During this period the soil was more subject to frost heaving and subsequent erosion.

Wilde et al. (1937) studied nutrient contents of forest floors in the Lake States and related different forest floors on the basis of fertilizer value for forest nurseries. Metz (1954) analyzed forest floors under three different timber types in South Carolina: pine, pine-hardwoods, and hardwoods. Forest floor accumulations were found to be the least under the hardwood stands. According to Metz this was attributable to higher decomposition rates in the hardwood stands, as all timber types had comparable annual litter inputs. Dominant hardwood species were yellow-poplar and various hickories, which produce leaf litter that is higher in bases and more readily decomposed than the more resistant pine litter.

Forest Floor Nutrient Dynamics

With the advent of ecosystem studies in the early 1960's (Ovington, 1962), interest in studying the forest floor was renewed. Scientists became interested in the role of the forest floor in ecosystem processes such as nutrient cycling and energy flow. Attempts were made to quantify the buildup and steady state condition of the forest floor and soil organic matter (Jenny et al., 1949; Olson, 1963; Minderman, 1968). Nutrient cycling studies carried out at the Hubbard Brook Experimental Forest in New Hampshire (Bormann and Likens, 1967; Likens and Bormann, 1970) indicated the importance of the forest floor as a buffer to ecosystem disturbance by releasing nutrients through decomposition at varying rates depending upon temperature and moisture as well as other environmental conditions. Pierce et al. (1972) reported that on nutrient-poor podzols in New Hampshire the forest floor was the major factor influencing tree growth and species diversity.

Reiners and Reiners (1970) carried out a project in three forest stands in Minnesota. Energy flows and nutrient fluxes were determined for forest floors along an elevational gradient from an upland oak stand to a white-cedar swamp. Turnover times for several nutrients were determined and it was found that turnover times increased greatly from upland to swamp conditions, due to the wet conditions present in the swamp.

A detailed look at nutrient cycling in European deciduous forests was undertaken by Duvigneaud and Denaeyer-De Smet (1970). The major nutrient contents were quantified in all portions of a forest stand, including the forest floor. Duvigneaud and Denaeyer-De Smet (1970) provided the forest floor nutrient data shown in Table 1. The beech forest in Great Britain accumulated greater quantities of nutrients in the forest floor, with the exception of Ca, than the other forest types studied. Much of the variation in nutrient contents of various forest stands can be attributed to past stand history and the successional development of vegetation. Switzer et al. (1979) traced the development of the forest floor in 40 stands on upland sites of the east Gulf Coastal Plain. Their data (Table 2) suggest an increase in most nutrients as a young stand develops, then a gradual leveling off or slight decrease as maturity is reached. As the hardwood component of the stands developed, the calcium and magnesium content of the forest floor increased.

Wells et al. (1972) investigated mineral nutrient cycling in a mixed hardwood and a loblolly pine stand in North Carolina. Litterfall was recognized as a major pathway of nutrient flow, and nutrient contents in hardwood litter were much greater than in pine litter.

Yount (1975) studied forest floor nutrient dynamics in southern Appalachian hardwood and white pine plantation ecosystems, and found that calcium contents were greater in the hardwood forest floor, while N and P storage was higher in the pine forest floor. Potassium and Na contents were nearly equal in both forest floors; however, the pine forest floor was significantly greater in total carbon storage.

One of the more recent and detailed investigations relating to the forest floor and nutrient cycling was reported by Gosz et al. (1976). Nutrient contents by forest floor layers were determined on an undisturbed watershed on the Hubbard Brook Experimental Forest in New Hampshire. Nitrogen was found to be the most abundant element in the forest

Table 1. Forest floor macronutrient data from several hardwood stands in Great Britain and Belgium. From Duvigneaud and Denaeyer-De Smet (1970).

Forest Type	Location	Age	Macronutrient Content				
			N	P	K	Ca	Mg
		Years	-------------kg/ha-------------				
Birch	Great Britain	22	47	6	8	72	4
Oak	Great Britain	47	71	5	8	35	5
Beech	Great Britain	37	180	11	20	51	14
Chestnut	Great Britain	47	80	6	10	32	7
Oak-Beech	Belgium	75	33	2	15	74	5

Table 2. Nutrient content of the forest floor by stage of succession and period of development based on 40 stands growing on upland sites in the east Gulf Coastal Plain. From Switzer et al. (1979).

	Stage of Succession and Period of Development					
	Early			Middle	Late	
Nutrient	Field	Small Pole	Large Pole	Standard	Veteran	Oak-Hickory-Pine
	---kg/ha---					
N	0	170	180	200	210	190
P	0	12	11	14	13	12
K	0	13	15	17	18	17
Ca	0	53	85	130	180	300
Mg	0	18	20	22	23	28

floor, followed in sequence by Ca, Fe, and S. Nitrogen and P had the longest residence times in the forest floor, while K had the shortest residence time.

Recently Sharpe et al. (1980) developed a model to predict foliage litterfall, L + F layer mass, and Mg, P, and K contents of the L + F layer. The model was tested using forest floor and litter samples from U.S. Forest Service inventory plots in the southern Appalachians. The model, based on a series of general allometric equations, adequately predicted litterfall and L + F layer mass. Elemental contents of litterfall and Mg and K mineralization rates were overestimated, whereas the P mineralization rate was underestimated. This modeling approach is unique and particularly useful when attempting to develop regionalized information based on normal forest inventory data.

Litterfall as a Pathway for Nutrient Cycling

Litterfall is an important dimension in the study of the forest floor. It is the major input source of organic matter, nutrients, and energy to the forest floor, and as such deserves special attention. There is certainly no paucity of information on amounts of litterfall in various forest types throughout the world. Earlier studies on nutrient contents of forest litter in the U.S. were reported by Alway and Zon (1930), Garstka (1932), Lunt (1935), Coile (1937), Chandler (1937, 1941, 1943), Broadfoot and Pierre (1939), Metz (1952), Daubenmire (1953), Blow (1955), and McGinnis (1958). As with the forest floor studies, interest in ecosystem processes in the 1960's led to more litterfall studies, particularly with respect to nutrient cycling. Decomposition and nutrient release from litter was of particular interest (Nykvist, 1959a, 1959b, 1961a, 1961b, 1962; Remezov, 1961; Shanks and Olson, 1961; Gosz et al., 1972 and 1973) as the need for quantification of ecosystem components became apparent. Current emphasis in ecosystem analysis is on the development of computer models to depict natural processes, an endeavor which requires the presence of large, accurate data sets for all ecosystem functions (Andersson, 1971). Because of the importance of litterfall in driving the nutrient cycling process in ecosystems, litterfall studies are still being conducted and will continue to be conducted in the future (Pearson and Weaver, 1978).

Several litterfall studies have been carried out in the southern Appalachian Mountains. Sims (1932) reported on a study in the Bent Creek Experimental Forest near Asheville, North Carolina. Leaf-fall for two plots in an oak-pine stand were 3,475 and 2,914 kg/ha for the year 1930. Metz (1952) studied annual litterfall in several stands on the South Carolina Piedmont. The annual litterfall ranged from 4,550 to 6,298 kg/ha. In addition, freshly fallen leaves from 14 tree species were analyzed for N, Ca, and Mg content. Litterfall from hardwood trees was found to contain twice as much N, three times as much Mg, and five times as much Ca as litterfall from pine trees. Blow (1955) studied litter deposition in the Tennessee River Watershed, and found an annual leaf-fall of 2,914 kg/ha in upland oak stands.

McGinnis (1958) carried out a detailed study comparing forest floors and litter deposition for stands in the Great Smoky Mountains of east Tennessee. Litterfall averaged 4,483 kg/ha for scrub pine stands and 4,988 kg/ha for oak-hickory stands. Bray and Gorham (1964) summarized litter production in forests throughout the world, and provided litterfall rates for various locations in Tennessee (Table 3). Annual litterfall was heavier in the *Pinus echinata* stand than in the *P. virginiana* or mixed hardwood stands. Topography and aspect did not appreciably influence hardwood litterfall; however, *P. echinata* stands on north and south slopes had much more annual litterfall than on level uplands, 6,600 and 6,200 vs. 3,800 kg/ha/yr, respectively.

Wells et al. (1972) reported on a nutrient cycling study in a hardwood and a pine stand on the Duke Forest in North Carolina. Litterfall was 5,725 and 4,587 kg/ha in the hardwood and pine stands, respectively. In addition, nutrient analyses indicated that hardwood litter contained 70% more N and 250% more Ca than the pine litter. Hardwood litter also contained about twice as much K, Mg, Mn, Cu, Na, and Al as pine litter.

Cromack and Monk (1975) reported on litterfall and decomposition in a mixed hardwood stand and a white pine plantation at Coweeta Hydrologic Laboratory near Franklin, North Carolina. Annual litter production was 4,369 and 3,253 kg/ha in the hardwood stand and pine plantation, respectively. Cotrufo (1977) analyzed litterfall and nutrient contents in a mixed hardwood forest on the Bent Creek Experimental Forest, where annual litterfall was 3,730 kg/ha. Comparisons were made between upper slope positions dominated by mixed oaks and lower slope positions dominated by *Liriodendron tulipifera* and *Betula lenta*. Litterfall was greater on the upper slopes, but lower slope litter had higher concentrations of N, Ca, and K.

Kreh et al. (1978) analyzed litterfall in several old-field Virginia pine stands representing a range of age classes in the western Piedmont of Virginia. Annual total litterfall was found to increase with stand

Table 3. Litterfall deposition rates for various species and topographic positions in Tennessee. From Bray and Gorham (1964).

Species	Topographic Position	Litterfall
		kg/ha/yr
Pinus virginiana	---	4600
Quercus spp.	---	4500
Pinus echinata	north slope	6600
Pinus echinata	south slope	6200
Pinus echinata	level upland	3800
Liriodendron tulipifera, *Populus* spp., *Fraxinus* spp.	sinkhole	4700
Liriodendron tulipifera, *Quercus* spp., *Carya* spp.	north slope	4000
Liriodendron tulipifera, *Quercus* spp., *Carya* spp.	south slope	5000
Liriodendron tulipifera, *Quercus* spp., *Carya* spp.	level upland	5400
Liriodendron tulipifera, *Quercus* spp., *Carya* spp.	valley	5300

age (7 to 36 years) from 3,940 to 5,580 kg/ha. Orndorff and Lang (1978) studied litterfall and downslope transport on steep hillsides in West Virginia. Although the study did not show increased forest floor masses at lower slope positions, a fenced enclosure showed that about 25% of leaf deposition moves downslope.

Effects of Clearcutting on Forest Floor Nutrient Dynamics

The effects of various forest management practices on the forest floor have not been well dodumented. Diebold (1941) discovered that logging caused a decrease in forest floor depth of 2.5 to 5.0 cm, but that this was insignificant in comparison to the 35 cm decrease commonly caused by fires. Hart (1961) found that the forest floors in clearcut stands averaged 1.3 to 2.5 cm less in depth than older stands 20 to 30 years after logging. Dominski (1971), reporting on studies in the Hubbard Brook Experimental Forest in New Hampshire, found that clearfelling and subsequent suppression of regeneration caused a 2.5 to 5.0 cm reduction in forest floor depth in the first 3 years following cutting.

Nykvist (1971) reported on a study initiated in 1966 at Garpenburg, Sweden. An old-growth spruce forest was clearcut with several treatments applied, including whole-tree removal, removal of bole-wood only, and removal of bole-wood with subsequent slash burning. Changes in the forest floor after one year are presented in Table 4. The nutrient contents in the forest floors under clearcut stands were considerably less than those under the uncut old-growth spruce forest. The whole-tree removal treatment produced the smallest nutrient contents in the forest floor.

One of the most detailed studies to date on the response of the

Table 4. Nitrogen, P, and K contents of the forest floor of spruce stands in Sweden prior to clearcutting and one year after conventional clearcutting, whole-tree harvesting, and conventional clearcutting with slash burning. From Nykvist (1971).

Treatment	Forest Floor Nutrient Content		
	N	P	K
	--------kg/ha------		
Prior to clearcutting	1166	62	94
Conventional clearcutting (slash remains on site)	760	48	76
Clearcutting with whole trees removed	688	45	52
Conventional clearcutting with slash burning	735	49	68

forest floor to logging was carried out by Covington (1976) in northern New Hampshire. Fourteen stands, ranging in age from 3 to over 200 years, were analyzed for forest floor organic matter, nutrient content, and litterfall. Forest floors decreased in thickness and organic matter content following clearcutting, due primarily to reduced litterfall and increased decomposition rates which are a function of higher temperatures and moisture, and the easily decomposed nature of successional litter. Covington found no differences in forest floor Mg, K, and N concentrations; however, Ca was significantly higher in stands with lower organic matter contents in the forest floors. The major decreases in forest floor organic matter during the revegetation period occurred in the F and H layers. The importance of logging slash as a "slow-release fertilizer" during the 15 to 64 year "rapidly aggrading phase" of regeneration was stressed, perhaps casting a foreboding shadow on logging practices that remove entire trees and leave no slash.

Wells and Jorgensen (1979) discussed the importance of the forest floor nitrogen reserve in stands that have been whole-tree harvested. Forest floor N was subject to loss from mineralization and subsequent leaching, and from fire; therefore, forest stands with large N reserves in the forest floor may be vulnerable to nutrient loss.

A computer model was developed by Aber et al. (1978) to simulate the effects of different harvesting regimes on forest floor nutrient dynamics in northern hardwood forests. Three levels of utilization, clearcutting, whole-tree harvesting, and complete forest harvesting (including root removal), were compared. It was concluded that nitrogen loss from the system increased with increasing removal of organic material from the site, and that the logging slash left after conventional clearcutting provided a carbon-rich substrate for microbes. The increased microbial activity resulted in more N immobilization, which is gradually released back into the system. Forest floor recovery after harvesting was also closely related to rotation length, with a 30-year whole-tree rotation resulting in a forest floor only one-half as large as that after a 90-year clearcut rotation.

Aside from disturbance caused by logging equipment, timber harvesting influences the forest floor by creating favorable conditions for decomposition, i.e., increased carbon source, increased moisture content, and increased temperature (Jurgensen et al., 1979). Elevated nutrient contents in streams draining clearcut areas (Pierce et al., 1972) have been attributed to these effects; however, on soils with rapid regrowth there is relatively little solution loss (Stark, 1979).

In western forests, soil organism activity is often limited by temperature and moisture, and on such sites wildfire is the principal carbon recycling agent (Harvey et al., 1980). Increased moisture content and soil temperatures following clearcutting may increase decomposition, and logging slash left in close contact with the forest floor would serve as a useful carbon source for soil organisms. Under these conditions, logging practices have the potential for increasing site productivity.

A number of studies have been initiated in the southern Appalachians to assess the effects of clearcutting on nutrient cycling (Monk et al., 1977; Swank and Douglass, 1977); however, the most recent work centered on a nitrogen removal model developed by Rauscher (1980). The model was developed for various combinations of site index and stand density, and utilized both a conventional harvest and a whole-tree removal with 90-year rotations. Soil N content was used as the variable expressing the effect of harvesting, and several interesting results were noted. Conventional clearcutting was found to reduce the soil N pool, and the reduction increased with increasing stand density and site index. Higher quality sites were found to be more vulnerable to N loss than lower quality sites, because of a higher amount of N removal in the biomass and the production of more litter after harvest, which resulted in greater decomposition and subsequent leaching losses. Vitousek et al. (1979) noted that during decay of forest floor material with a wide C:N ratio, nitrogen is assimilated by soil microorganisms and thus immobilized, resulting in reduced N leaching losses. Phytomass with a wide C:N ratio is more likely to be produced on lower quality sites, thereby further substantiating Rauscher's conclusion that poorer sites are less vulnerable to N loss.

METHODS

Study Area Description

The study area is located on a north-facing side slope on Price Mountain in the Fishburn Forest. The area is situated approximately 11 km southwest of Blacksburg in Montgomery County, Virginia, and is in the Ridge and Valley Physiographic Region (Fenneman, 1938) and the Oak-Chestnut Forest Region (Braun, 1950).

The area is characterized by a humid, continental climate that is modified by elevation (Crockett, 1972). The mean annual air temperature is 11°C, with the growing season extending for 161 days, from April 30 to October 8. The annual precipitation averages 97 cm and is well-distributed throughout the year, with the maximum in July and the minimum in November. The annual precipitation during the period of this study was 112 cm and 91 cm for 1979 and 1980, respectively.

The study area consisted of a 0.86 ha mixed upland oak forest stand. The average age of the dominant oaks was 130 years and the average oak site index was 56 (Hampf, 1965). Elevation across the study area ranged from 610 to 628 m, and the slope averaged 17 percent. The entire area occupied a uniform side slope extending from the ridgetop to a mid-slope position, and is generally moderately well drained.

Soils on the study area ranged from loamy-skeletal, mixed, mesic, Typic Dystrochrepts of the Calvin and Berks series to a clayey, mixed, mesic Typic Hapludult of the Muse series. Soils of the Calvin and Muse series were derived from shale, while soils of the Berks series were derived from sandstone. Profile descriptions of the three series are provided in Appendix Tables 1-3.

The forest floor was uniform throughout the study area, and was characterized as a typical mull, or a vermiol using the classification scheme of Wilde (1971). The F and H layers were readily distinguished throughout the year, with the L layer present only during the period of autumn litterfall. The F and H horizons averaged 3.6 and 2.9 cm in depth, respectively.

An initial survey of the vegetation on the study area revealed 2,875 stems per ha and 24.3 m^2 of basal area per ha in the upper stratum, which consisted of all stems greater than 2.5 cm dbh. The middle stratum, which consisted of stems greater than 1 m tall but less than 2.5 cm dbh, contributed 1,215 stems per ha. The vegetation survey also revealed that *Quercus prinus* L., *Q. alba* L., and *Acer rubrum* L. were the dominant upper stratum species, while *A. rubrum* L., *Carya tomentosa* Poir. Nutt., *Q. prinus* L., and *Cornus florida* L. dominated the middle stratum. The lower stratum, or woody ground vegetation less than 1 m tall, was dominated by *A. rubrum* L., *Vaccinium vacillans* Torr., *Q. prinus* L., and *Viburnum acerifolium* L. The relative importance of major woody plant species by stratum is presented in Tables 5, 6, and 7.

Field Methods

Timber Harvesting

In August, 1979, a 0.47 ha portion of the stand was clearcut using chain saws. All stems and tops were removed from the site with a rubber-tired skidder, and after the merchantable sawlogs were removed all remaining material was chipped. Although some woody slash was left on the site, the operation closely resembled an actual commercial whole-tree harvesting operation.

Table 5. Relative density, relative dominance, relative frequency and importance values for major upper stratum (>2.5 cm dbh) species in the study area on Price Mountain, Montgomery County, Virginia.

Species	A Relative Density (% of Total No. Stems/ha)	B Relative Dominance (% of Total BA/ha)	C Relative Frequency (% of Total Frequency)	D Importance Value (Mean of A,B, and C)
Quercus prinus L.	15.5	46.8	3.7	22.0
Quercus alba L.	7.0	26.8	11.0	14.9
Acer rubrum L.	20.2	4.5	13.7	12.8
Amelanchier arborea (Michx. f.) Fern.	10.4	1.7	11.0	7.7
Carya tomentosa Poir. Nutt.	10.3	1.1	10.3	7.2
Pinus strobus L.	4.7	7.5	8.2	6.8
Cornus florida L.	8.9	0.9	10.3	6.7
Quercus velutina Lam.	5.6	1.7	8.9	5.4
Carya glabra (Mill.) Sweet	2.6	2.3	6.8	3.9
Nyssa sylvatica Marsh.	2.6	0.2	6.2	3.0
Minor species*	12.2	6.5		

*Minor species:

Sassafras albidum (Nutt.) Nees
Viburnum rafinesquianum Schultes.
Acer saccharum Marsh.
Castanea dentata (Marsh.) Borkh.
Hamamelis virginiana L.
Quercus coccinea Muenchh.
Viburnum prunifolium L.
Liriodendron tulipifera L.
Oxydendrum arboreum (L.) Dc.
Pinus virginiana Mill.
Prunus serotina Ehrh.
Fraxinus pennsylvanica Marsh.
Fraxinus americana L.
Viburnum acerifolium L.

Table 6. Relative density, relative frequency, and importance values for major middle stratum (>1 m tall but <2.5 cm dbh) species in the study area on Price Mountain, Montgomery County, Virginia.

Species	A Relative Density (% of Total No. Stems/ha)	B Relative Frequency (% of Total Frequency)	C Importance Value (Mean of A and B)
Acer rubrum L.	25.1	18.0	21.6
Carya tomentosa Poir. Nutt.	11.5	13.5	12.5
Quercus prinus L.	12.3	11.2	11.8
Cornus florida L.	9.1	12.4	10.8
Amelanchier arborea (Michx. f.) Fern.	6.2	11.2	8.7
Quercus velutina Lam.	5.3	9.0	7.2
Viburnum rafinesquianum Schultes.	9.1	4.5	6.8
Nyssa sylvatica Marsh.	4.1	5.8	4.9
Quercus alba L.	3.3	5.6	4.5
Viburnum acerifolium L.	3.3	4.5	3.9
Carya glabra (Mill.) Sweet	1.6	4.5	3.1
Minor species*	9.1		

*Minor species:

Prunus serotina Ehrh.
Hamamelis virginiana L.
Viburnum prunifolium L.
Castanea dentata (Marsh.) Borkh.
Fraxinus pennsylvanica Marsh.
Sassafras albidum (Nutt.) Nees
Liriodendron tulipifera L.
Corylus cornuta Marsh.

Table 7. Relative density, relative frequency, and importance values for major lower stratum (<1 m tall) species in the study area on Price Mountain, Montgomery County, Virginia.

Species	A Relative Density (% of Total No. Stems/ha)	B Relative Frequency (% of Total Frequency)	C Importance Value (Mean of A and B)
Acer rubrum L.	15.4	16.4	15.9
Vaccinium vacillans Torr.	18.2	11.2	14.7
Quercus prinus L.	8.7	9.5	9.1
Viburnum acerifolium L.	9.1	7.8	8.5
Gaylussacia baccata (Wang.) K. Koch.	8.5	6.0	7.3
Amelanchier arborea (Michx. f.) Fern.	5.7	8.6	7.2
Gaultheria procumbens L.	4.2	9.5	6.9
Quercus alba L.	5.5	6.9	6.2
Carya tomentosa Poir. Nutt.	3.0	6.9	5.0
Cornus florida L.	4.7	4.3	4.5
Quercus velutina Lam.	2.0	6.0	4.0
Vaccinium stamineum L.	2.0	3.4	2.7
Carya glabra (Mill.) Sweet	0.8	3.4	2.1
Minor species*	12.2		

*Minor species:

Viburnum rafinesquianum Schultes.
Nyssa sylvatica Marsh.
Parthenocissus quinquefolia (L.) Planch.
Sassafras albidum (Nutt.) Nees
Rhododendron nudiflorum (L.) Torr.
Prunus serotina Ehrh.
Oxydendrum arboreum (L.) Dc.
Crataegus spp. L.
Hamamelis virginiana L.
Pinus strobus L.
Castanea dentata (Marsh.) Borkh.
Viburnum prunifolium L.
Acer saccharum Marsh.
Corylus cornuta Marsh.

Forest Floor Sampling

Forest floor sampling dates were established as follows: June, August, and November. The first collection was in June, 1979, prior to clearcutting. Subsequent collections were made in August and November, 1979, and June, August, and November, 1980.

In order to facilitate ground control, eight 2.8 x 2.8 m sampling units were randomly located in the cut area each year. Eight sampling units were also located in the uncut area each year. The sampling units were square, and consisted of four 1.4 x 1.4 m cells (Figure 1). For each year of the study, three of the cells were randomly selected as locations for forest floor and mineral soil collections, while the fourth contained a litter trap. Thus, for a given sampling date, eight observations were obtained for each area. A map of the study area, showing sampling unit locations, is provided in Figure 2.

To collect the forest floor samples, a 0.5 m^2 plywood template was placed on the ground within a cell, and a machete was used to cut out a sample forest floor plot around the template. The organic material in each of the L, F, and H layers was removed by hand, bagged, and transported to the laboratory for analysis. The layers were distinguished according to the description by Hoover and Lunt (1952). Living plant tissue was not sampled.

Forest floor depth by layers was measured to the nearest cm on all four sides of the sample plot, and a mean was determined. The percent slope of the plot was measured with an Abney level, and an areal correction factor was applied for conversion to a per hectare basis.

Figure 1. Typical sampling unit consisting of four 1.4 x 1.4 m cells, located in the clearcut area, Price Mountain, Montgomery County, Virginia.

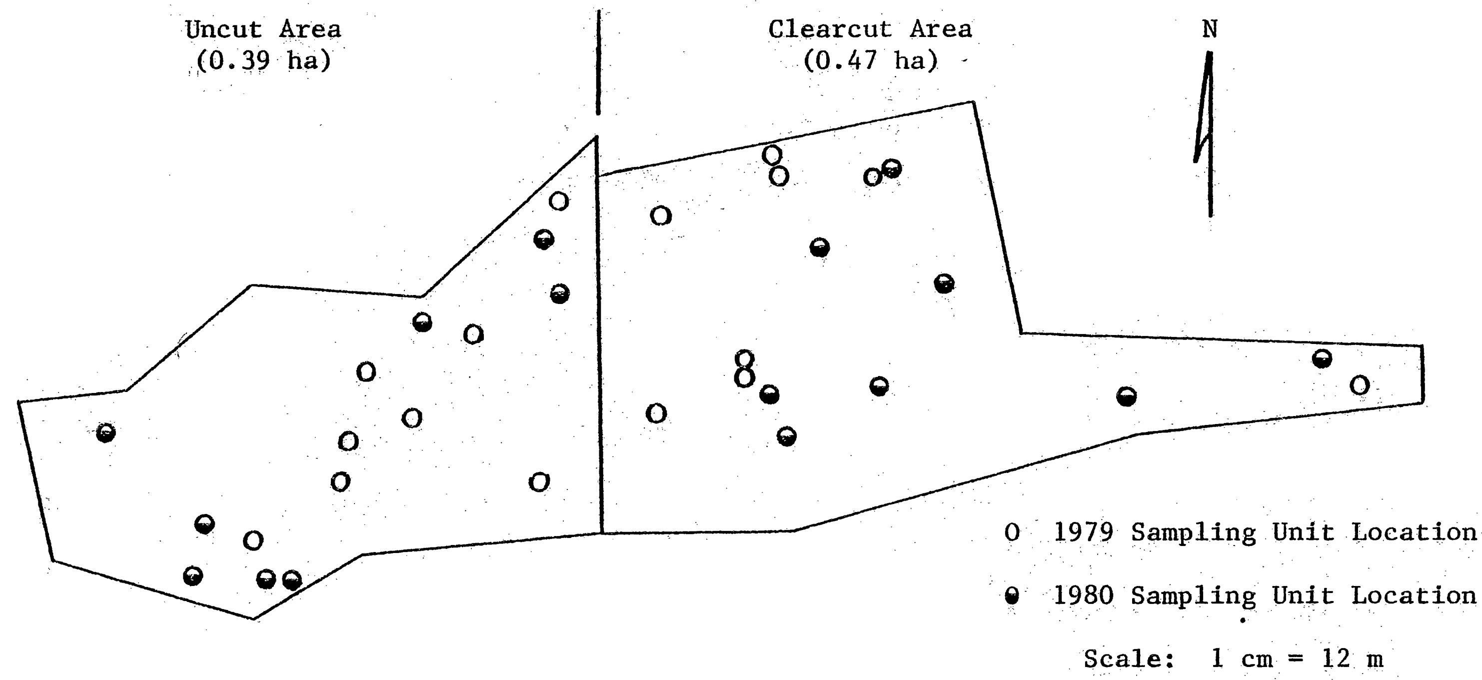

Figure 2. Map of the study area showing clearcut and uncut area boundaries and sampling unit locations. Study area is on Price Mountain, Montgomery County, Virginia.

Mineral Soil Sampling

A composite sample of the A_1 horizon was obtained on each forest floor plot after removal of the H layer. Five cores to a depth of 5 cm were extracted with a bulk density sampler and composited. Two additional samples from each forest floor plot were composited for a bulk density determination.

Soil samples were collected for a microbiological characterization of the study area in June, 1980. Samples were obtained from the H-A_1 zone at five locations in both the cut and uncut portions of the stand. Each group of five samples was then mixed to produce a composite sample.

Litterfall Sampling

Litterfall traps were randomly placed in one cell of each sampling unit. Traps were set out by October 1, 1979, and litter was collected monthly through October, 1980. The litter collected in December through February was composited as a winter increment. The traps were repositioned in the 1980 sampling units in June, 1980.

Each litterfall trap consisted of a 0.5 m^2 box constructed of 10 x 2.5 cm untreated redwood boards with a fiberglass screen bottom. The traps were equipped with side spikes which were driven into the ground so that each trap was positioned level and just above the L layer of the forest floor (Figure 1).

Soil Solution Sampling

Porous ceramic cup lysimeters (Wagner, 1962) were installed at 15 and 30 cm depths adjacent to each of the 1979 sampling units. Lysimeters were constructed using 3.8 cm PVC pipe and were weathered in a 2% HCl solution prior to installation. Each lysimeter was placed in an auger hole in a soil slurry to obtain a close contact between the PVC pipe and the soil. A 60 cb vacuum was placed on the lysimeters 24 hours prior to the time of collections. Soil solutions were collected on a biweekly basis from April, 1980, through March, 1981.

Soil Moisture, Soil Temperature, and Precipitation Measurements

Soil moisture and soil temperature measurements were made adjacent to each of the 1979 sampling units at the same time as soil solution collections. Soil moisture was determined gravimetrically using a 10 cm core extracted with a punch tube, while soil temperature was determined at a 2.5 cm depth using a soil thermometer.

Precipitation data were obtained using a standard rain gage at the VPI & SU College of Agriculture and Life Sciences, Price's Fork Research Station, which is located about 3.2 km from the study site.

Lab Methods

Sample Preparation

All forest floor, litterfall, and soil samples were individually bagged in the field and allowed to air dry in the lab. The organic samples were then dried to a constant weight in a convection oven at 70°C, weighed to the nearest 0.1 g, and ground in a Wiley Mill to pass a 2 mm mesh screen. Ground samples were randomly reduced in size using a Fisher sample splitter.

Soil samples for nutrient analysis were air-dried and then ground to pass a 2 mm mesh screen. All material greater than 2 mm was discarded. The soil samples used for bulk density measurements were oven-dried at 105°C, weighed, then ground to pass a 2 mm mesh screen. Coarse fragments greater than 2 mm were treated with a 2% Calgon solution, washed, oven-dried, and reweighed. A corrected bulk density was then computed for the less than 2 mm fine earth fraction.

Soil samples for the microbiological characterization were returned to the lab in plastic containers, air-dried for several days, then gently passed through a 2 mm sieve.

Nutrient Analysis of Litterfall and L and F Layer Samples

Litterfall and L and F layer samples were ashed in Pyrex ignition tubes using a 500°C muffle furnace, and then dissolved in 6N HCl. Total P was determined using the ascorbic acid colorimetric procedure of Murphy and Riley (1962). Total Ca and Mg were determined by atomic absorption, and K by flame emission. A Perkin-Elmer model 460 atomic absorption spectrophotometer was used for K, Ca, and Mg determinations. Total N was determined using the micro-Kjeldahl procedure outlined by Bremner (1965), and the salt-catalyst mixture (100 g K_2SO_4:10 g $CuSO_4 \cdot 5H_2O$:1g Se) recommended by Nelson and Sommers (1973).

Nutrient Analysis, Organic Matter, and pH Determinations of Soil and H Layer Samples

Soil and H layer samples were digested using the perchloric acid procedure of Sommers and Nelson (1972). For the H layer samples, concentrated nitric acid was used as an oxidant. Total P, K, Ca, Mg, and N were determined using the same procedures as for the litterfall and L and F layer samples. Organic matter content for the soil was determined by the Walkley-Black wet oxidation procedure outlined by Allison (1965). For the H layer samples, organic matter was determined as loss on ignition using Jackson's (1958) procedure, and organic carbon was computed using the method recommended by Lunt (1931) for H layer material. The pH of soil samples was determined using a combination glass electrode in a 1:1 soil-water mix.

Nutrient Analysis of Soil Solutions

Soil solutions were analyzed for P using the ascorbic acid method, K using flame emission, and Ca and Mg using atomic absorption spectrophotometry. The pH was determined using a combination glass electrode. Ammonium-nitrogen was determined using an ammonia electrode and an Orion 901 ionalyzer with 10 M NaOH as a pH adjuster. Nitrate-nitrogen was determined colorimetrically after reduction to NO_2-N using a copper-cadmium column (Henrikson and Selmer-Olsen, 1970).

Microbiological Characterization

Duplicate dilution series, ranging from 10^{-1} to 10^{-8}, were prepared using 10 g subsamples from the composite samples from the clearcut and uncut areas.

The 10^{-4} to 10^{-8} dilutions were used to test for actinomycetes. Sodium caseinate agar was used, and plates were incubated at 30°C for 14 days prior to counting actinomycete colonies.

Fungi were enumerated using the 10^{-2} to 10^{-4} dilutions and acidified potato dextrose agar (pH 4.2). Plates were incubated at 30°C for four days prior to counting fungal colonies.

The 10^{-4} to 10^{-8} dilutions and sodium caseinate agar were used to enumerate bacteria. The number of bacteria was determined as colony-forming units after incubation at 30°C for four weeks.

The 10^{-2} to 10^{-7} dilutions were used for enumeration of denitrifiers. Five nitrate broth tubes were prepared for each duplicate subsample, and incubated at 30°C for 14 days. The procedure of Focht and

Joseph (1973), modified to include the use of N,N, dimethyl-1-naphthylamine as a substitute for α-naphthylamine (Miller and Neville, 1976), was followed to enumerate denitrifiers. The Most Probable Number (MPN) technique of Alexander (1965) was used.

The nitrifying bacteria, *Nitrosomonas* and *Nitrobacter*, were enumerated using the 10^{-2} to 10^{-6} dilutions and a 30-day incubation at 30°C. The procedure of Alexander and Clark (1965) was followed to determine the MPN of nitrifying organisms.

Statistical Analysis

Three major tests for differences in means were performed in this study. The first test was designed to determine significant differences between the clearcut and uncut areas at each sampling date; student's t test was used for these comparisons, and was preceded by an F test for equality of variance. If the variances were not equal, an approximate t was computed. The test was performed for the litterfall, forest floor layer, soil solution, and soil temperature and moisture data.

The second test involved comparisons of means across sampling dates. For this test an analysis of variance procedure was used, followed by Duncan's Multiple Range Test for individual comparisons. This test was employed for individual forest floor layers and soil solution depths within each area, as well as for litterfall, soil moisture, and soil temperature. For each of the Duncan's Multiple Range Tests, the error mean square for the overall F test in the analysis of variance was used.

The final test involved comparisons of means between forest floor layers at each sampling date, and also involved an analysis of variance followed by Duncan's Multiple Range Test. This test was performed only on the forest floor data set. The error mean square used in the Duncan's test was computed for the overall F test.

All statistical analyses were performed at an α level of 0.05 using the Statistical Analysis System available at the VPI & SU Computing Center.

RESULTS

As mentioned in the introduction, only the Phase I results of the study will be presented here. This section is divided into six parts as follows: litterfall nutrient dynamics, forest floor nutrient dynamics, soil solution nutrient dynamics, soil temperature and moisture dynamics, precipitation, and microbiological characterization. The results for each section will be presented with accompanying tables and figures.

Litterfall Nutrient Dynamics

Litterfall, the major pathway for nutrient transfer in forest ecosystems, was collected in the clearcut and uncut areas for the period October, 1979, through October, 1980. The total amount of litterfall, expressed as dry weight in kg/ha, for all sampling dates is presented in Appendix Table 4 and Figure 3. The largest amount of litterfall for both the clearcut and uncut areas was recorded during October. For example, during October, 1979, 3,905 and 552 kg/ha were recorded in the uncut and clearcut areas, respectively. These values differed significantly, and were also significantly greater than the amounts of litterfall recorded during the remaining months of collection in both the cut and uncut areas. Although significantly higher amounts of litter fell in the uncut area as compared to the clearcut area, monthly litterfall within either of the two areas did not vary significantly, with the exception of October.

Total N contents transferred in monthly litterfall are presented in Appendix Table 5 and Figure 4. The trends in N contents paralleled the biomass data of Appendix Table 4 and Figure 3; however, some variations existed. For example, in the uncut area, 1.5 times more litter fell in

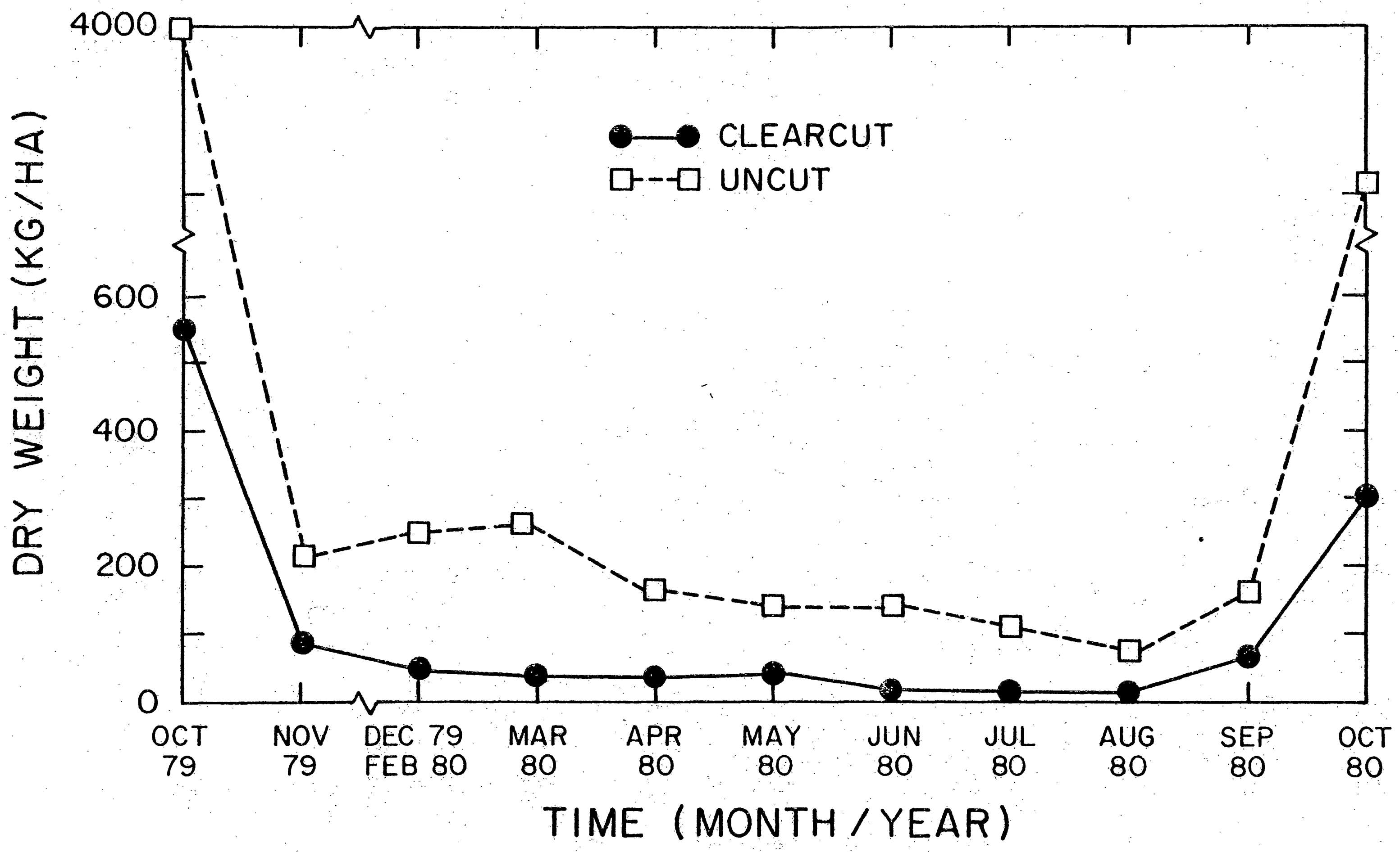

Figure 3. Dry weight of monthly litterfall for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

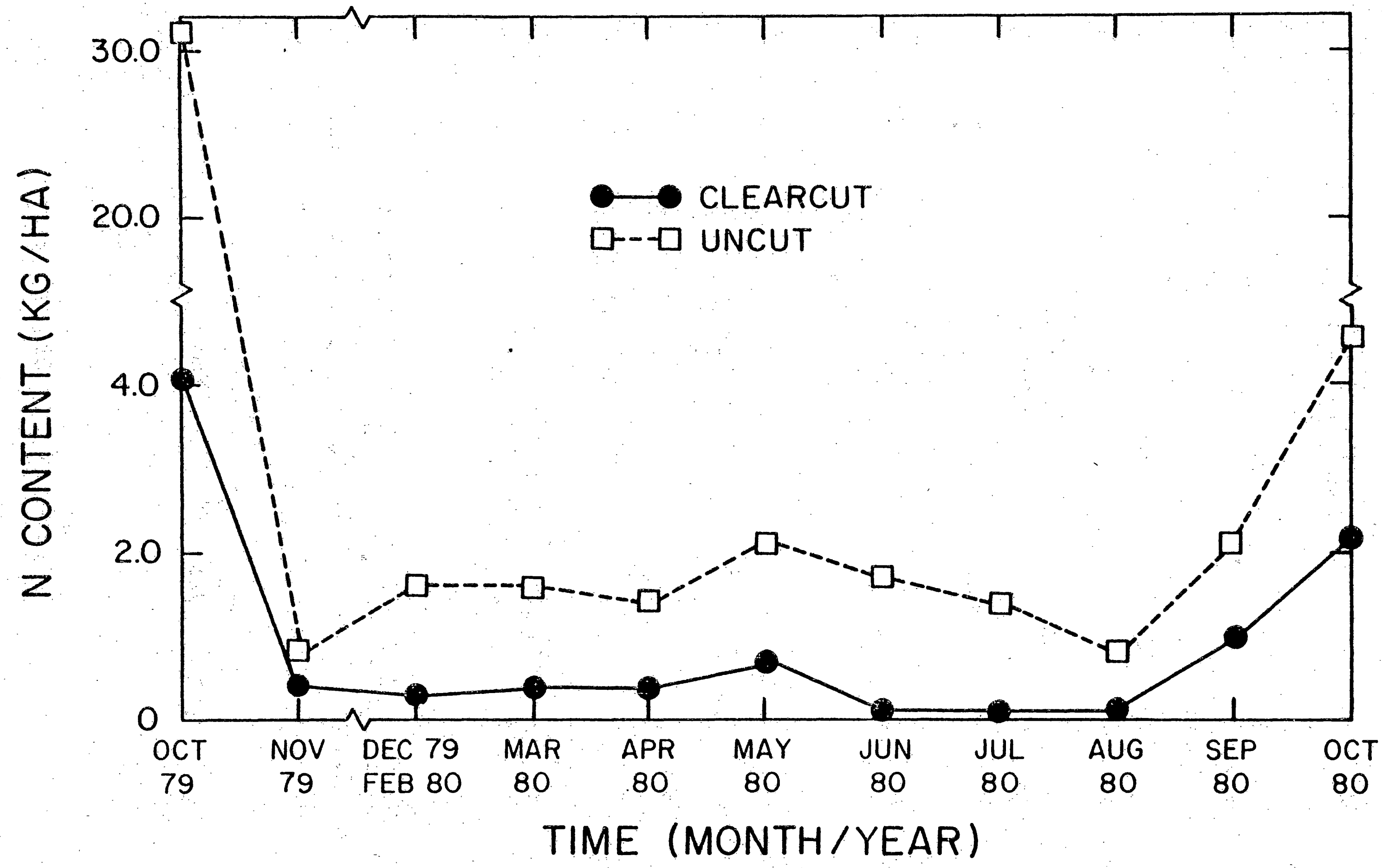

Figure 4. Total N content of monthly litterfall for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

November, 1979, as compared to June, 1980; however, over two times the amount of N was transferred in June as compared to November. Overall, October was the major month during which N was cycled in litterfall. The smallest quantity of N was transferred during the months June through August; however, in both the clearcut and uncut areas October was the only month during which a significantly greater quantity of N was cycled.

Total P contents, shown in Table 8, were significantly higher in litterfall from the uncut area for all months except March and September. The largest amount of P was cycled in the October litterfall; for example, 1.7 and 0.3 kg/ha were recorded for the uncut and clearcut areas, respectively, during October, 1979. Overall, there was very little difference noted within each area between P contents in litterfall for months other than October.

The total K contents contained in monthly litterfall are presented in Table 9. The pattern of K transfer was similar to that of P, although somewhat more variable. The greatest amount of K cycled was associated with the large biomass which fell during October. The 15.1 kg/ha of K recorded for the uncut area during October, 1979, was significantly greater than the 1.7 kg/ha recorded for the clearcut area during the same month. In the clearcut area little variation was noted in the amount of K cycled between months. In the uncut area, however, much more variation was noted. The K content in litterfall ranged from 0.1 kg/ha in August, 1980, to 0.5 kg/ha in June, 1980; however, there were no significant differences between months.

Consistently more Ca was cycled in litterfall in the uncut area as compared to the clearcut area (Table 10), and October was the month of

Table 8. Litterfall P contents by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	P Content	
	Clearcut	Uncut
	---------kg/ha---------	
Oct 79	0.3bA*	1.7aA
Nov 79	<0.1bC	0.1aC
Dec 79-Feb 80	<0.1bC	0.1aC
Mar 80	<0.1aC	0.1aC
Apr 80	<0.1bC	0.1aC
May 80	0.1bC	0.2aC
Jun 80	<0.1bC	0.1aC
Jul 80	<0.1bC	0.1aC
Aug 80	<0.1bC	0.1aC
Sep 80	0.1aB	0.1aC
Oct 80	0.2bA	1.1aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Table 9. Litterfall K contents by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	K Content	
	Clearcut	Uncut
	--------kg/ha----------	
Oct 79	1.7bA*	15.1aA
Nov 79	0.1bB	0.4aC
Dec 79–Feb 80	0.1bB	0.2aC
Mar 80	0.1aB	0.2aC
Apr 80	<0.1bB	0.1aC
May 80	0.1bB	0.4aC
Jun 80	<0.1bB	0.5aC
Jul 80	0.1aB	0.4aC
Aug 80	<0.1bB	0.1aC
Sep 80	0.4bB	1.1aC
Oct 80	1.3bA	9.7aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Table 10. Litterfall Ca contents by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Ca Content	
	Clearcut	Uncut
	---------kg/ha---------	
Oct 79	5.6bA*	38.4aA
Nov 79	0.7bC	2.2aC
Dec 79-Feb 80	0.5bC	3.3aC
Mar 80	0.5bC	3.7aC
Apr 80	0.4bC	2.2aC
May 80	0.3bC	1.5aC
Jun 80	0.2bC	1.7aC
Jul 80	0.3aC	1.1aC
Aug 80	0.1bC	0.7aC
Sep 80	0.5bC	2.4aC
Oct 80	3.1bB	27.8aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

greatest Ca transfer. In october, 1979, 38.4 and 5.6 kg/ha of Ca were cycled in the uncut and clearcut areas, respectively. The lowest amounts of Ca were transferred during May through August.

The total Mg contents in litterfall (Table 11) followed the same pattern as the other bases. October, 1979, was the dominant month for Mg cycling litterfall, with 4.1 and 0.6 kg/ha cycled in the uncut and clearcut areas, respectively. Extremely low amounts of Mg were found in the clearcut area during the other months, in most cases less than 0.1 kg/ha. In the uncut area significantly more Mg was transferred in the litterfall than in the clearcut area.

Forest Floor Nutrient Dynamics

To evaluate the effects of clearcutting and whole-tree harvesting on the forest floor, forest floor dry weight, depth, and nutrient contents were compared between clearcut and uncut areas. Organic matter content, C:N ratio, pH, and nutrient contents of the A_1 mineral soil layer (A_1 horizon to a depth of 5 cm) were also included in this analysis. Results will be presented on an individual forest floor layer basis.

The dry weight of the L layer differed significantly between the clearcut and uncut areas only during August, 1979, and November, 1980 (Table 12). During August, 1979, the presence of logging slash was evident as the dry weights of the L layer for the clearcut and uncut areas were 9,518 and 1 kg/ha, respectively. During June and August, 1980, the L layer was nonexistent in both the clearcut and uncut areas.

The nutrient contents followed a pattern similar to the L layer dry weight (Table 12). Total N, K, Ca, and Mg were significantly

Table 11. Litterfall Mg contents by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Mg Content	
	Clearcut	Uncut
	---------kg/ha---------	
Oct 79	0.6bA*	4.1aA
Nov 79	0.1bB	0.2aB
Dec 79-Feb 80	<0.1bB	0.2aB
Mar 80	<0.1aB	0.2aB
Apr 80	<0.1bB	0.1aB
May 80	<0.1bB	0.2aB
Jun 80	<0.1bB	0.2aB
Jul 80	<0.1bB	0.1aB
Aug 80	<0.1bB	0.1aB
Sep 80	0.2bB	0.3aB
Oct 80	0.5bA	3.3aA

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t-test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Table 12. L layer dry weight, nutrient contents, and depths for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date		Clearcut	Uncut
		--------kg/ha-------	
Jun 79	Dry weight	4a*	2a
	N	Trace a	Trace a
	P	Trace a	Trace a
	K	Trace a	Trace a
	Ca	Trace a	Trace a
	Mg	Trace a	Trace a
	Depth (cm)	<0.1a	<0.1a
Aug 79	Dry weight	9,518a	1b
	N	52a	0b
	P	3a	0a
	K	18a	0b
	Ca	84a	0b
	Mg	4a	0b
	Depth (cm)	<0.1a	<0.1a
Nov 79	Dry weight	2,298a	1,949a
	N	7a	14a
	P	<1a	1a
	K	3a	7a
	Ca	19a	20a
	Mg	1a	2a
	Depth (cm)	<0.1b	2.6a
Jun 80	Dry weight	0a	0a
	N	0a	0a
	P	0a	0a
	K	0a	0a
	Ca	0a	0a
	Mg	0a	0a
	Depth (cm)	0a	0a
Aug 80	Dry weight	0a	0a
	N	0a	0a
	P	0a	0a
	K	0a	0a
	Ca	0a	0a
	Mg	0a	0a
	Depth (cm)	0a	0a

Table 12. L layer dry weight, nutrient contents, and depths for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia (continued).

Sampling Date		Clearcut	Uncut
		---------kg/ha--------	
Nov 80	Dry weight	243b	1,633a
	N	2b	11a
	P	<1b	1a
	K	1b	4a
	Ca	3b	18a
	Mg	<1b	2a
	Depth (cm)	0.2b	3.2a

*Means within a row with the same lower-case letter are not significantly different using the 0.5 level of the student's t test.

higher in the uncut area during November, 1980. For example, during August, 1979, the L layer in the uncut area was essentially nonexistent, while the L layer in the clearcut area contained 52, 3, 18, 84, and 4 kg/ha of N, P, K, Ca, and Mg, respectively. By November, 1980, the L layer nutrient contents in the uncut area were significantly greater than the clearcut area.

The F layer dry weight, nutrient contents, and depths, presented in Table 13, are different from those in the L layer. The F layer dry weight tended to be greater in the clearcut area, although no statistical differences were shown. The greatest difference occurred just after cutting, in August, 1979, when the F layer dry weight in the clearcut area was 23,077 kg/ha and the dry weight in the uncut area was 13,362 kg/ha.

The nutrient contents of the F layer in the clearcut and uncut areas were quite similar for all sampling dates (Table 13). Only during August, 1979, immediately after cutting, were the nutrient contents of the F layer in the clearcut area consistently greater than in the uncut area. At this date, however, only K was significantly greater in the clearcut area, 21 vs. 11 kg/ha.

In addition to dry weight, nutrient contents, and depths, organic matter content and C:N ratio were included as variables for comparing H layers. These data are provided in Table 14. The H layer dry weight was consistently higher in the clearcut area than in the uncut area; however, significant differences were noted only during June and August, 1980. The respective values for the clearcut and uncut areas for these two months were 42,059 and 21,250 kg/ha for June, and 32,149 and 18,747

Table 13. F layer dry weight, nutrient contents, and depths for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date		Clearcut	Uncut
		---------kg/ha-------	
Jun 79	Dry weight	20,230a*	17,309a
	N	191a	241a
	P	9a	15a
	K	13a	13a
	Ca	209a	295a
	Mg	12a	15a
	Depth (cm)	4.4a	2.8b
Aug 79	Dry weight	23,077a	13,362a
	N	229a	205a
	P	16a	12a
	K	21a	11b
	Ca	304a	233a
	Mg	18a	12a
	Depth (cm)	2.5a	2.3a
Nov 79	Dry weight	12,929a	15,090a
	N	136a	147a
	P	7b	11a
	K	13a	16a
	Ca	157a	197a
	Mg	8a	11a
	Depth (cm)	2.1b	2.9a
Jun 80	Dry weight	24,197a	16,074a
	N	177a	191a
	P	8a	10a
	K	28a	15a
	Ca	245a	220a
	Mg	11a	11a
	Depth (cm)	2.1a	2.7a
Aug 80	Dry weight	22,156a	17,758a
	N	155a	236a
	P	8a	11a
	K	20a	15a
	Ca	279a	244a
	Mg	10a	14a
	Depth (cm)	1.3b	1.8a

Table 13. F layer dry weight, nutrient contents, and depths for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia (continued).

Sampling Date		Clearcut	Uncut
		--------kg/ha-------	
Nov 80	Dry weight	17,174a	16,129a
	N	157a	135a
	P	8a	9a
	K	17a	18a
	Ca	202a	199a
	Mg	11a	12a
	Depth (cm)	1.5b	2.7a

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test.

Table 14. H layer dry weight, nutrient contents, depths, organic matter contents, and C:N ratios for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date		Clearcut	Uncut
		---------kg/ha-------	
Jun 79	Dry weight	38,526a*	36,023a
	N	379a	402a
	P	29a	34a
	K	70a	63a
	Ca	167a	174a
	Mg	52a	53a
	Depth (cm)	2.9a	2.9a
	OM Content (%)	49.4a	48.7a
	C:N	27.2a	24.6a
Aug 79	Dry weight	31,553a	20,227a
	N	304a	235a
	P	24a	18a
	K	70a	34b
	Ca	172a	88a
	Mg	52a	30a
	Depth (cm)	2.6a	1.7b
	OM Content (%)	48.5a	49.4a
	C:N	27.7a	24.1a
Nov 79	Dry weight	35,760a	32,543a
	N	290a	365a
	P	21a	26a
	K	50a	36a
	Ca	142a	152a
	Mg	59a	50a
	Depth (om)	2.2b	3.3a
	OM Content (%)	34.5b	43.2a
	C:N	23.3a	21.7a
Jun 80	Dry weight	42,059a	21,250b
	N	362a	271a
	P	28a	18a
	K	101a	28b
	Ca	207a	159a
	Mg	68a	30b
	Depth (cm)	2.4a	2.7a
	OM Content (%)	38.4b	50.5a
	C:N	24.9a	21.7a

Table 14. H layer dry weight, nutrient contents, depths, organic matter contents, and C:N ratios for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia (continued).

Sampling Date		Clearcut	Uncut
		---------kg/ha-------	
	Dry weight	32,149a	18.747b
	N	332a	251a
	P	23a	16a
	K	37a	14b
Aug 80	Ca	189a	105a
	Mg	55a	24b
	Depth (cm)	1.7a	1.4a
	OM Content (%)	41.1b	50.1a
	C:N	21.8a	20.9a
	Dry weight	34,168a	25,146a
	N	419a	307a
	P	25a	21a
	K	59a	40a
Nov 80	Ca	186a	171a
	Mg	57a	38a
	Depth (cm)	2.1a	2.5a
	OM Content (%)	42.2a	44.9a
	C:N	22.1a	20.6a

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test.

kg/ha for August.

A comparison of H layer nutrient contents between clearcut and uncut areas revealed mixed results (Table 14). Only total K was consistently higher in the clearcut area, significantly so during August, 1979, and June and August, 1980. During the 1980 sampling season, all nutrient contents tended to be higher in the clearcut area.

Organic matter contents showed a delayed response to clearcutting (Table 14). During June and August, 1979, there was no significant difference in H layer organic matter content between the clearcut and uncut areas. In November, 1979, however, the organic matter content of the uncut area was significantly greater than the clearcut area, 43.2% as compared to 34.5%. This same trend also occurred during June and August, 1980, but by November, 1980, no significant difference was detected between the two areas.

The C:N ratio, computed as the quotient of total organic carbon and total Kjeldahl nitrogen, was also used to compare the clearcut and uncut areas (Table 14). Although the ratio was higher in the clearcut area at all sampling dates, no significant differences were detected. The highest ratio in the clearcut area was recorded in August, 1979. During this sampling period the C:N ratio in the clearcut area was 27.7, while in the uncut area the ratio was 24.1.

Periodic comparisons between A_1 layer total nutrient contents at the various sampling dates yielded variable results (Table 15). The A_1 layer total N varied between clearcut and uncut areas and between sampling dates; however, no significant differences were noted. During August, 1979, only K, Ca, and Mg were noted as significantly greater in

Table 15. A_1 layer nutrient contents, pH, organic matter contents, and C:N ratios for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date		Clearcut	Uncut
		--------kg/ha------	
Jun 79	N	795a*	723a
	P	126b	142a
	K	2348a	2229a
	Ca	264a	249a
	Mg	893a	992a
	pH	3.8a	3.9a
	OM Content (%)	6.2a	4.9a
	C:N	21.4a	19.5a
Aug 79	N	950a	744a
	P	151a	136a
	K	3358a	2271b
	Ca	282a	214b
	Mg	1070a	869b
	pH	4.0a	3.8a
	OM Content (%)	6.5a	6.0a
	C:N	20.5a	22.0a
Nov 79	N	842a	836a
	P	152a	147a
	K	2653a	2229a
	Ca	285a	257a
	Mg	1024a	1053a
	pH	3.9a	3.8a
	OM Content (%)	5.6a	5.8a
	C:N	20.6a	22.8a
Jun 80	N	730a	917a
	P	145a	159a
	K	3183a	2640a
	Ca	290a	300a
	Mg	1212a	1086a
	pH	4.3a	4.1a
	OM Content (%)	4.3b	5.7a
	C:N	20.8a	19.6a

Table 15. A_1 layer nutrient contents, pH, organic matter contents, and C:N ratios for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia (continued).

Sampling Date		Clearcut	Uncut
		--------kg/ha------	
Aug 80	N	828a	914a
	P	145a	141a
	K	2766a	2688a
	Ca	297a	225b
	Mg	1141a	947a
	pH	4.2a	4.0b
	OM Content (%)	5.8a	5.6a
	C:N	21.2a	17.6a
Nov 80	N	812a	669a
	P	146a	131a
	K	2795a	2758a
	Ca	306a	218a
	Mg	1031a	1036a
	pH	4.2a	4.1a
	OM Content (%)	6.5a	4.6b
	C:N	22.3a	18.8a

*Means within a row with the same lower-case letter are not significantly different using the 0.5 level of the student's t test.

the clearcut than in the uncut area. Potassium was the only element that was consistently higher in the clearcut area at all sampling dates; however, a significant difference was determined only during August, 1979.

Soil pH was consistent throughout the two sampling seasons (Table 15). Following clearcutting, in August, 1979, the pH of the A_1 layer in the clearcut area was consistently greater than in the uncut area, but was significantly higher only during August, 1980, when values of 4.2 and 4.0 were recorded for the two areas, respectively.

The organic matter contents of the A_1 layer were extremely variable and generally not significantly different (Table 15). Significant differences were detected only for June and November, 1980. No significant differences in C:N ratios were detected between the two areas.

Comparisons of total dry weight between forest floor layers and between sampling dates within the clearcut and uncut areas are presented in Appendix Table 6 and Figures 5-7. In both the clearcut and uncut areas the greatest dry weight was contained within the H layer, followed by the F and L layers, respectively. During nearly every sampling date the three layers had significantly different weights. Within the clearcut area significant changes in layer biomass over time were noted only with the L layer. The L layer biomass increased from less than 100 kg/ha in June, 1979, to 9,500 kg/ha in August, 1979. In the uncut area the L layer was significantly higher in dry weight during November, 1979, and 1980.

Total N comparisons between forest floor layers and between sampling dates within the clearcut and uncut areas are presented in Appendix

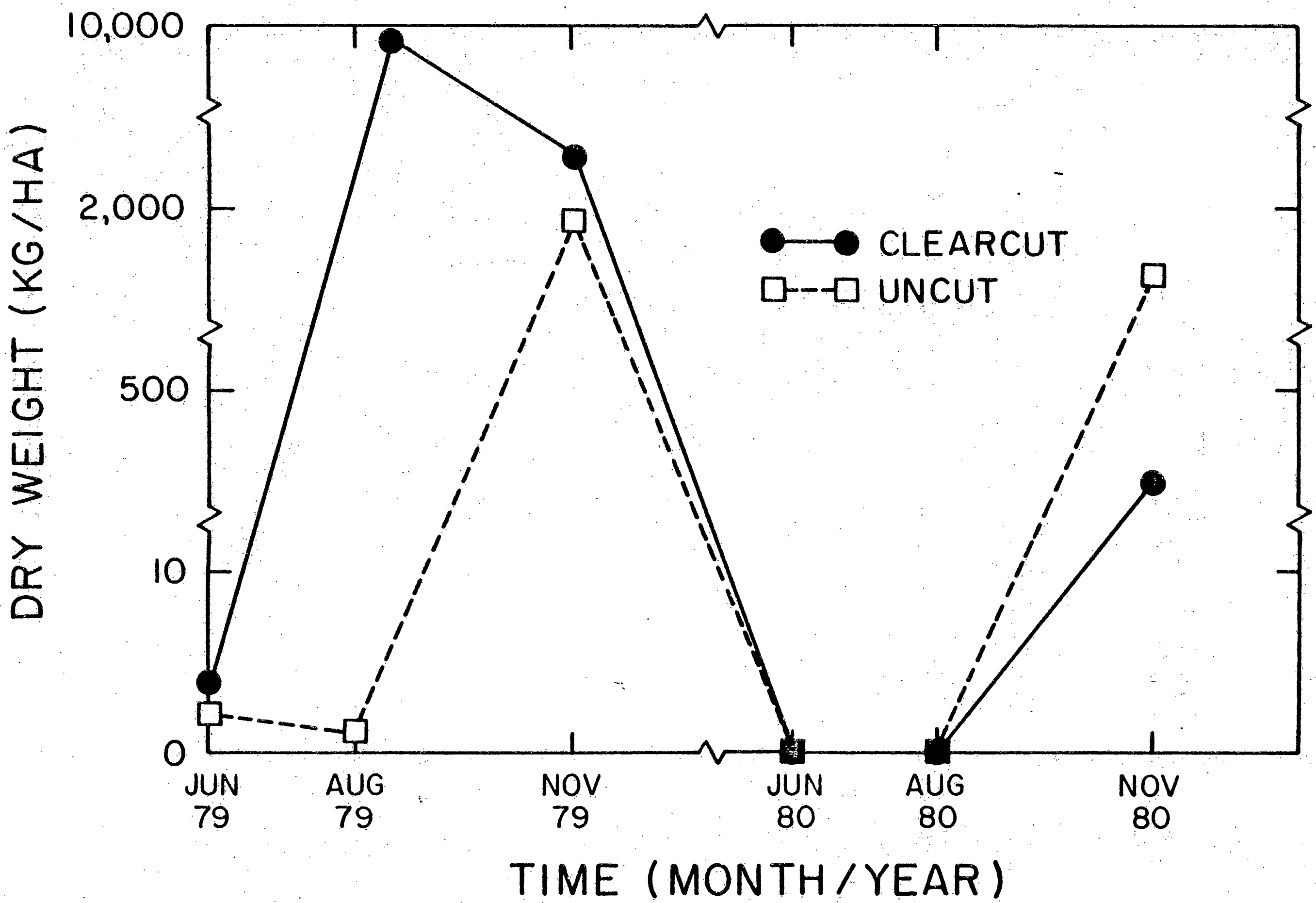

Figure 5. Dry weight of the L layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

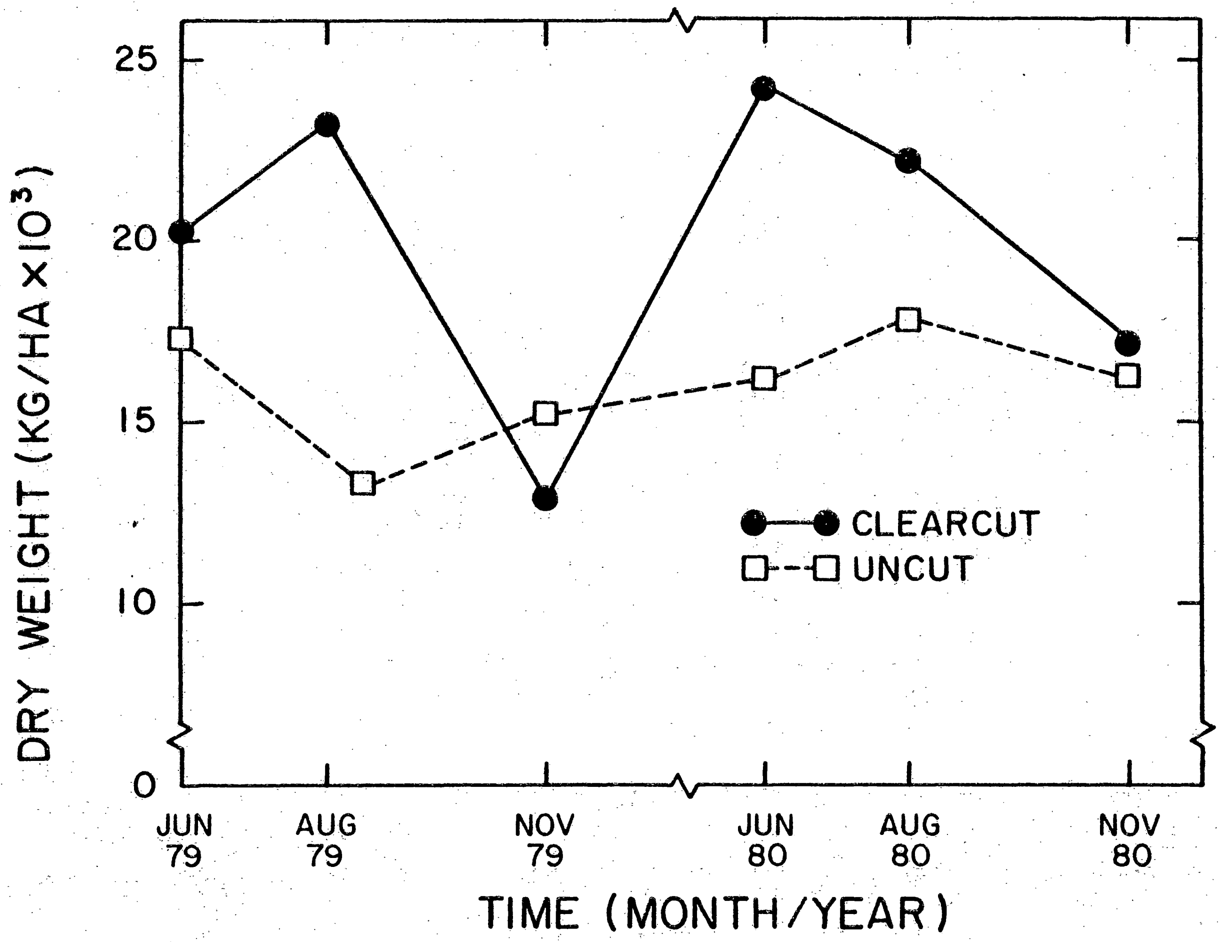

Figure 6. Dry weight of the F layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

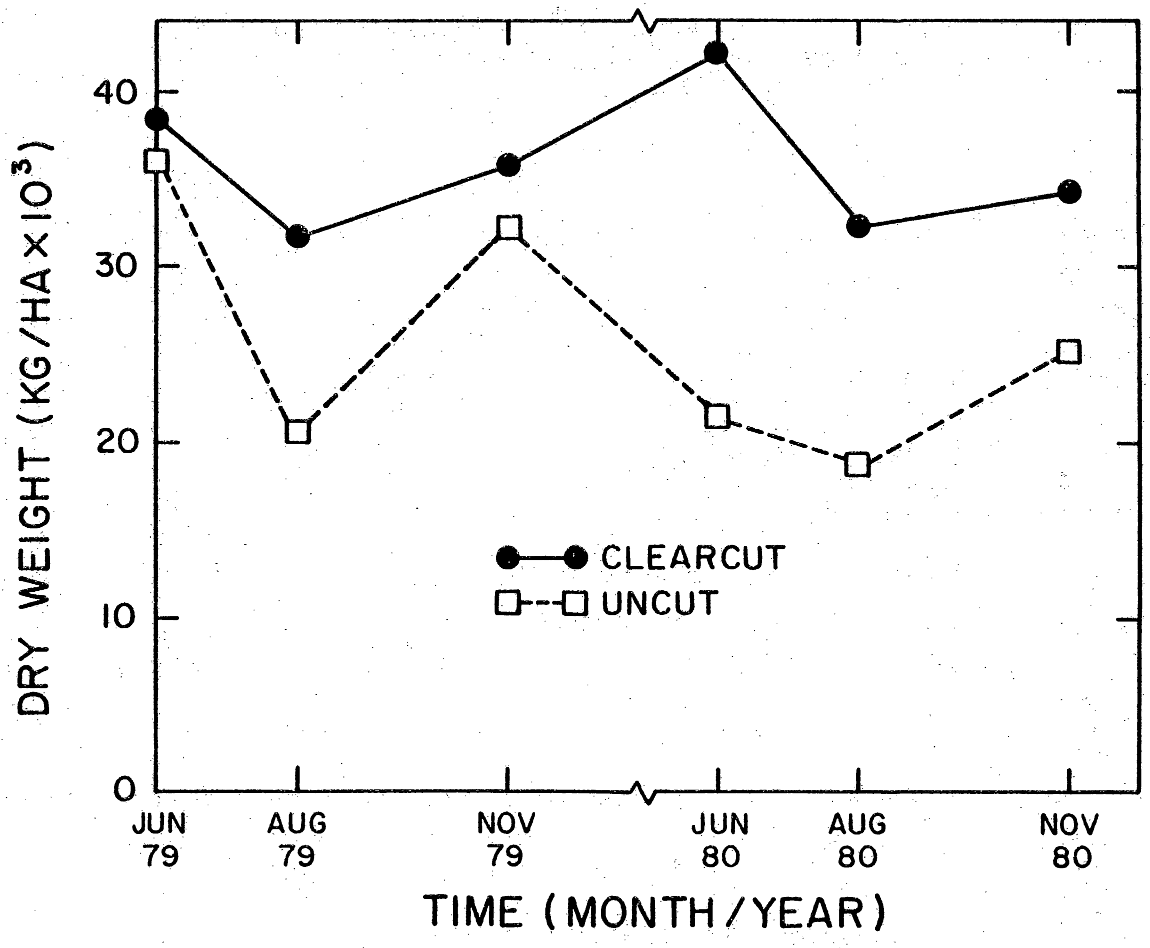

Figure 7. Dry weight of the H layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Table 7 and Figures 8-13. The A_1 layer consistently contained significantly greater amounts of total N across all sampling dates within both the clearcut and uncut areas (Appendix Table 7, Figures 12 and 13). With a few exceptions, the H layer in both the clearcut and uncut areas contained significantly more total N than the F or L layers, and the F layers contained more than the L layers (Figures 12 and 13). Within the clearcut area a significant increase in total N in the L layer was noted in August, 1979, when 52 kg/ha were recorded (Appendix Table 7, Figure 8). No significant differences were recorded over time in the H or A_1 layers of the clearcut area. In the uncut area the N content of the L layer was significantly greater during the November sampling dates (Figure 8). In the F layer, however, the smallest N contents were observed during the November sampling dates (Figure 9). Total N in the A_1 layer was highest in the uncut area during June, 1980, when 917 kg/ha were recorded. No significant differences were noted within the A_1 layer over time.

Comparisons of total P between forest floor layers and between sampling dates within the clearcut and uncut areas are presented in Table 16. The A_1 layer contained the largest amount of total P of all the forest floor layers, and this trend was consistent across all sample dates within both the clearcut and uncut areas. The relationships between the total P contents in the L, F, and H layers were not as well-defined. In all cases except August and November, 1980, in the uncut area, the H layers contained significantly more total P than the L layers; however, there were often no significant differences between total P contents in the L and F layers. In the clearcut area significant

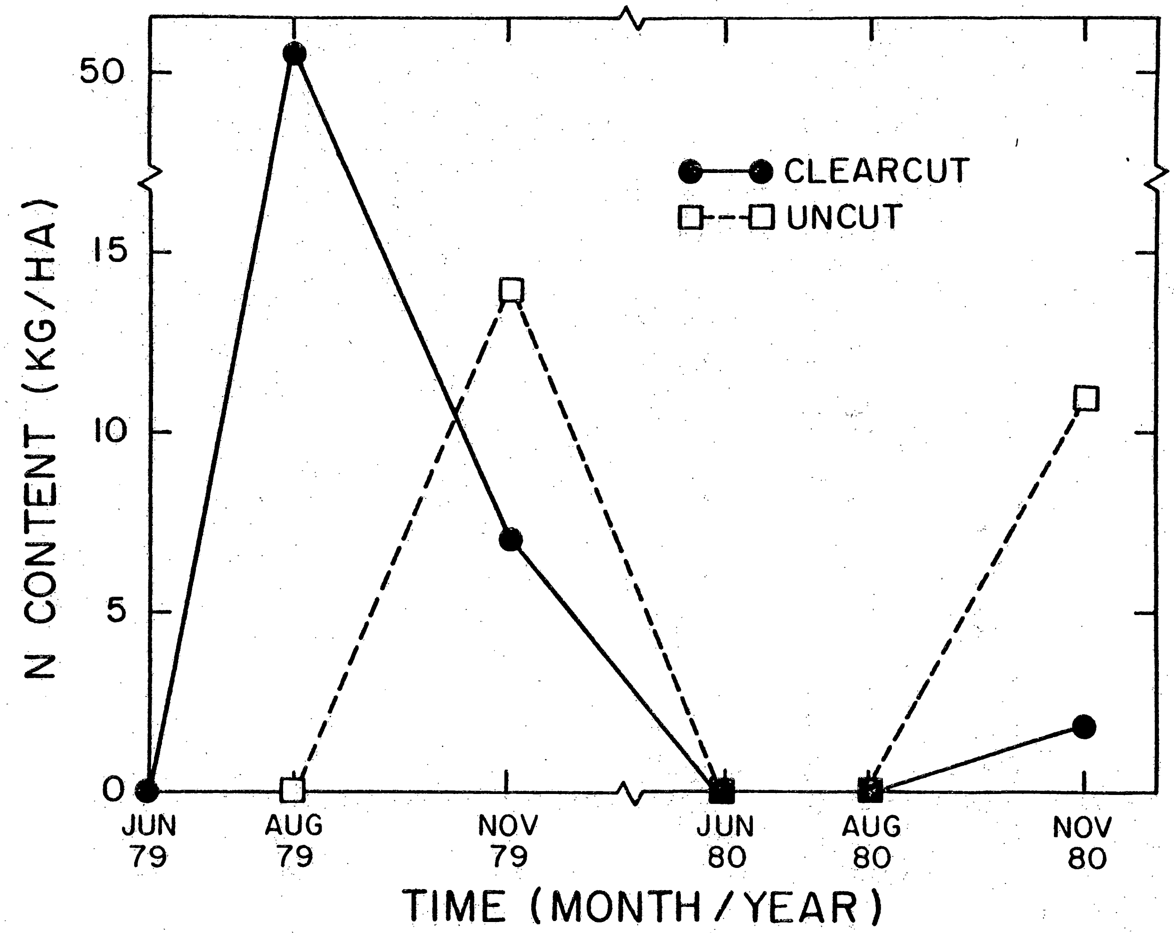

Figure 8. Total N content of the L layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

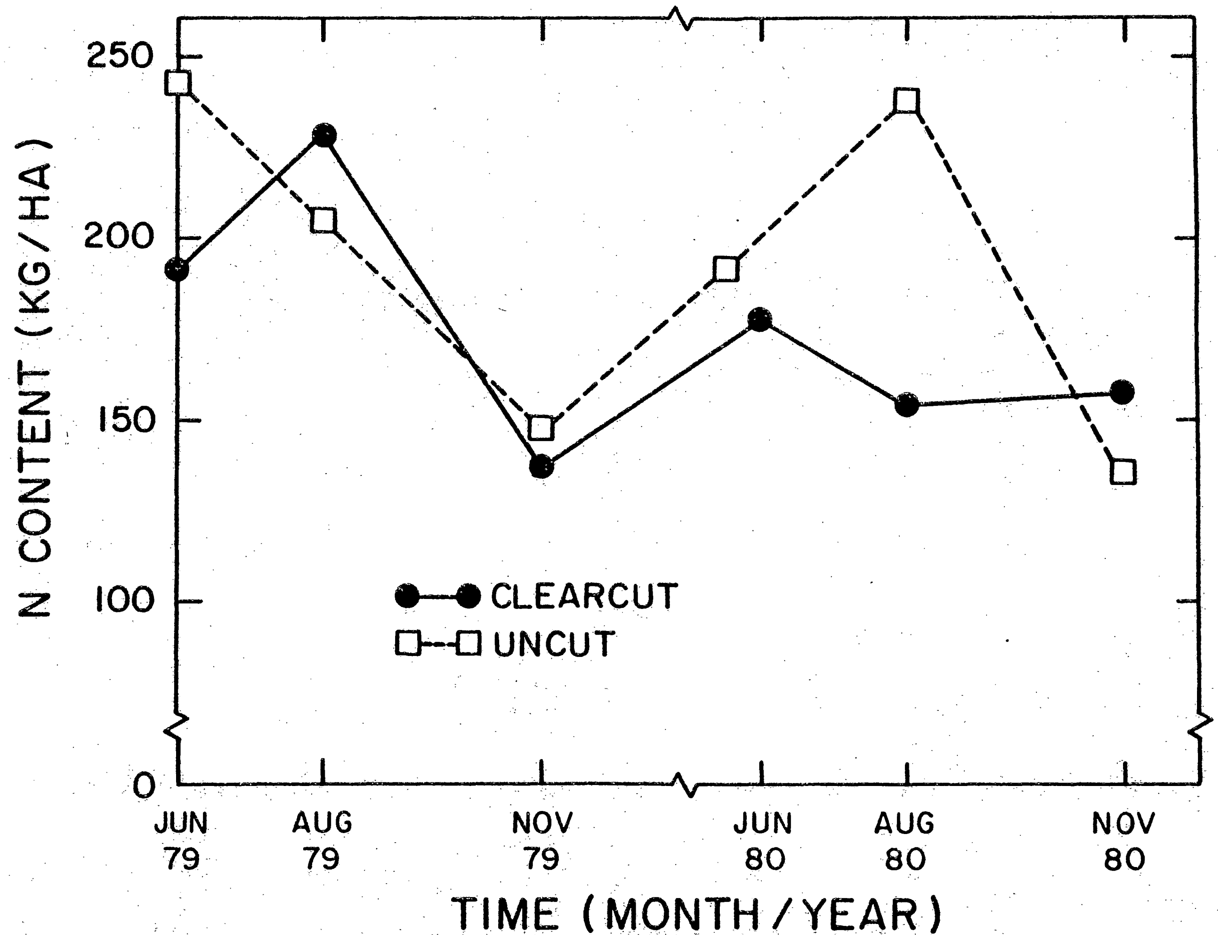

Figure 9. Total N content of the F layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

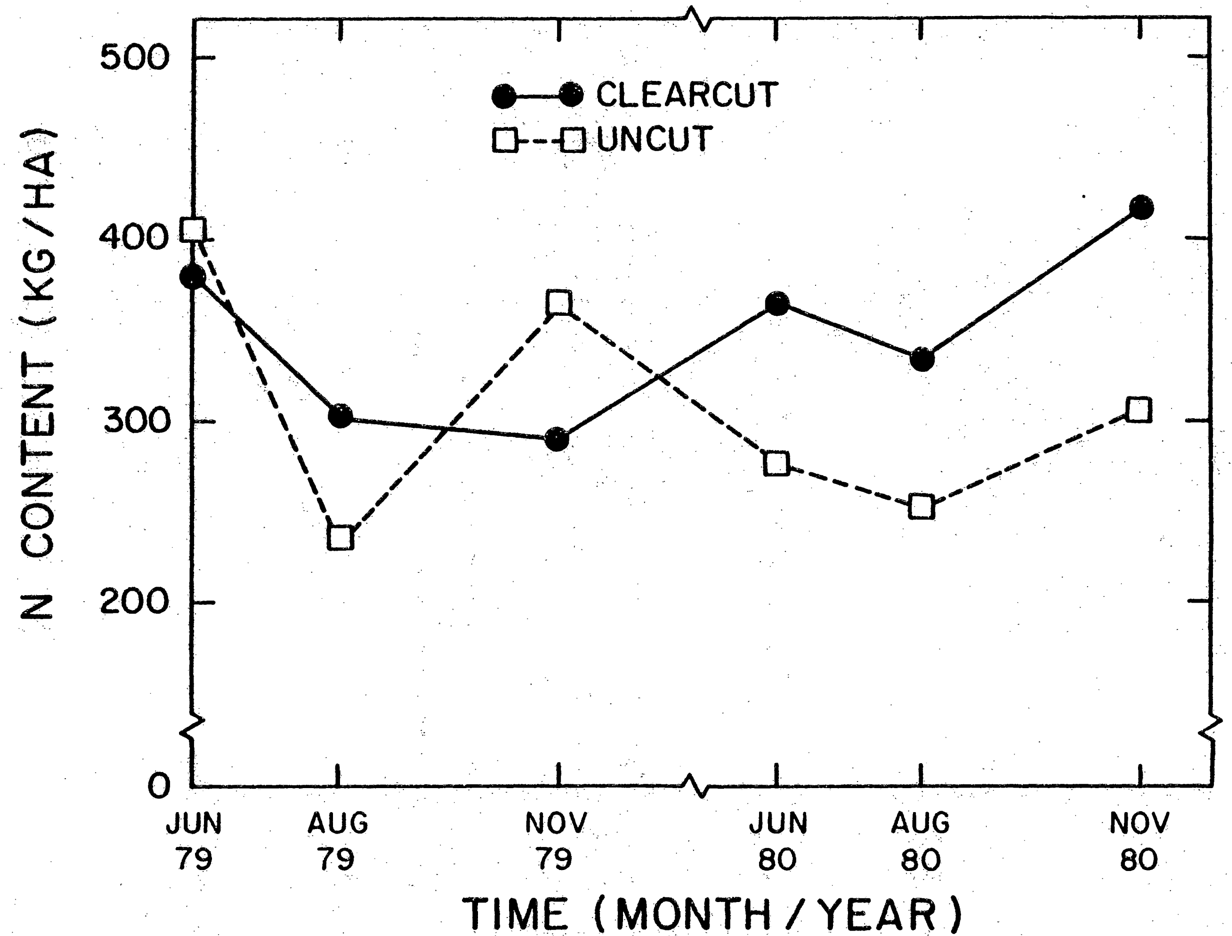

Figure 10. Total N content of the H layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

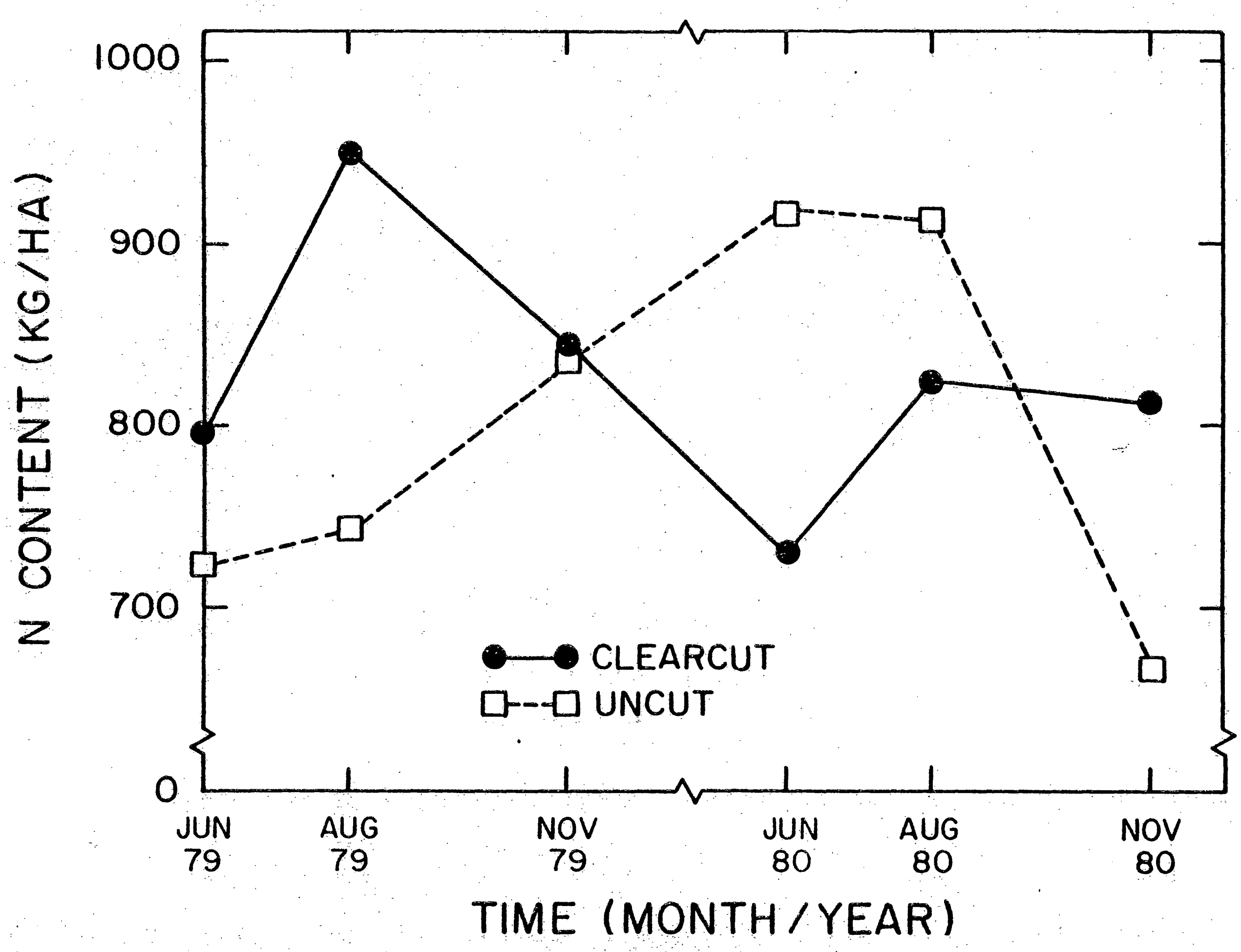

Figure 11. Total N content of the A_1 layer for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

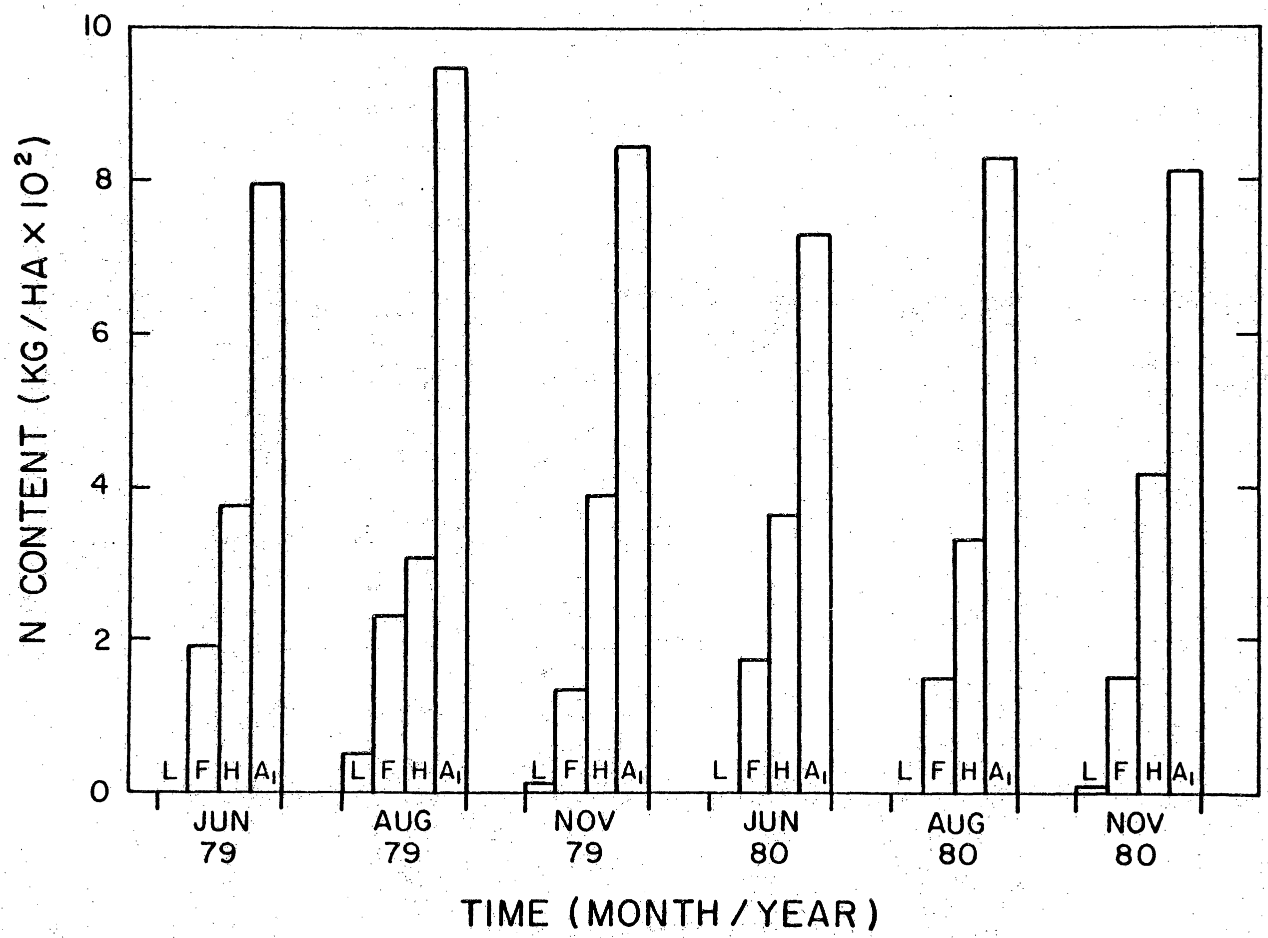

Figure 12. Comparison of total N contents between forest floor layers for six sampling dates. Data from the clearcut oak forest site, Price Mountain, Montgomery County, Virginia.

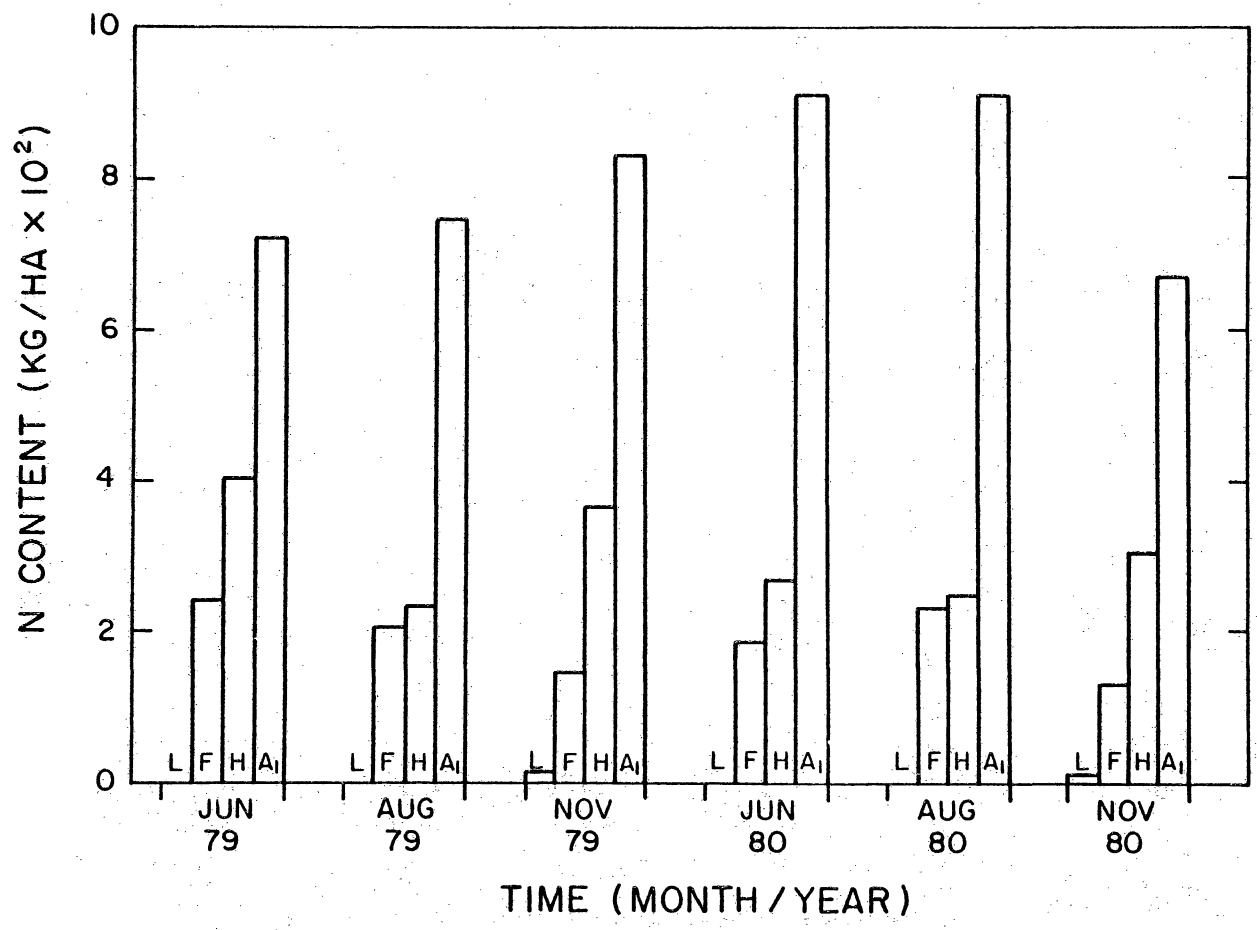

Figure 13. Comparison of total N contents between forest floor layers for six sampling dates. Data from the uncut oak forest site, Price Mountain, Montgomery County, Virginia.

Table 16. Total P in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total P							
	Clearcut				Uncut			
	L	F	H	A_1	L	F	H	A_1
	kg/ha							
Jun 79	00cB*	09cB	29bA	126aA	00dB	15cA	34bA	142aA
Aug 79	03cA	16bA	24bA	151aA	00cB	12bAB	18bBC	136aA
Nov 79	<1cB	07cB	21bA	152aA	1cA	11cB	26bB	147aA
Jun 80	00dB	08cB	28bA	145aA	00cB	10bcB	18bBC	159aA
Aug 80	00cB	08cB	23bA	145aA	00bB	11bB	16bC	141aA
Nov 80	<1cB	08cB	25bA	146aC	<1bA	09bB	21bBC	131aA

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences are determined using the 0.05 level of the Duncan's Multiple Range Test.

increases in total P were noted for the August, 1979, sampling date in both the L and F layers (Table 16). No significant differences occurred over time in either the H or A_1 layers in the clearcut area. In the uncut area significantly more total P was recorded for the November sampling dates in the L layer. No significant differences were noted in total P contents in the A_1 layers in the uncut area.

A comparison of total K between forest floor layers and between sampling dates within clearcut and uncut areas is presented in Table 17. Large amounts of total K were observed in the A_1 layer, and these were significantly greater than the amounts of total K found in the other layers in both the clearcut and uncut areas. Significant differences were not noted between the K contents of the L, F, and H layers in both the clearcut and uncut areas. Within the clearcut area, different trends were apparent in K contents between the various layers (Table 17). In the L layer a significant increase in total K was noted in August, 1979. In June, 1979, the K content of the L layer was 0 kg/ha, and in August, after clearcutting, the K content of the L layer increased to 18 kg/ha. In the H layer no increase in K was found from June to August, 1979. The A_1 layer showed the same increase in K between June and August, 1979, as the L and F layers. In the uncut area the K contents of the L and F layers were the greatest during the November sampling dates. In the H layer the highest K content, 63 kg/ha, was recorded during June, 1979. Significant differences in the H layer were not noted among the remaining sampling dates, nor were significant differences noted among sampling dates in the A_1 layer.

The total Ca comparisons between forest floor layers and between

Table 17. Total K in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total K							
	Clearcut				Uncut			
	L	F	H	A_1	L	F	H	A_1
	kg/ha							
Jun 79	00bB*	13bB	70bAB	2,348aB	00bC	13bAB	63bA	2,229aA
Aug 79	18bA	21bAB	70bAB	3,358aA	00bC	11bB	34bB	2,271aA
Nov 79	03bB	13bB	50bB	2,653aAB	07bA	16bA	36bB	2,229aA
Jun 80	00bB	28bA	101bA	3,183bAB	00bC	15bAB	28bB	2,640aA
Aug 80	00bB	20bAB	37bB	2,766aAB	00bC	15bAB	14bB	2,688aA
Nov 80	01bB	17bAB	59bAB	2,795aAB	04bB	18bA	40bAB	2,758aA

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

sampling dates within the clearcut and uncut areas are presented in Table 18. The A_1 layer was not as great a pool for Ca as it was for the other nutrients. Although the A_1 layer usually contained more Ca than the others, there were numerous instances where significantly greater amounts were not noted. For example, during June, 1979, in the clearcut area, the total Ca contents of the A_1, F, and H layers were, respectively, 264, 209, and 167 kg/ha. These values were not significantly different. In the clearcut area a significant increase in total Ca in the L layer was recorded from June to August, 1979 (Table 18). Total Ca increased from 0 to 84 kg/ha during this period. No significant differences were found over time in the F, H, or A_1 layers. In the L layer in the uncut area significantly higher amounts of Ca were found during the November sampling dates. Variable Ca contents were found in the F, H, and A_1 layers in the uncut area (Table 18).

Comparisons of total Mg contents between forest floor layers and between sampling dates for the clearcut and uncut areas are presented in Table 19. The highest amounts of Mg were found in the A_1 layers throughout all sampling dates in both the clearcut and uncut areas. Overall, the order of decreasing Mg concentration in the remaining layers was as follows: H > F > L. In most cases, however, significant differences were not noted between the Mg contents in these layers. Within the clearcut area, significantly greater amounts of Mg were recorded in the L and F layers during the August, 1979, sampling date than for most of the other sampling dates in those two layers (Table 19). No significant differences were found between the various sampling dates for the H layer. In the uncut area significantly greater quantities of

Table 18. Total Ca in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total Ca							
	Clearcut				Uncut			
	L	F	H	A_1	L	F	H	A_1
	kg/ha							
Jun 79	00bB*	209aA	167aA	264aA	00cB	295aA	174bA	249abAB
Aug 79	84cA	304abA	172bcA	282aA	00cB	233aAB	88bB	214aB
Nov 79	19cB	157bA	142bA	285aA	20dA	197bB	152cAB	257aAB
Jun 80	00bB	245aA	206aA	290aA	00cB	220abAB	159bAB	300aA
Aug 80	00bB	279aA	189aA	297aA	00cB	244aAB	105bAB	225aB
Nov 80	03cB	202bA	186bA	306aA	18bA	199aB	171aA	218aB

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Table 19. Total Mg in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total Mg							
	Clearcut				Uncut			
	L	F	H	A_1	L	F	H	A_1
	kg/ha							
Jun 79	00cB*	12bcAB	52bA	893aB	00bB	15bA	53bA	992aA
Aug 79	04bA	18bA	52bA	1,070aAB	00bB	12bA	30bB	869aA
Nov 79	01bB	08bB	59bA	1,024aAB	02bA	11bA	50bA	1,053aA
Jun 80	00bB	11bAB	68bA	1,212aA	00bB	11bA	30bB	1,086aA
Aug 80	00bB	10bB	55bA	1,141aAB	00bB	14bA	24bB	947aA
Nov 80	<1bB	11bAB	57bA	1,031aAB	02bA	12bA	38bAB	1,036aA

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Mg were recorded during the November sampling dates for the L layer. No significant differences in Mg contents for the F layers were evident; however, for the H layers significantly greater Mg contents were recorded for June and November, 1979. No significant differences were noted in Mg content for the A_1 layers in the uncut area.

Comparisons of forest floor layer depths between sampling dates within clearcut and uncut areas are presented in Table 20. The F and H layer depths were generally greater than the L layer depths in both the clearcut and uncut areas; however, during the November sampling dates in the uncut area no significant differences were noted between the three layers. As an example, in November, 1979, in the uncut area the respective depths for the L, F, and H layers were 2.6, 2.9, and 3.3 cm. Within the clearcut area the L layer remained largely nonexistent, with the exception of November, 1980, when a slight 0.2 cm depth was recorded (Table 20). For the F and H layers a generally decreasing trend was noted from June, 1979, through August, 1980. The values for November, 1980, were slightly higher than August, but still significantly below June, 1979. In the uncut area significant L layer depths were recorded only for the November sampling dates. The smallest depths in the F and H layers were found during the August sampling dates, while the greatest depths were found in November, 1979.

Comparisons of organic matter contents between the H and A_1 layers and across sampling dates within the clearcut and uncut areas are presented in Table 21. The organic matter contents of the H layers were significantly greater than the A_1 layers during all sampling dates in both the clearcut and uncut areas. The values for the H layer ranged

Table 20. Depths of forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Depth					
	Clearcut			Uncut		
	L	F	H	L	F	H
	cm					
Jun 79	0.1cB*	4.4aA	2.9bA	0.1bB	2.8aA	2.9aAB
Aug 79	0.1bB	2.5aB	2.6aAB	0.1bB	2.3aAB	1.7aC
Nov 79	0.1bB	2.1aBC	2.2aABC	2.6aA	2.9aA	3.3aA
Jun 80	0.0bB	2.1aBC	2.4aABC	0.0bB	2.7aA	2.7aB
Aug 80	0.0bB	1.3aC	1.7aC	0.0bB	1.8aB	1.4aC
Nov 80	0.2bA	1.5aC	2.1aBC	3.2aA	2.7aA	3.2aB

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Table 21. Organic matter contents of H and A_1 forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Organic Matter Content			
	Clearcut		Uncut	
	H	A_1	H	A_1
	------------------ % ------------------			
Jun 79	49.4aA*	6.2bA	48.7aAB	4.9bAB
Aug 79	48.5aAB	6.5bA	49.4aAB	6.0bA
Nov 79	34.5aC	6.0bA	43.2aB	5.8bAB
Jun 80	38.4aC	4.3bB	50.5aA	5.7bAB
Aug 80	41.1aBC	5.8bA	50.1aAB	5.6bAB
Nov 80	42.2aABC	6.5bA	44.9aAB	4.6bB

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

from 34.5 to 50.0%, while those for the A_1 layer ranged from 4.3 to 6.5%. The organic matter content of the H layer in the clearcut area was at a maximum in June, 1979, then declined to a low of 34.5% during November, 1979. Significant differences in organic matter content in the A_1 layer in the clearcut area were not noted, with the exception of a low of 4.3% recorded in June, 1980 (Table 21).

Comparisons of C:N ratios between the H and A_1 layers and across sampling dates within the clearcut and uncut areas are presented in Table 22. Significant differences were found only during the August, 1979, sampling date in the clearcut area and the June, 1979, sampling date in the uncut area. Within the clearcut area no significant differences in C:N ratio were evident over time in either the H or A_1 layers (Table 22). In the H layer within the uncut area a decreasing trend was noted as the C:N ratio dropped from a high of 24.6 in June, 1979, to a low of 20.6 in November, 1980. No significant differences in C:N ratio were observed over time in the A_1 layer of the uncut area.

A comparison of A_1 layer pH over time in the clearcut and uncut areas is presented in Table 23. In the clearcut area the pH observed for the 1980 sampling season was significantly higher than for the 1979 sampling season. No significant changes were noted within either of the two sampling seasons. A similar trend occurred in the uncut area; however, it was not as well-defined. The pH recorded for August and November, 1980, was 4.0 and 4.1, respectively, and these did not differ significantly from the 3.9 recorded for June, 1979, in the uncut area.

Table 22. Carbon:nitrogen ratios in H and A_1 forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	C:N Ratio			
	Clearcut		Uncut	
	H	A_1	H	A_1
Jun 79	27.2aA*	21.4aA	24.6aA	19.5bA
Aug 79	27.7aA	20.5bA	24.1aAB	22.0aA
Nov 79	23.3aA	20.6aA	22.8aABC	21.7aA
Jun 80	24.9aA	20.8aA	21.7aABC	19.6aA
Aug 80	21.8aA	21.2aA	20.9aBC	17.6aA
Nov 80	22.3aA	22.1aA	20.6aC	18.8aA

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Table 23. A_1 layer pH between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Clearcut	Uncut
	-----------pH-----------	
Jun 79	3.8B*	3.9BC
Aug 79	4.0B	3.8C
Nov 79	3.9B	3.8C
Jun 80	4.3A	4.1A
Aug 80	4.2A	4.0ABC
Nov 80	4.2A	4.1AB

*Means within a column with the same uppercase letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Soil Solution Nutrient Dynamics

Comparisons of soil solution pH between clearcut and uncut areas and sampling dates for both 15 and 30 cm depths are presented in Table 24. No significant differences were found between the clearcut and uncut areas at either depth. Within the clearcut area, the soil solution pH at a depth of 15 cm was much less variable than at the 30 cm depth. For example, at the 15 cm depth only the pH recorded on April 10 and May 15, 4.01 and 3.94, respectively, were significantly lower than the remaining sample dates (Table 24). In the uncut area, soil solution pH also varied throughout the year. At the 15 cm depth a high value of 6.07 was recorded on May 29, while low values of 4.04 and 4.26 were reported on April 10 and May 15, respectively (Table 24). Similar high and low pH were also recorded at the 30 cm depth in the uncut area.

Comparisons of 15 and 30 cm soil solution NH_4-N concentrations between sampling dates and between clearcut and uncut areas are presented in Appendix Table 8 and Figures 14 and 15. Ammonium-nitrogen concentrations in the clearcut area soil solution were consistently greater than in the uncut area. The highest concentration in the clearcut area, recorded at the 15 cm depth on May 1, was 2.84 ppm, which was significantly greater than the 1.83 ppm recorded on the same date in the uncut area (Appendix Table 8 and Figure 14). At the 30 cm depth on the same date, 2.19 and 2.13 ppm were noted for the clearcut and uncut areas, respectively (Appendix Table 8 and Figure 15). Within the clearcut area the lowest concentrations of NH_4-N were observed from July through March, while significantly higher concentrations were observed during May. Similar trends occurred at the 15 and 30 cm depths. In the uncut

Table 24. Soil solution pH for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	pH 15 cm Clearcut	pH 15 cm Uncut	pH 30 cm Clearcut	pH 30 cm Uncut
10 Apr 80	4.01aB*	4.04aE	4.05aD	4.03aD
01 Apr 80	5.35aA	5.03aCD	4.98aBCD	5.11aBC
15 May 80	3.94aB	4.26aE	4.44aD	4.10aD
29 May 80	5.56aA	6.07aA	5.48aABC	5.86aA
18 Jun 80	6.20A	---**	5.37ABC	---
02 Jul 80	---	---	5.57ABC	---
17 Jul 80	---	---	5.32ABC	---
30 Jul 80	5.70aA	5.20aBCD	5.61aAB	5.85aAB
26 Aug 80	---	---	5.20ABCD	---
20 Oct 80	4.90AB	---	---	---
12 Nov 80	5.70A	---	---	---
03 Dec 80	5.75aA	5.95aAB	5.58AB	---
06 Feb 81	---	---	5.15ABCD	---
20 Feb 81	5.08aA	4.83aD	4.81aCD	4.84aC
05 Mar 81	5.20aA	5.04aCD	5.00aBCD	4.85aC
17 Mar 81	5.88aA	5.69aAB	5.83aA	5.78aAB
31 Mar 81	5.74aA	5.44aBC	5.50aABC	5.53aAB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

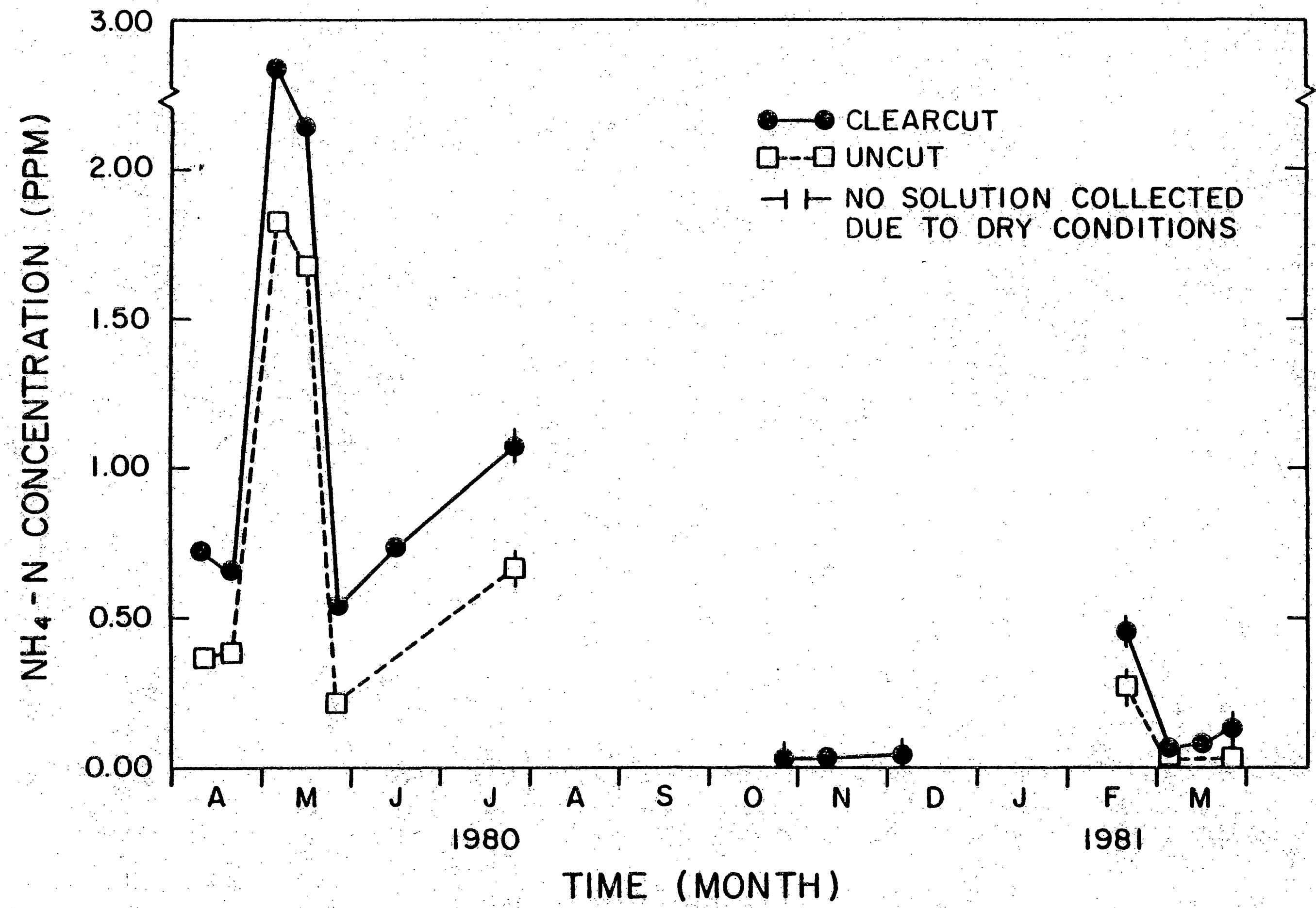

Figure 14. Soil solution NH_4-N concentration at a depth of 15 cm for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

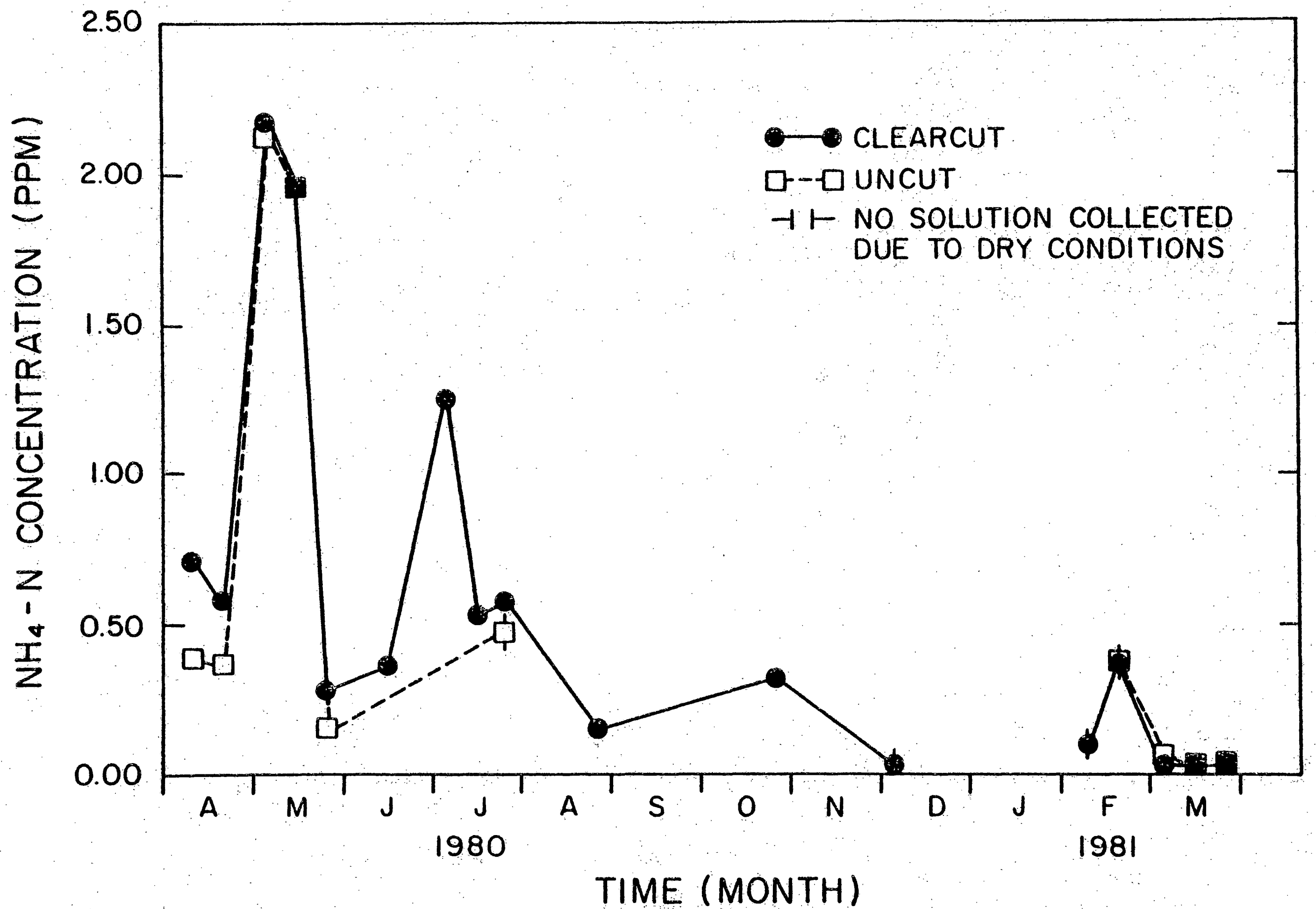

Figure 15. Soil solution NH_4-N concentration at a depth of 30 cm for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

area, the highest NH_4-N concentrations were also recorded during May, with intermediate concentrations found for April, and lowest concentrations recorded during March.

Fifteen and 30 cm soil solution NO_3-N concentrations between sampling dates and between clearcut and uncut areas are presented in Appendix Table 9 and Figures 16 and 17. Significant differences in soil solution NO_3-N concentrations were recorded between the clearcut and uncut areas only for the March sampling dates and only at the 15 cm depth (Appendix Table 9, Figure 16). At the 15 cm depth in the clearcut area no significant differences were found in soil solution NO_3-N concentration from April through December; however, the February through March concentrations were significantly higher. Few significant differences were found in the uncut area; however, the highest concentrations at the 15 and 30 cm depths, 0.88 and 0.73 ppm, respectively, were recorded on February 20.

Soil solution P concentrations for 15 and 30 cm depths are presented in Table 25. Very low concentrations of P were observed; from December through March no soil solution P was detected in either the clearcut or uncut area. In the clearcut area the highest concentration of P was recorded on October 29; 1.15 and 0.49 ppm were recorded for the 15 and 30 cm depths, respectively. In the uncut area the highest P concentrations occurred during the April sampling dates.

The comparisons of soil solution K between sampling dates and between clearcut and uncut areas for 15 and 30 cm depths are presented in Table 26. Significant differences in the clearcut area were noted in April and May at both depths, and in March at the 30 cm depth. The

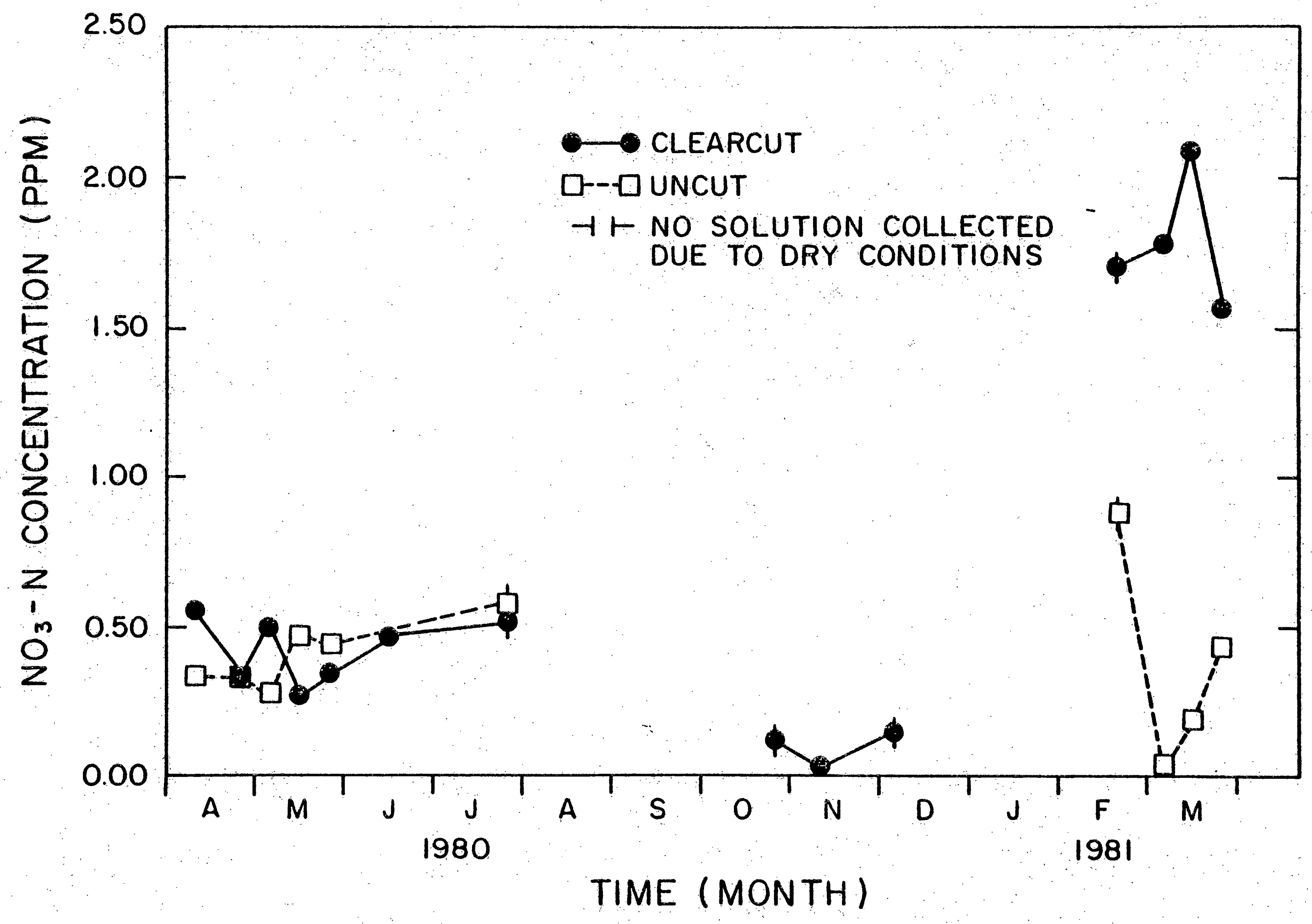

Figure 16. Soil solution NO_3-N concentration at a depth of 15 cm for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

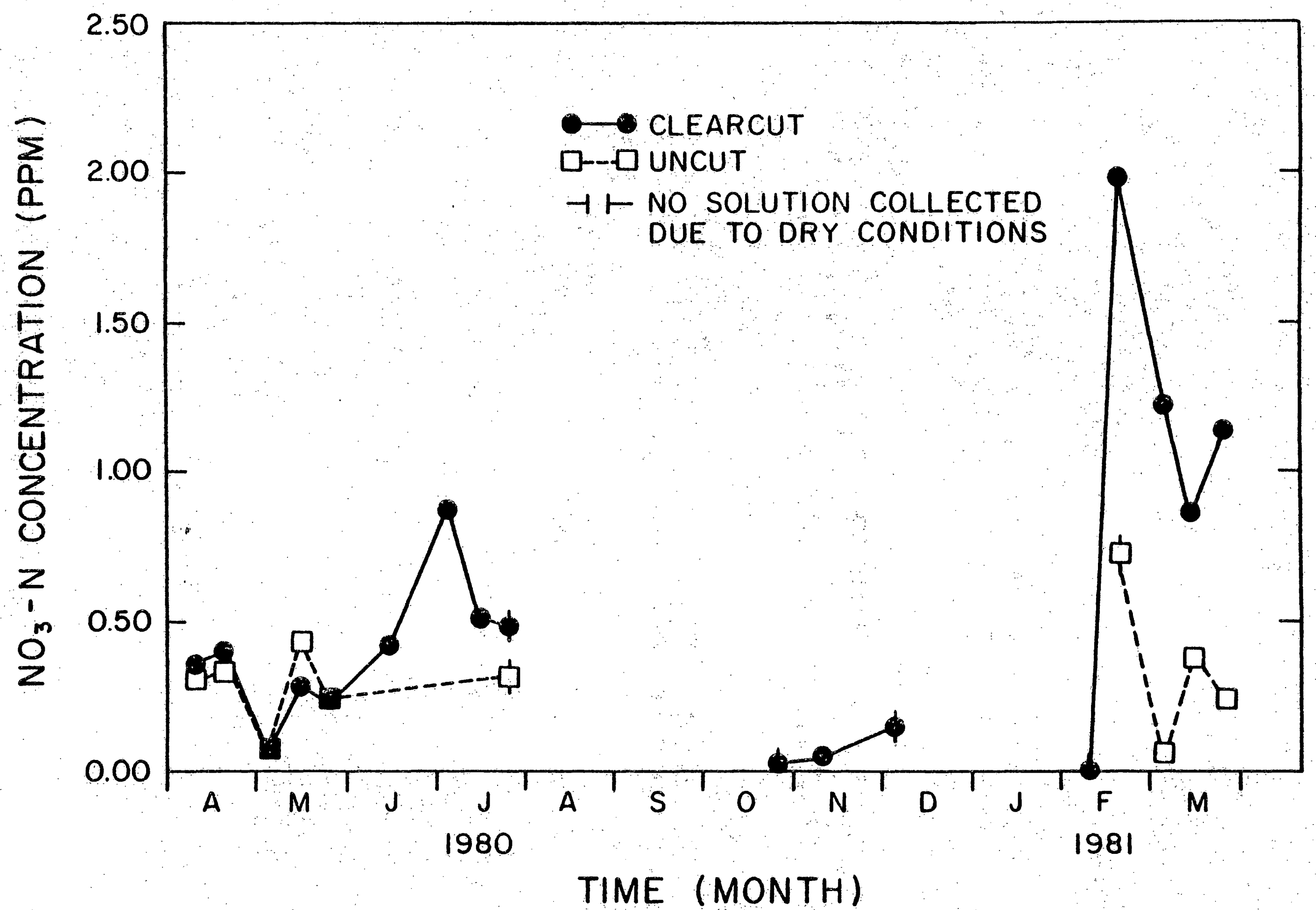

Figure 17. Soil solution NO_3-N concentration at a depth of 30 cm for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Table 25. Soil solution P concentration for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	P Concentration			
	15 cm		30 cm	
	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	0.03aC*	0.02aA	0.01aC	0.02aA
17 Apr 80	0.03aC	0.02aA	0.02aC	0.02aA
01 May 80	0.01aD	0.01aB	<0.01bC	0.01aB
15 May 80	<0.01aD	<0.01aC	0.01C	---
29 May 80	0.01aD	<0.01bC	<0.01aC	<0.01aBC
18 Jun 80	0.01D	---**	---	---
02 Jul 80	---	---	0.14B	---
17 Jul 80	---	---	0.03C	---
30 Jul 80	0.03C	---	0.03C	---
26 Aug 80	---	---	0.02C	---
29 Oct 80	1.15A	---	0.49A	---
12 Nov 80	0.94B	---	---	---
03 Dec 80	<0.01D	---	<0.01C	---
06 Feb 81	---	---	<0.01C	---
20 Feb 81	<0.01aD	<0.01aC	<0.01aC	<0.01aC
05 Mar 81	<0.01aD	<0.01aC	<0.01aC	<0.01aC
17 Mar 81	<0.01aD	<0.01aC	<0.01aC	<0.01aC
31 Mar 81	<0.01aD	<0.01aC	<0.01aC	<0.01aC

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

Table 26. Soil solution K concentration for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	K Concentration			
	15 cm		30 cm	
	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	5.28aA*	2.39aBC	3.24aA	2.41aA
17 Apr 80	2.80aB	1.78bCD	2.68aAB	1.76bBC
01 May 80	2.84aB	1.67bD	2.68aAB	1.54bBC
15 May 80	1.86aB	1.52aD	1.97aBC	1.12bCD
29 May 80	1.97aB	1.40aD	1.76aBC	0.52bD
18 Jun 80	2.50B	---**	1.65BC	---
02 Jul 80	---	---	2.23BC	---
17 Jul 80	---	---	1.55C	---
30 Jul 80	2.19bB	2.90aAB	2.62aAB	2.34aAB
26 Aug 80	---	---	2.21BC	---
29 Oct 80	0.95B	---	1.79BC	---
12 Nov 80	1.73B	---	---	---
03 Dec 80	2.60aB	3.37aA	2.89AB	---
06 Feb 81	---	---	1.79BC	---
20 Feb 81	2.66aB	2.10aBCD	2.07aBC	1.56aBC
05 Mar 81	2.40aB	1.71aD	2.01aBC	1.23bC
17 Mar 81	2.00aB	1.62aD	1.98aBC	1.30aC
31 Mar 81	2.95aB	2.06aBCD	2.26aBC	1.64aBC

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

highest K concentration, 5.28 ppm, was observed on April 10 in the clearcut area, while the lowest concentration, 0.52 ppm, was recorded on May 29 in the uncut area. In the uncut area, the highest K concentrations were recorded in April, July, and December. At the 15 cm depth the highest concentration, 3.37 ppm, was recorded on December 3, while at the 30 cm depth the high concentration of 2.41 ppm was noted on April 10.

Comparisons of soil solution Ca between sampling dates and between clearcut and uncut areas for 15 and 30 cm depths are presented in Table 27. No significant differences in soil solution Ca were noted between clearcut and uncut areas at either the 15 or 30 cm depth. During portions of the year the Ca concentration was higher in the uncut area, and at other times the reverse occurred. Within the clearcut area the highest concentrations at both depths occurred in April; however, only slightly lower concentrations were recorded in the sampling period from December through March. Similar trends occurred at both depths in the uncut area.

Fifteen and 30 cm soil solution Mg concentrations between sampling dates and between clearcut and uncut areas are presented in Table 28. Only on April 10 at the 30 cm depth were the uncut area soil solution Mg concentrations significantly greater than in the clearcut area. The concentrations for this sampling date were 5.27 ppm for the uncut area and 3.52 ppm for the clearcut area (Table 34). At all other sampling dates no significant differences were found. Within the clearcut area the highest Mg concentrations were found during the April sampling dates. The same trend also occurred in the uncut area. Magnesium concentrations

Table 27. Soil solution Ca concentration for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

	Ca Concentration			
	15 cm		30 cm	
Sampling Date	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	11.06aA*	9.37aA	8.11aA	10.85aA
17 Apr 80	8.86aAB	6.83aB	5.83aAB	6.28aB
01 May 80	6.04aBCD	5.35aBC	5.79aAB	4.88aBC
15 May 80	3.07aCD	3.98aC	3.39aB	3.11aC
29 May 80	3.95aCD	4.17aC	3.10aB	2.66aC
18 Jun 80	4.69BCD	---**	3.78B	---
02 Jul 80	---	---	4.54AB	---
17 Jul 80	---	---	3.63B	---
30 Jul 80	2.47aD	4.52aBC	3.12aB	3.60aC
26 Aug 80	---	---	3.10B	---
29 Oct 80	5.04BCD	---	5.25AB	---
12 Nov 80	4.10BCD	---	---	---
03 Dec 80	6.42aBCD	6.72aBC	5.41AB	---
06 Feb 81	---	---	4.34B	---
20 Feb 81	7.52aBC	5.21aBC	5.59aAB	4.34aC
05 Mar 81	6.52aBCD	5.58aBC	5.52aAB	4.21aC
17 Mar 81	5.36aBCD	5.25aBC	4.34aB	4.87aBC
31 Mar 81	6.40aBCD	5.11aBC	5.60aAB	4.18aC

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

Table 28. Soil solution Mg concentration for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Mg Concentration			
	15 cm		30 cm	
	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	4.30aA*	4.64aA	3.52bA	5.27aA
17 Apr 80	2.84aB	3.38aB	3.19aA	3.21aB
01 May 80	1.60aBC	1.61aC	1.72aBC	1.74aCD
15 May 80	0.98aBC	0.84aC	1.21aBC	0.86aD
29 May 80	0.78aC	0.94aC	1.18aBC	0.90aD
18 Jun 80	1.24BC	---**	1.08BC	---
02 Jul 80	---	---	0.96C	---
17 Jul 80	---	---	0.98C	---
30 Jul 80	0.83aBC	0.99aC	1.03aC	1.01aCD
26 Aug 80	---	---	0.75C	---
29 Oct 80	2.10BC	---	0.84C	---
12 Nov 80	2.94AB	---	---	---
03 Dec 80	1.82aBC	1.90aC	1.68BC	---
06 Feb 81	---	---	1.95BC	---
20 Feb 81	1.96aBC	1.68aC	2.08aB	2.09aC
05 Mar 81	1.76aBC	1.88aC	2.16aB	2.26aC
17 Mar 81	1.79aBC	1.99aC	1.93aBC	1.97aCD
31 Mar 81	1.71aBC	1.66aC	2.11aB	2.16aC

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

in the clearcut area ranged from 4.30 ppm, at a depth of 15 cm, on April 10, to 0.75 ppm, at a depth of 30 cm, on August 26.

Soil Temperature and Moisture Dynamics

Soil temperatures between sampling dates and between clearcut and uncut areas are presented in Appendix Table 10 and Figure 18. Throughout most of the year the soil temperatures recorded for the clearcut area were significantly higher than the uncut area. The only exception occurred on February 20, when the soil temperature recorded for the uncut area was 7.5°C, which was significantly higher than the 4.7°C recorded for the clearcut area. The greatest differences in temperature between the two areas were recorded during July and August. On July 17 the temperatures recorded in the uncut and clearcut areas were 26.7 and 33.9°C, respectively (Appendix Table 10). Within both the clearcut and uncut areas, increases in temperature were noted from April through July, with subsequent declines thereafter (Figure 18). The highest temperatures were recorded in both areas in July, and the lowest in January and February. On February 6, the temperatures recorded in the clearcut and uncut areas were, respectively, -1.2 and -0.1°C.

Soil moisture (expressed as percent of oven-dry weight) comparisons between sampling dates for clearcut and uncut areas are presented in Appendix Table 11 and Figure 19. From March through early May the soil moisture recorded in the clearcut area was less than in the uncut area; however, for the remainder of the year the opposite occurred. On numerous occasions the soil moisture in the clearcut area was significantly higher than in the uncut area. For example, on July 2 the soil moisture recorded in the clearcut area was 28%, while that recorded in the uncut

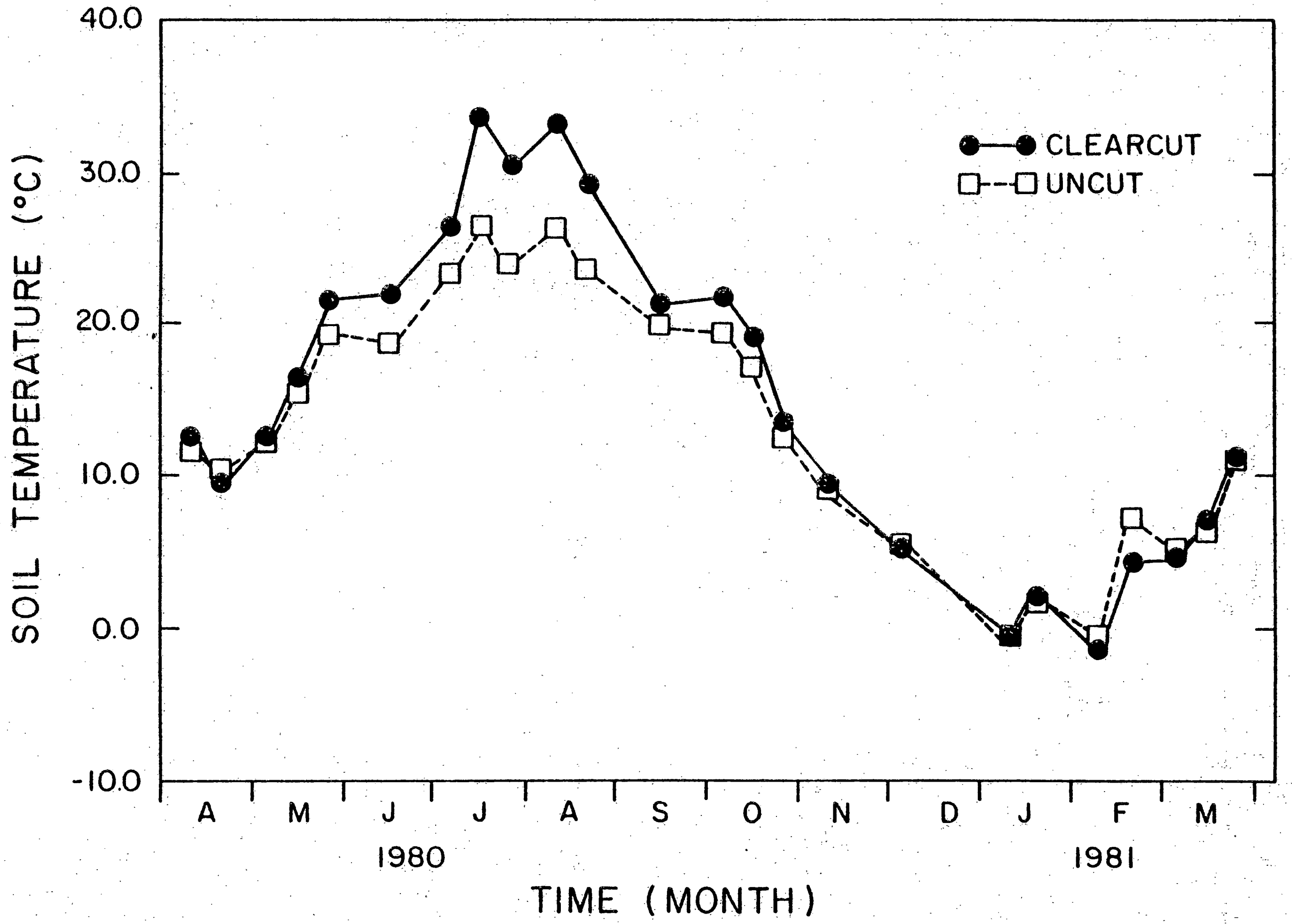

Figure 18. Soil temperatures for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

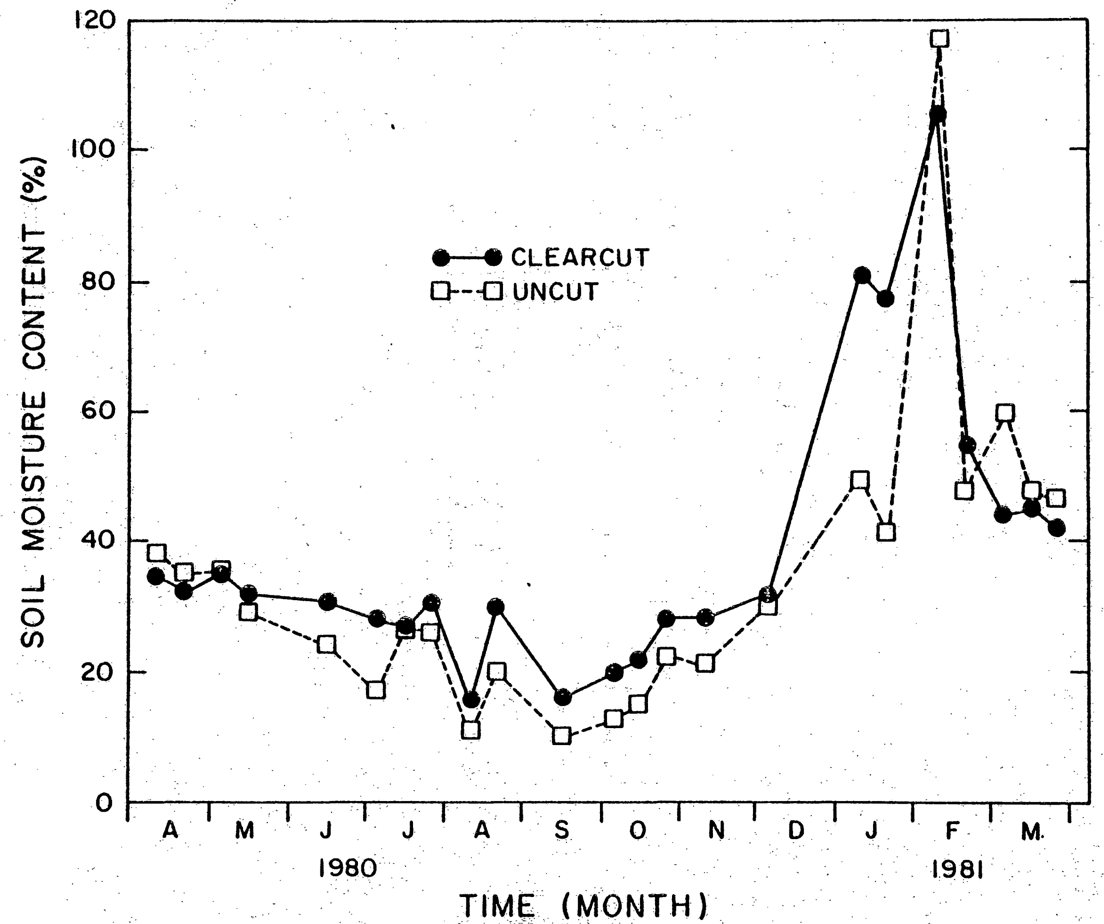

Figure 19. Soil moisture content for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

area was 17%, a significant difference (Appendix Table 11). The highest moisture contents in both areas were recorded when the ground was frozen in January and February, and the lowest moisture contents were recorded during August and September (Figure 19). The highest moisture content recorded in the clearcut area was 106%, on February 6, while the lowest moisture content, 16% was recorded on August 14 and September 16. Extremes in the uncut area were recorded on the same dates as the clearcut area, 117% and 11%, respectively.

Precipitation

Monthly precipitation for the period of January, 1979, through March, 1981, is presented in Appendix Table 12. The normal annual precipitation is 101.6 cm. The data in Appendix Table 12 show that 1979 was about 10 cm above normal, while 1980 was about 10 cm below. The precipitation during 1979 was better distributed throughout the year than in 1980, when 20.2 cm of rain fell in July. The precipitation for the first three months of 1981 was below normal. During this period 14.2 cm were recorded, as compared to 23.4 and 31.0 cm for the same periods during 1980 and 1979, respectively.

Microbiological Characterization

The results of the microbiological characterization are presented in Table 29. Bacteria were the most numerous microorganisms in both the clearcut and uncut areas, followed by actinomycetes and fungi. Actinomycetes and bacteria were more numerous in the clearcut area, while fungi were more plentiful in the uncut area. The denitrifying microorganisms were more common in the clearcut area; 1.0×10^4 organisms per gram of soil recorded as compared to 9.0×10^2 organisms per gram

Table 29. Number of organisms per gram of oven-dry soil from clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Organism	Clearcut	Uncut
	---No./g OD soil x 10^4---	
Actinomycetes	130.0	70.0
Fungi	3.0	4.0
Bacteria	150.0	120.0
Denitrifiers	1.00	0.09
Nitrosomonas	1.40	0.25
Nitrobacter	0.054	0.017

of soil in the uncut area. The nitrifying organisms, *Nitrosomonas* and *Nitrobacter*, were also more numerous in the clearcut area.

DISCUSSION

Litterfall Nutrient Dynamics

Litterfall is the major pathway by which most nutrients are cycled in forest ecosystems (Medwecka-Kornas, 1971), and the resultant forest floor buildup which occurs serves as the single most important feature distinguishing a forest soil from an agricultural soil. Litterfall also serves as a stabilizing influence which helps to maintain the conservative nature of forest nutrient cycles and preserve site quality in the absence of disturbance. When a disturbance, such as clearcutting, occurs in a forest stand, nutrient cycling is disrupted and a host of modified environmental factors begins to affect nutrient dynamics.

Litterfall nutrient dynamics in the clearcut and uncut areas were markedly different (Appendix Tables 4-5, Tables 8-11, Figures 3-4). A much larger quantity of litter fell throughout the year in the uncut area, but the difference was most pronounced during October, the period of maximum litterfall. The litter which fell in the clearcut area originated either from vegetation outside the cut area and was transported by wind, or from stump sprouts or successional vegetation which seeded into the cut area. The interruption of the litterfall portion of the nutrient cycle is one of the major factors contributing to a decline in forest floor size following clearcutting (Covington, 1976).

Covington (1976) found that four to six years were required for litterfall in a clearcut area to approach pre-cutting levels. The present litterfall study was conducted for 14 months following clearcutting, and no evidence of an approach to pre-cutting levels was observed from October 1979 through October 1980. The following data from Appendix

Table 4 are of particular interest:

	Litter Dry Weight	
	Clearcut	Uncut
	--------kg/ha------	
Oct 79	552	3,905
Oct 80	300	2,126
Percent Change	45.7	45.6

The normal successional trend would require a larger litterfall during 1980, until eventually the clearcut and uncut areas would have similar rates. Since the reduction in October litterfall from 1979 to 1980 occurred equally in both areas, the decrease cannot be attributed to a successional trend, but rather to an environmental factor manifesting itself in both areas. Since 1979, the year of higher October litterfall, had over 20 cm more precipitation than 1980 (Appendix Table 12), the difference in October litterfall may be attributed to less primary production during 1980.

For most of the nutrients studied, a significantly greater quantity was associated with the increased litter that fell in the uncut area. There were several months during which a significantly greater amount of litter fell in the uncut area, but the amount of a given nutrient cycled in that litter was not significantly greater; however, a clear trend was not evident. Marks and Bormann (1972) reported that early successional stands that developed after logging in central New Hampshire had annual N uptake rates 50% higher than in a mature, undisturbed ecosystem. This may be attributed to the ability of the successional vegetation to take up the larger amount of available nutrients.

Low P, K, and Mg contents were cycled in the litterfall in both the clearcut and uncut areas. Cotrufo (1977) found that the order of importance of nutrients in mixed hardwood litter in North Carolina was N > Ca > K > Mg > P. This same pattern emerged in this study with nutrients expressed on a kg/ha basis. The nutrient quality of litterfall varies throughout the year. The relationship of biomass to N content from November, 1979, to June, 1980, in the uncut area was made previously. In this case, twice the amount of N was transferred to the forest floor in a much smaller quantity of litter. The N, P, and K concentrations of developed leaves remain relatively constant until the autumnal leaf abscission process begins, after which a decline occurs so that subsequent leaf fall contains reduced nutrient concentrations (Pritchett, 1979).

Although autumnal litter accounts for the largest amount of dry weight cycled (Cotrufo, 1977), the collective importance of litterfall in the remaining months cannot be overlooked, particularly when the high nutrient contents associated with this litter are considered. The clearcut area Ca data from Table 10 show that from December, 1979, through September, 1980, 2.8 kg/ha of Ca were cycled in litterfall, while only 3.1 kg/ha were cycled in the October litterfall. Large amounts of litter (primarily in the form of twigs and fully developed leaves) are often produced by summer storms (Gosz et al., 1976), and the quantity of nutrients cycled in this dry weight may be considerable.

Forest Floor Nutrient Dynamics

While the effects of clearcutting on monthly litterfall are readily apparent, the immediate influence on the forest floor is no less noticeable. The trends of Figures 5 and 6 show the changes incurred by the L layer following clearcutting. During June, 1979, no significant differences were noted in L layer characteristics between the clearcut and uncut areas; however, in August, 1979, the dry weight and nutrient content of the L layer in the clearcut area increased dramatically. This increase was entirely due to the logging slash which was left after the clearcutting operation. It should be pointed out that since this operation was a whole-tree removal, the large L layer that was measured would account for only a fraction of the L layer that would be present following a conventional clearcut. When comparing conventional clearcutting with whole-tree removal, Kimmins (1977) reported that in a 100-year-old hardwood stand 69% more P, 47% more K, and 37% more Ca would be removed in the whole-tree harvest. Thus, it seems that with conventional clearcutting the logging slash left after the operation would result in a much larger forest floor and higher nutrient contents than reported here.

Although the L layer in the clearcut area in August, 1979, was significantly larger than in the uncut area, by November, 1979, no significant differences were noted in dry weight or nutrient content between the two areas. Although the dry weight was greater in the clearcut area, the nutrient contents were greater in the uncut area, indicating a greater nutrient concentration of the L layer material in the uncut area. The composition of the L layer in the clearcut was largely residual, undecomposed woody material left after the clearcutting operation, while the L layer in the uncut area was composed mostly of the October litterfall. By June, 1980, the clearcut influence on the L layer had disappeared, and the expected trend of larger L layers in the uncut area was evident by November, 1980. All of the logging slash had essentially become incorporated into the F layer by June, 1980, which is not surprising, since by definition the F layer consists of organic matter in any stage of decomposition.

The dynamics of the F layer following clearcutting are not as pronounced as for the L layer. The data of Table 13 and Figures 7 and 8 show that through the 1980 sampling season the F layer in the clearcut area had a greater dry weight than in the uncut area. This was due largely to the input of logging slash from the L layer. The lower nutrient quality of the F layer material was also evident, since in most cases the smaller F layer in the uncut area contained more nutrients with the exception of Ca. Since Ca is a structural component of litter that is released slowly by decomposition (Gosz et al., 1973), it remains in woody tissue longer than the other nutrients.

Although changes in F layer dry weight within both the clearcut and uncut areas occurred over the course of the study, significant differences within either area did not occur. Some trends were apparent, however. Within the clearcut area the smallest F layer was recorded during the November sampling dates (Figure 7). The most active mineralization period on this site extends from April through September; throughout this period the F layer is the exposed forest floor surface, as the L layer is essentially absent. Since the October litterfall provides an input to the L layer and not the F layer, by November the F layer is at its minimum size, and subsequently builds in dry weight as the autumnal litterfall is incorporated. In both the clearcut and uncut areas in both years a decrease in F layer dry weight was observed from June to November.

The H layer was less affected by the clearcut operation than the L or F layers. Throughout the course of the study the H layer dry weight in the clearcut area was larger than in the uncut area. This is partially explained by the greater mineral soil component that occurred in this layer in the clearcut area. Reiners and Reiners (1970) and Yount (1975) reported on the large amount of A_1 mineral soil mixed with the H layer in undisturbed hardwood stands. This was encountered in the present study; however, in the clearcut area the H layer was further mixed with the A_1 horizon due to the logging operation. This was especially apparent where skid trails happened to traverse a forest floor plot. A comparison of organic matter contents between the clearcut and uncut areas (Table 14) revealed that after clearcutting, the organic matter content of the H layer material was less in the clearcut area.

Throughout the 1980 sampling season the H layer in the clearcut area contained a larger overall nutrient content, although significant differences were noted only for K and Mg. The importance of the nutrient content in the forest floor cannot be overemphasized, since nutrients mineralized in the F and H layers are often directly taken up by plants (Viro, 1955). For the most part, the F layer contained a lower nutrient content than the uncut area during 1980, and it is important to note the total amount of nutrients in the H layer. In the Appalachian forest region, the mineral soil comprises the largest nutrient pool (Rauscher, 1980), and it is likely that much of the nutrient content is associated with mineral soil and soil humus mixed with H layer material.

The greatest amount of variation in nutrient content occurred in the A_1 layer. According to the data in Table 15, the total nutrient contents, organic matter contents, and C:N ratios were not consistently higher in either the clearcut or uncut areas. Since the mineral soil is overlain by the L, F, and H layers, it was not as sharply affected by the clearcutting operation, except where the entire forest floor was removed or mixed with the soil. The clearcutting effects were most pronounced on the surface forest floor layers; as a result changes in the mineral soil would probably not occur for from three to five years.

In order to summarize the most recent nutrient status of the forest floor in the clearcut area and compare it to the uncut area, the following data were excerpted from Tables 12, 13, and 14:

Dry Weight and Nutrient Contents
for L, F, and H Layers for November, 1980

	Clearcut	Uncut
	--------kg/ha--------	
Dry Weight	51,585	42,908
N	578	453
P	33	31
K	77	62
Ca	391	388
Mg	68	52

When the total nutrient contents for the L, F, and H layers are combined it becomes apparent that the forest floor in the clearcut area has not diminished in terms of dry weight or nutrient content. Since the above data were collected during November 1980, 14 months after clearcutting, it is hypothesized that the forest floor in the clearcut area is still experiencing the nutrient benefit of the logging slash. It is useful to point out, however, that much of the nutrient benefit is contained within the H layer, which indicates that after 14 months a sizeable portion of the logging slash has become incorporated into the H layer. This transferral of organic matter and associated nutrients from the L layer to the H layer in 14 months appears to be rather rapid incorporation; however, it is important to point out that much of the logging slash consisted of green leaves and small debris that were left on site. By comparison, Reiners and Reiners (1970) reported a 15-year turnover time for organic matter in the forest floor of an undisturbed oak forest. The relatively rapid incorporation of the logging slash in the present study may be attributed to the following:

1. Green leaves on the average contain twice the amount of N as yellowed leaves, and thus would decompose much more rapidly than autumnal litterfall (Viro, 1955).
2. Increases in temperature and moisture in the clearcut area would favor more rapid decomposition (Bormann et al., 1974).

Soil Solution Nutrient Dynamics

Nutrient concentrations in the soil solution respond quickly to site disturbance and provide useful indicators of decomposition and mineralization (McColl and Powers, 1976). Gessel and Cole (1965) and McColl (1978) used the ionic composition of forest soil solutions to study the effects of timber harvesting in western forests. Soil solution nutrient concentrations and pH were used in the present study as indicators of mineralization in the clearcut and uncut areas.

Previous studies have indicated that favorable conditions for rapid organic matter decomposition exist after clearcutting (Likens et al., 1970; Dominski, 1971; Likens and Bormann, 1972). Miller et al. (1976) presented the data of Table 30 to delineate boundaries of environmental factors that influence microbial activity in soil. Information was

Table 30. Environmental factors and their approximate values for general microbial activity in soil, Miller et al. (1975).

Factor	Rate of Microbial Activity		
	Minimum	Optimum	Maximum
Moisture (% of approximate field capacity)	5	50	80
Temperature (^oC)	2	28	40
Aeration (% of approximate field capacity)	Variable	50	Variable
pH	4	7	10
Food Supply (C:N)	Variable	25:1	Variable

gathered in the present study to assess the conditions under which decomposition occurs. The effects of clearcutting on soil solution nutrient dynamics and comparisons with the uncut area are shown in Appendix Tables 8-9 and Tables 24 through 28. Overall, conditions were favorable for decomposition from April through November, with exceptions in very dry portions of August and October.

The pH of a soil solution is a useful indicator of appropriate conditions for decomposition. After clearcutting in a California *Eucalyptus globulus* forest, McColl (1978) found decreases in soil solution pH. Stark (1979) studied soil solutions after clearcutting and whole-tree removal in a larch/Douglas-fir forest and found soil solution pH to be slightly higher than in forested control areas. Soil solution pH's for the present study are presented in Table 24. A large amount of variability was associated with these pH values, and thus no significant differences were discernible between the clearcut and uncut areas. It is important to note, however, that for numerous sampling dates no solution was extracted from the uncut area due to dry conditions, and during these sample dates the pH of the soil solution collected from the clearcut area was high. Overall, the pH's ranged from 4 to 6, or between the minimum and optimum range for microbial activity (Miller et al., 1975).

Soil solution N dynamics provide the best indicator of the effects of clearcutting, since ionic forms of N in solution are derived principally from organic sources. Of the two forms of N analyzed in this study, NH_4-N provided the most straightforward results. The NH_4-N data, presented in Appendix Table 8 and Figures 14 and 15, show increased concentrations in the clearcut area throughout the sample year. Although the majority of the NH_4-N is fixed or adsorbed on exchange complexes (Wollum and Davey, 1975), a sizeable quantity is in solution at any given point in time. The ammonification process is directly dependent upon the soil and forest floor microbial population, which is in turn influenced by the environmental conditions following clearcutting.

The NO_3-N concentrations were much more variable than NH_4-N. Nitrification occurs to some degree in this system, but is probably limited to a large extent by pH. Wollum and Davey (1975) reported that the optimum pH range for *Nitrosomas* is 7 to 9, while that for *Nitrobacter* is 5 to 10. Both of these organisms were enumerated in the microbiological characterization (Table 29), and they occurred in greater numbers in the clearcut area. Since the NO_3-N concentrations were lower than NH_4-N concentrations throughout most of the year, it appears that nitrification is a localized phenomenon in this system. During the spring, when warm ambient temperatures heat the surface of the clearcut area forest floor, nitrification proceeds at a faster rate, as evidenced by Figure 18. Freezing and thawing followed by rain can leach many nutrients formerly immobilized in microbial biomass (Witkamp, 1969). This situation commonly occurred at the forest floor surface in the clearcut area, and the NH_4-N thus released may be converted to NO_3-N, if conditions are favorable, adsorbed to soil colloids, or taken up by growing vegetation.

Denitrification, although it can only be discussed in terms of conjecture, is an additional factor which may account for the variability of NO_3-N concentrations in soil solution. Denitrification proceeds readily at low O_2 concentrations, as long as a carbon source for energy and a NO_3^- source as an electron acceptor are present (Wollum and Davey, 1975). Denitrifying microorganisms were enumerated in the microbiological characterization (Table 29), and more denitrifiers were present in the clearcut area. In the forest floor there is a large carbon source available, and anaerobic sites are present, particularly within the clearcut area, due to higher soil moistures (Figure 19). Although denitrification has not been investigated in forest soils, it is generally considered to occur, and unaccounted N losses in nutrient cycling studies are often attributed to denitrification (Wollum and Davey, 1975).

The concentrations of the other nutrients generally were not useful indices of mineralization in the clearcut and uncut areas. The P concentrations were much lower than the other nutrients studied; however, the general trend was toward higher concentrations in the clearcut area (Table 25). Potassium concentrations clearly were higher in the cut area; however, Ca concentrations were variable and Mg concentrations were higher in the uncut area (Tables 26-28). The Ca and Mg data do not reflect the general trend of increasing nutrient concentrations in the clearcut area; however, they may be more greatly affected by other factors, such as release from mineral forms, varying concentrations of elements in precipitation, and the porous ceramic cup variability (Hansen and Harris, 1975).

Although soil temperature, moisture, and pH are known to be major factors influencing decomposition and mineralization, none were closely correlated to the concentration of nutrients in solution. During the winter months, when soil temperatures are low, considerable mineralization may occur at the surface if the ambient temperature is high enough.

An example is provided with the Feb 20 NH_4-N data from Appendix Table 8. A large increase in NH_4-N in solution was noted, even though soil temperatures were low (4.7°C in the clearcut, Appendix Table 10). The four days prior to sample collection were the warmest on record for three months, and the high ambient temperatures influenced surface activity of microorganisms, even though the temperatures at a depth of 2.5 cm were below the range of normal microbial activity. Future studies should include surface temperature measurements to account for this phenomenon.

Soil microorganisms play a critical role in the maintenance of a forest floor and the release of available nutrients for plant growth. Bacteria and actinomycetes were the dominant microorganisms in terms of overall numbers (Table 29); however, large numbers of fungi were also enumerated. More bacteria and actinomycetes were found in the clearcut area, which may be due to higher soil pH (Table 15). The higher pH may also explain the lower numbers of fungi and higher numbers of nitrifying organisms in the cut area. Although natural variation in microbial populations are great, and quantitative relationships are difficult to obtain, the trends measured seem to indicate that decomposition and mineralization occur more rapidly in the clearcut area, and a decrease in forest floor size and nutrient content will occur as long as these conditions prevail.

SUMMARY AND CONCLUSIONS

The intent of the current project was to critically analyze changes in forest floor size and nutrient content over time following clearcutting and whole-tree removal in an Appalachian oak forest stand. Previous work by Huttinger (1950), Trimble and Lull (1956), and Covington (1976) indicated that forest floor size decreased after clearcutting. This study was established to investigate this phenomenon more thoroughly.

Forest floor and A_1 soil horizon samples were collected in June, 1979, prior to clearcutting, then in August and November, 1979, and June, August, and November, 1980. Forest floor samples were separated by L, F, and H layers, and comparison samples were collected in an adjacent, uncut control area. Monthly litterfall was collected from October, 1979, through October, 1980, in both areas, and soil solution samples were collected on a biweekly basis from April, 1980, through March, 1981. The clearcutting operation, carried out in August, 1980, simulated an actual commercial whole-tree harvest.

Nutrient analysis included total N, P, K, Ca and Mg. In addition, other variables were determined on selected samples, such as organic matter content and C:N ratio for H layers and soil samples. Soil temperatures, soil moistures, precipitation, and numbers of microorganisms in clearcut and uncut area soil samples were all determined.

The results reported here clearly show that the forest floor in the cut area has not decreased in either dry weight or nutrient content when compared to an uncut control area. The logging slash left after clearcutting caused an immediate increase in the L layer, and by November, 1980, much of the organic material in the logging slash had passed through the F layer and was incorporated into the H layer. After the most recent forest floor sampling, November, 1980, the forest floor in the clearcut area was still larger than in the uncut area, but this trend is not expected to continue. It is important to point out here that the logging slash effect that occurred is minor by comparison to a conventionally clearcut area. Boyle (1976) reported that about twice as much slash is produced by conventional clearcutting; therefore, the inputs to the L, F, and H layers would be much higher, and a longer period of time would be required for a forest floor reduction to occur.

The factors which cause reduced forest floor sizes after clearcutting were analyzed in this study. The litterfall in the cut area was only about 14% of the litterfall in the uncut area. Although this percentage will increase as the young stand develops in the cut area, there will be a number of years before the two areas receive equivalent litter inputs. Soil temperatures and moistures were generally higher in the cut area. During dry parts of the year soil moisture was often extracted from the cut area while none could be extracted from the uncut area. Soil pH's were consistently higher in the clearcut area. Such soil temperature, moisture, and pH conditions result in a more favorable environment for organic matter decomposition in the cut area. This increased decomposition, coupled with reduced litter inputs, will eventually result in a decreased forest floor size and nutrient content. The fact that decreases were not noted by November, 1980, can be attributed to the organic matter input to the forest floor in the form of logging slash in the clearcut area.

In order to further substantiate the increased decomposition in the clearcut area, soil solution nutrient content was analyzed as an index of mineralization. Ammonium-nitrogen, the nutrient most closely associated with mineralization from organic sources, was present in the clearcut area soil solution in higher concentrations than in the uncut control area. Bacteria, actinomycetes, denitrifying and nitrifying microorganisms were all present in greater numbers in soil samples collected from the clearcut area.

To fully evaluate the effects of the clearcutting operation on the forest floor, results from Phase II of this research project will be necessary. Although a forest floor reduction in dry weight and nutrient content has not been observed to date, all of the factors necessary for such a reduction are present, and the extent to which the forest floor is affected will be determined through future sampling.

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APPENDIX

Appendix Table 1. Profile description for a Calvin series soil sample from the study area on Price Mountain, Montgomery County, Virginia.

Series: Calvin

Classification: Loamy-skeletal, mixed, mesic Typic Dystrochrept

Parent Material: Shale

Physiography: Side slope

Described by: K. Molten, Soil Scientist
Soil Survey Staff
VPI & SU

Date: 27 Jun 79

Horizon	Depth	Pedon Description
01,02	5- 0 cm	Undecomposed and partially decomposed leaves and twigs.
A_1	0- 8 cm	Reddish brown (5YR 5/3) shaly silt loam; moderate fine and very fine granular structure; friable, slightly sticky, slightly plastic; 25% shale fragments; many very fine, fine, medium, and coarse roots; clear smooth boundary.
B_2	8-53 cm	Reddish brown (5YR 5/4) shaly silt loam; weak fine and medium subangular blocky structure; friable, slightly sticky, slightly plastic; few thin patchy clay films in pores and on ped faces; 40% shale fragments; common very fine, fine, medium, and coarse roots; clear smooth boundary.
C	53-64 cm	Reddish brown (5YR 5/4) very shaly silt loam; massive structure; friable, slightly sticky, slightly plastic; 70% shale fragments; few fine and very fine roots; clear smooth boundary.
C_r	64-99 cm	Weathered (purple) shale bedrock.
R	99 cm	Hard (purple) shale bedrock.

Appendix Table 2. Profile description for a Berks-like series soil sample from the study area on Price Mountain, Montgomery County, Virginia.

Series: Berks-like

Classification: Loamy-skeletal, mixed, mesic Typic Dystrochrept

Parent Material: Sandstone

Physiography: Side slope

Described by: K. Molten, Soil Scientist
Soil Survey Staff
VPI & SU

Date: 27 Jun 79

Horizon	Depth	Pedon Description
01,02	5- 0 cm	Undecomposed and partially decomposed leaves and twigs.
A_1	0- 3 cm	Brown (7.5YR 5/4) silt loam; moderate fine granular structure; friable, slightly sticky, slightly plastic; 50% fine-grained sandstone stones; many very fine, fine, medium, and coarse roots; clear smooth boundary.
B_2	3-61 cm	Brown (7.5YR 5/4) silt loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few thin patchy clay films in pores and on ped faces; 50% fine-grained sandstone stones; common very fine, fine, medium, and coarse roots; clear wavy boundary.
R	61 cm	Hard sandstone.

Appendix Table 3. Profile description for a Muse series soil sample from the study area on Price Mountain, Montgomery County, Virginia.

Series: Muse

Classification: Clayey, mixed, mesic, Typic Hapludult

Parent Material: Shale

Physiography: Side slope

Described by: K. Molten, Soil Scientist
Soil Survey Staff
VPI & SU

Date: 27 Jun 79

Horizon	Depth	Pedon Description
01,02	5- 0 cm	Undecomposed and partially decomposed leaves and twigs.
A_1	0-13 cm	Brown to dark brown (7.5YR 4/4) silt loam; moderate fine granular structure; firm, sticky, plastic; many very fine, fine, medium, and coarse roots; clear smooth boundary.
B_{2t}	13-71 cm	Reddish brown (5YR 5/4) silty clay; few fine prominent red (2.5YR 4/8) and brownish yellow (10YR 6/8) mottles; moderate, medium, subangular blocky structure; firm, sticky, plastic; common medium clay films; common very fine, fine, and medium roots; gradual smooth boundary.
C	71-157 cm	Mottled yellowish brown (10YR 6/8), dusky red (2.5YR 3/2) and white (10YR 8/1) silty clay; massive structure; friable, sticky, plastic; clay flows; few very fine and fine roots; 2% shale fragments.

Appendix Table 4. Litterfall dry weight by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Dry Weight	
	Clearcut	Uncut
	---------kg/ha--------	
Oct 79	552bA*	3,905aA
Nov 79	82aC	214aC
Dec 79-Feb 80	49bC	250aC
Mar 80	44aC	257aC
Apr 80	38bC	164aC
May 80	45bC	142aC
Jun 80	11bC	145aC
Jul 80	6bC	104aC
Aug 80	6bC	66aC
Sep 80	63bC	161aC
Oct 80	300bB	2,126aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 5. Litterfall N contents by sampling dates between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	N Content	
	Clearcut	Uncut
	----------kg/ha---------	
Oct 79	4.1bA*	31.1aA
Nov 79	0.4aCD	0.8aC
Dec 79-Feb 80	0.3bCD	1.6aC
Mar 80	0.4aCD	1.6aC
Apr 80	0.4aCD	1.4aC
May 80	0.7bCD	2.1aC
Jun 80	0.1bCD	1.7aC
Jul 80	<0.1bD	1.4aC
Aug 80	<0.1bD	0.8aC
Sep 80	1.0bC	2.1aC
Oct 80	2.2bB	13.0aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 6. Total dry weight in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total Dry Weight					
	Clearcut			Uncut		
	L	F	H	L	F	H
	kg/ha x 10^3					
Jun 79	<0.1cB*	20.2bA	38.5aA	<0.1cB	17.3bA	36.0aA
Aug 79	9.5bA	23.1aA	31.6aA	<0.1cB	13.4bA	20.2aC
Nov 79	2.3bB	12.9bA	35.8aA	1.9cA	15.1bA	32.5aAB
Jun 80	0.0cB	24.2bA	42.1aA	0.0bB	16.1aA	21.3aC
Aug 80	0.0bB	22.2aA	32.1aA	0.0bB	17.8aA	18.7aC
Nov 80	0.2cB	17.2bA	34.2aA	1.6cA	16.1bA	25.1aBC

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 7. Total N in forest floor layers between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Total N							
	Clearcut				Uncut			
	L	F	H	A_1	L	F	H	A_1
	kg/ha							
Jun 79	00dB*	191cAB	379bA	795aA	00dB	241cA	402bA	723aA
Aug 79	52cA	229bA	306bA	950aA	00cB	205bAB	235bC	744aA
Nov 79	07dB	136cB	290bA	842aA	14cA	147bcB	365bAB	836aA
Jun 80	00dB	177cAB	362bA	729aA	00cB	191bAB	271bBC	917aA
Aug 80	00dB	155cAB	332bA	828aA	00cB	236bA	251bBC	924aA
Nov 80	02cB	157cAB	419bA	812aA	11dA	135cB	307bABC	669aA

*Means within a row with the same lower-case letter are not significantly different; means within a column with the same upper-case letter are not significantly different. Differences were determined using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 8. Soil solution NH_4-N concentration for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	NH_4-N Concentration			
	15 cm		30 cm	
	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	0.73aBC*	0.36aBC	0.71aCB	0.39aB
17 Apr 80	0.65aBC	0.38bBC	0.58aCD	0.36aB
01 May 80	2.84aA	1.83bA	2.19aA	2.13aA
15 May 80	2.64aA	1.67bA	1.97aA	1.97aA
29 May 80	0.53aBC	0.21aCD	0.30aCD	0.15aB
18 Jun 80	0.74BC	---**	0.37CD	---
02 Jul 80	---	---	1.25B	---
17 Jul 80	---	---	0.53CD	---
30 Jul 80	1.08aB	0.67aB	0.59aC	0.49aB
26 Aug 80	---	---	0.15CD	---
29 Oct 80	0.03C	---	0.32CD	---
12 Nov 80	0.03C	---	---	---
03 Dec 80	0.05aC	0.06aCD	0.03D	---
06 Feb 81	---	---	0.10CD	---
20 Feb 81	0.46aBC	0.27aC	0.37aCD	0.37aB
05 Mar 81	0.06aC	0.02bD	0.03aD	0.06aB
17 Mar 81	0.09aC	0.02bD	0.04aD	0.03aB
31 Mar 81	0.17aC	0.02aD	0.04aD	0.02aB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means with a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

Appendix Table 9. Soil solution NO_3-N concentrations for 15 and 30 cm depths between sampling dates for clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	NO_3-N Concentration			
	15 cm		30 cm	
	Clearcut	Uncut	Clearcut	Uncut
	ppm			
10 Apr 80	0.55aB*	0.34aAB	0.35aBC	0.30aAB
17 Apr 80	0.33aB	0.34aAB	0.40aBC	0.33aAB
01 May 80	0.50aB	0.27aAB	0.06aC	0.07aB
15 May 80	0.26aB	0.47aAB	0.29aBC	0.43aAB
29 May 80	0.35aB	0.44aAB	0.21aBC	0.24aAB
18 Jun 80	0.47B	---**	0.42BC	---
02 Jul 80	---	---	0.86ABC	---
17 Jul 80	---	---	0.50BC	---
30 Jul 80	0.51aB	0.56aAB	0.48aBC	0.32aAB
29 Oct 80	0.12B	---	<0.01C	---
12 Nov 80	0.02B	---	0.05C	---
03 Dec 80	0.15aAB	0.35aAB	0.15aBC	0.35aAB
06 Feb 81	---	---	<0.01C	---
20 Feb 81	1.70aA	0.88aA	1.99aA	0.73aA
05 Mar 81	1.79aA	0.01bB	1.21aAB	0.05aB
17 Mar 81	2.10aA	0.19bB	0.85aBC	0.37aAB
31 Mar 81	1.56aA	0.43bAB	1.14aAB	0.23aAB

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

**No soil solution collected due to dry conditions.

Appendix Table 10. Comparison of soil temperature (^{o}C) between sampling dates and between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Soil Temperature	
	Clearcut	Uncut
	----------^{o}C----------	
10 Apr 80	12.6aGH*	11.6bH
17 Apr 80	9.7aI	10.3aIJ
01 May 80	12.4aGH	12.1aGH
15 May 80	16.5aF	15.3bF
29 May 80	21.8aD	19.2bCD
18 Jun 80	21.5aD	18.7bD
02 Jul 80	26.5aC	23.1bB
17 Jul 80	33.9aA	26.7bA
30 Jul 80	30.4aB	24.0bB
14 Aug 80	33.1aA	26.5bA
26 Aug 80	29.3aB	23.9bB
16 Sep 80	21.2aD	20.0bC
01 Oct 80	22.0aD	19.6bCD
15 Oct 80	19.2aE	17.2bE
29 Oct 80	13.7aG	12.9bG
12 Nov 80	9.8aI	9.6aJ
03 Dec 80	5.5aK	5.7aL
08 Jan 80	-0.2aM	-0.2aN
22 Jan 80	2.2aL	1.8aM
06 Feb 81	-1.2aM	-0.1aN
20 Feb 81	4.7bK	7.5aK
05 Mar 81	4.9aK	5.6aL

Appendix Table 10. Comparison of soil temperature (^{o}C) between sampling dates and between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia (continued).

Sampling Date	Soil Temperature	
	Clearcut	Uncut
	------------^{o}C------------	
17 Mar 81	7.4aJ	6.6aKL
31 Mar 81	11.5aH	11.1aHI

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 11. Comparison of soil moisture (%) between sampling dates and between clearcut and uncut oak forest sites, Price Mountain, Montgomery County, Virginia.

Sampling Date	Soil Moisture	
	Clearcut	Uncut
	------------%------------	
10 Apr 80	35aDEFG	38aBCDEF
17 Apr 80	32aDEFG	35aCDEFG
01 May 80	35aDEFG	37aCDEF
15 May 80	32aDEFGH	29aCDEFGH
18 Jun 80	31aDEFGHI	24bEFGH
02 Jul 80	28aFGHI	17bFGH
17 Jul 80	27aFGHI	26aDEFGH
30 Jul 80	31aDEFGHI	26aDEFGH
14 Aug 80	15aHI	11bH
26 Aug 80	30aDEFGHI	20bEFGH
16 Sep 80	16aI	11bH
01 Oct 80	20aGHI	13bGH
15 Oct 80	22aGHI	15aFGH
29 Oct 80	28aEFGHI	22bEFGH
12 Nov 80	28aEFGHI	21bEFGH
03 Dec 80	32aDEFGHI	30aCDEFGH
08 Jan 81	81aB	50aBC
22 Jan 81	77aB	41bBCDE
06 Feb 81	106aA	117aA
20 Feb 81	55aC	48aBCD
05 Mar 81	44aCDE	60aB
17 Mar 81	45aCD	48aBCD
31 Mar 81	42aCDEF	47aBCD

*Means within a row with the same lower-case letter are not significantly different using the 0.05 level of the student's t test. Means within a column with the same upper-case letter are not significantly different using the 0.05 level of the Duncan's Multiple Range Test.

Appendix Table 12. Monthly precipitation (cm) for January, 1979, through March, 1981, recorded at the VPI & SU College of Agriculture and Life Sciences Prices Fork Research Station, Montgomery County, Virginia.

Month	Precipitation		
	1979	1980	1981
	cm		
Jan	13.5	8.8	1.4
Feb	9.4	2.0	7.1
Mar	8.1	12.6	5.7
Apr	10.5	9.8	
May	9.4	6.4	
Jun	9.2	6.1	
Jul	8.0	20.2	
Aug	6.0	6.7	
Sep	13.0	3.0	
Oct	9.0	7.3	
Nov	11.6	5.6	
Dec	3.6	2.4	
Total	111.3	90.9	

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NUTRIENT DYNAMICS OF THE FOREST FLOOR
IN AN APPALACHIAN OAK FOREST STAND
FOLLOWING CLEARCUTTING AND WHOLE-TREE REMOVAL

by

James E. Johnson

(ABSTRACT)

Experiments were conducted to monitor nutrient dynamics in the forest floor of an upland Appalachian oak forest stand following clearcutting and whole-tree removal. Samples from the L, F, H, and A_1 layers were collected during June, August, and November of 1979 and 1980. Monthly litterfall was collected from October, 1979, through October, 1980. Soil solution samples were extracted on a biweekly basis from April, 1980, through March, 1981, and concurrent soil moisture and temperature determinations were made. All samples were collected from the clearcut area and an adjacent uncut area. Nutrient analyses included total N, P, K, Ca, and Mg, and pH, NH_4-N, and NO_3-N for the soil solutions only.

Comparisons were made between nutrient contents in the forest floor and mineral soil from the clearcut and uncut areas, between nutrient contents within forest floor layers within each area, and between nutrient contents collected over time within each area. Similar comparisons were made using litterfall nutrient contents and soil solution nutrient concentrations. Immediate clearcutting effects were most pronounced on the L layer of the forest floor, due to the logging slash input. Immediately after cutting the L layer in the cut area had a dry weight over 9,500

times that of the L layer in the uncut area. This logging slash rapidly became incorporated into the forest floor of the cut area, and after 15 months, the cut area had a forest floor slightly higher in dry weight and nutrient content than did the uncut area. Slash inputs accounted for these increases, since over the course of the study the cut area received only 14% of the litterfall that occurred in the uncut area. Soil temperature, moisture, and soil solution NH_4-N concentration were all higher in the clearcut area. Soil solution NO_3-N concentrations were variable but generally the same in both areas. After 15 months following clearcutting and whole-tree removal, the forest floor in the clearcut area was slightly higher in dry weight and nutrient content than an adjacent uncut area, and no site degradation was noted.