LITTERFALL AND NUTRIENT DYNAMICS OF A 12-YEAR-OLD LOBLOLLY PINE (*PINUS TAEDA* L.) PLANTATION FOLLOWING PRECOMMERCIAL THINNING

By

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CHAPTER I

INTRODUCTION

Loblolly pine (Pinus taeda L.) has been extensively planted in the South for over 40 years. Thousands of acres of nutrient-depleted and eroded farm land have been reclaimed by these plantations, as well as by naturally invading conifers and hardwoods. Although loblolly pine is the major commercial species planted in the southern United States, knowledge is limited concerning many aspects of the growth and management of the species.

Loblolly plantations extend from Delaware along the Atlantic and Gulf Coastal Plains to Texas and Oklahoma; the range includes most of the Piedmont region and parts of the Ouachita Mountains in Arkansas (Figure 1). This type was once limited by repeated wildfires, but with improved fire protection it has spread gradually southward onto sites formerly dominated by longleaf pine (Pinus palustris Mill.). It now occupies about 58 million acres (USDA, 1965).

Loblolly pine grows well on soils ranging from heavy clays to sandy loams and differing broadly in moisture conditions (Ashe, 1915). Growth is best along the margins

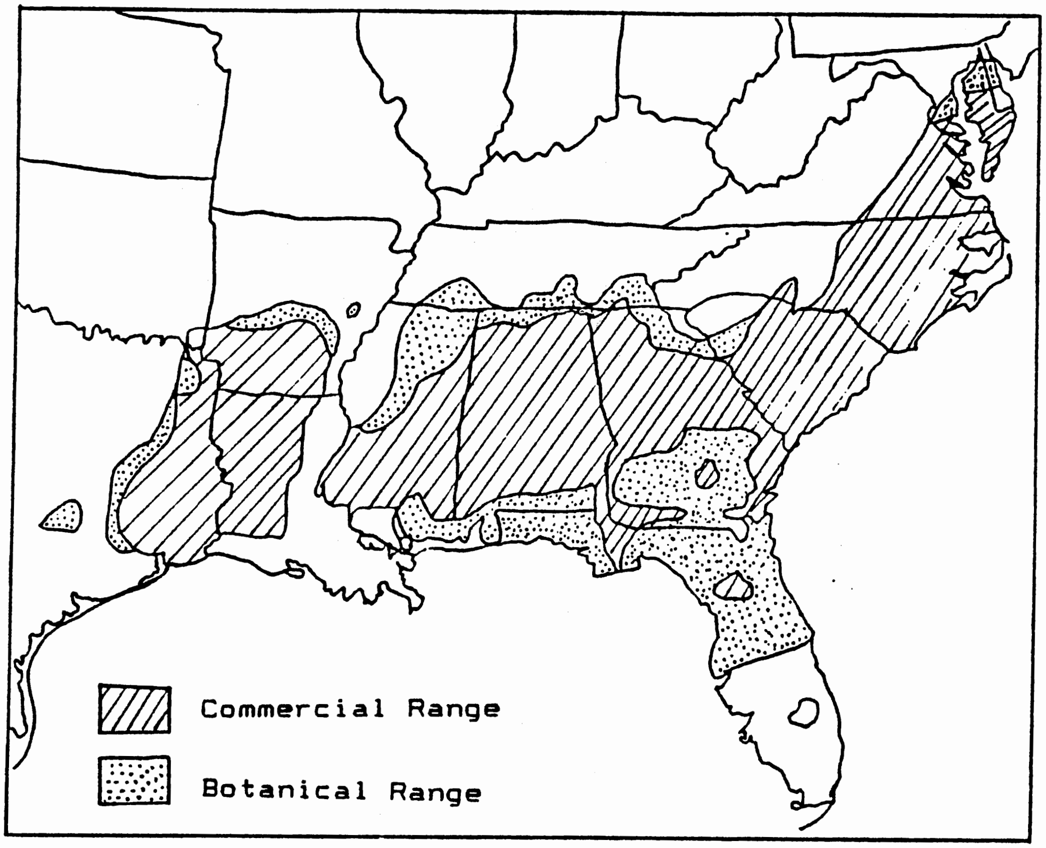

Figure 1. Botanical and Commercial Range of Loblolly Pine

of streams where surface drainage is often slow, but a deep, permeable surface layer affords good internal drainage. Poorest performance is on shallow, eroded soils (Mann, 1979).

Regeneration of loblolly pine can be obtained by artificial or natural methods. In recent years, management has shifted from dependence on natural regeneration to planting and direct seeding. These methods of artificial regeneration reduce the time needed for restocking, provide control of spacing, and enable land managers to establish genetically improved pines. As fast-growing, pest-resistant strains of pine become increasingly available, artificial regeneration will most likely predominate.

The key to maintaining the productivity of intensively managed sites is to effectively manage nutrient cycles (Jorgensen and others 1975). The forest floor acts like a reservoir for the storage of plant nutrients, but it is a reservoir with differential storage ability for different nutrients (Van Lear and Goebel, 1976).

Another aspect that deserves adequate characterization is the litterfall and additions to the forest floor component in loblolly pine plantations. The significance of both in meeting the annual nutrient requirements of loblolly pine has been demonstrated (Switzer and Nelson, 1972; Wells and Jorgensen, 1975) and, therefore, a better understanding of seasonal and annual changes is desirable.

The cycling of nutrients in the forest ecosystem is controlled by a series of interdependent processes (Curlin, 1970). The cycle is usually pictured as a number of nutrient pools or components that occur in soil or branches and are connected by pathways.

Rates of nutrient cycling and the accumulation of nutrients within the naturally occurring loblolly pine forests are being altered as the demand for wood and paper increases and intensive management develops. Studies of nutrient cycling in loblolly pine will help resolve problems associated with increased production, efficient use of fertilizer, soil productivity, and overall quality of the environment (Well and Jorgensen, 1975).

The primary objectives of this study were as follows: (1) to determine the seasonal pattern and quantity of leaf fall in thinned and unthinned loblolly pine stands, and (2) to determine the concentration and quantity of nutrients in annual leaf fall and forest floor components of young loblolly pine stands.

The null hypothesis tested in this study was, thinning to different residual stand density levels has no effect on litterfall quantity or nutrient concentrations in pine needle fall. To test this hypothesis, litterfall amounts and nutrient concentrations will be sampled periodically to determine if there is significant variation. Statistical analysis will be used to test this hypothesis.

CHAPTER II

LITERATURE REVIEW

Forest Nutrient Cycle

The five major factors required for plant growth (sunlight, water, CO_2, O_2, and nutrients), may be manipulated to some extent, to regulate rate of growth (Jorgensen, Wells and Metz, 1975). Each factor is also renewed: sunlight, daily; water, usually every week or two; nutrients, every hundred years or so. The key to an adequate supply of nutrients is the nutrient cycle, which permits reuse of nitrogen, phosphorus, and potassium (N,P,K) and other elements.

The forest nutrient cycle has three segments: an input, an intracycle or system within which nutrient movement takes place, and an output (Figure 2). Inputs to a forest system are small quantities of nutrients usually sufficient enough to offset losses. Nutrients on a site found in the vegetation, the forest floor, and the mineral soil make up the intracycle component.

The nutrient cycle is usually pictured as a number of nutrient pools or components that occur in soil or branches

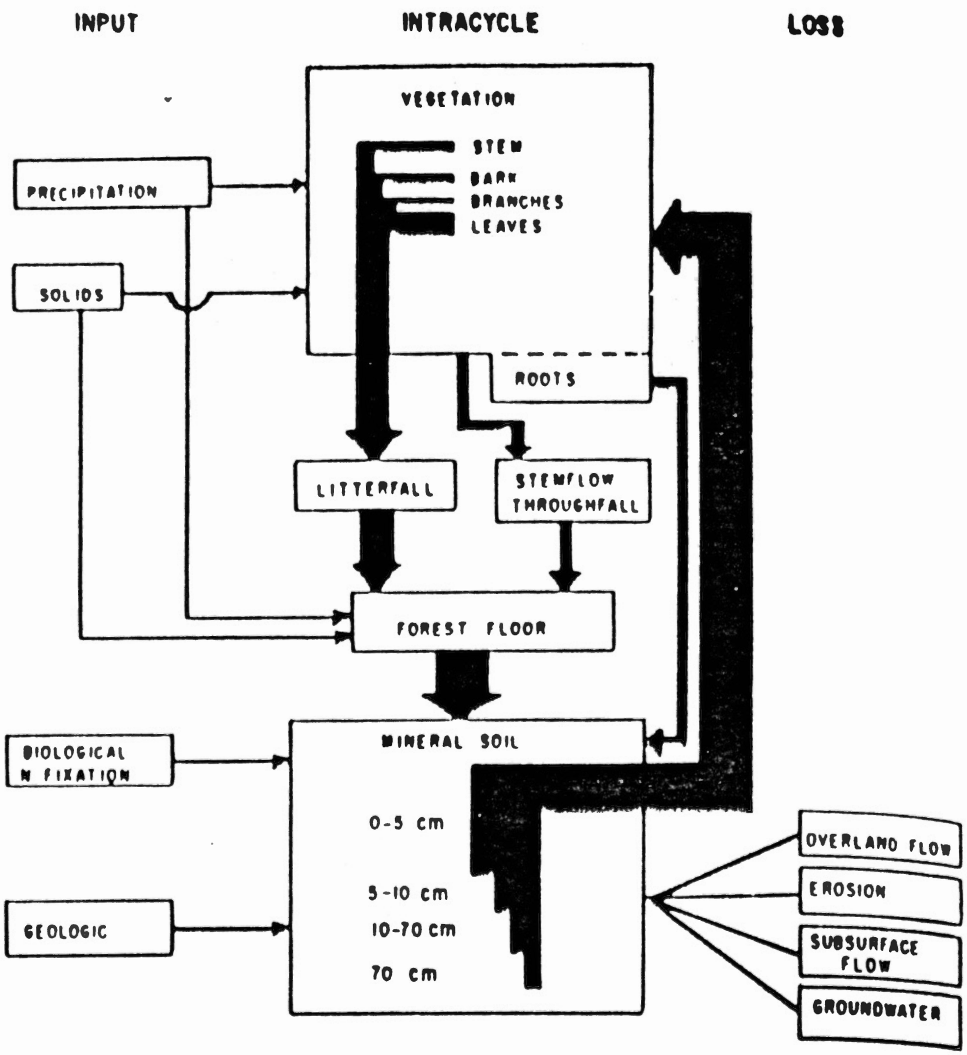

Figure 2. Source: Jorgensen et. al., 1975.
The Nutrient Cycle: Key to
Continuous Forest Production.

and are connected by pathways (Curlin, 1970). Nutrient quantity within the components and transfer rates between the components vary with soil, species, management practices, and ecosystems.

The basic mineral nutrition of the vegetation is provided by the weathering of the soil minerals, and the soil itself is recharged and changed by the organic products of the vegetation. Other organisms form essential parts of the ecosystem. Bacteria are essential for the fixation of N, fungi are essential for the absorption of nutrients by tree roots, and a whole complex of soil biota are needed to effect the decomposition of organic debris to a state where it can be utilized over again by the vegetation (Spurr and Barnes, 1980). The cycling of organic matter, water, and chemical elements is so basic that quantitative ecologists in recent years have developed concepts of the ecosystem based on them (Ovington, 1962, 1968). This cycling, however, is dependent in large measure upon the water cycle, which controls the availability of nutrients to tree roots, their rate of movement through the tree, the conditions under which the tree litter is decomposed, and the development of the soil profile which in turn affects the availability of nutrients to the tree roots as recycling is initiated (Wells and Jorgensen, 1975).

Nutrient accumulation in the forest floor is rapid during the first few years after stand closure and continues at a reduced rate until equilibrium is approached at about 30 years of age. However, the amount of N, P, and K in the forest floor continually increase with age. This increase shows that organic decomposition is more rapid than nutrient release and that nutrients are accumulated in the decomposition-resistant organic fraction of the forest floor (Jorgensen and others, 1975).

The long-term ability of the mineral soil to supply nutrients to trees is related to the total supply of each nutrient and its availability. The continuous availability of ample nutrients is one factor of site productivity, but because nutrient availability varies greatly between stands, timber production is not necessarily well correlated with total nutrients in the soil.

Removal of Nutrients by Timber Harvesting

A considerable number of harvest options are available to the forest manager. Timber may be clearcut or thinned, and the biomass removed may range from debarked pulpwood to the entire tree including roots. It is important to consider the long-range effect of the selected option on site nutrients.

Jorgensen et al., (1975) stated that at age 16, highly productive plantations can be clearcut or thinned for pulpwood. In a 16-year-old stand, removal of needles, bark, branches, stems, and large roots would yield 185 metric tons/ha of biomass. This material would contain about 80 to 90 percent of the nutrients in the tree biomass, and 12 percent of the total N, 8 percent of the extractable P, and 31 percent of the extractable K on the entire site. Removing only debarked pulpwood takes about 20 percent less N, P, and K from the site than a normal pulpwood harvest, and reduces the weight yield by only 10 percent.

The effect of rotation length on the nutrient cycle should also be considered with removal of biomass. The longer the rotation, the more nutrients will be removed during harvest. However, because maximum nutrient accumulation occurs during the early stages of stand development, the shorter the rotation the greater will be the nutrient removal on an annual basis (Jorgensen et al., 1975). The amount and number of times biomass can be removed before productivity is effected will vary from site to site.

Conventional harvesting, particularly clearcutting, disrupts the annual circulation of nutrients: (1) more organic matter becomes available for decomposition than in the undisturbed stand, and the rate of decomposition and mineralization is increased due to a warmer and moister forest floor; (2) root mortality of many species following cutting results in less nutrient absorption; (3) trees no longer absorb or intercept as much precipitation, thus reducing transpiration, increasing streamflow, and increasing the leaching of nutrients by percolating water; and (4) soil erosion may increase (Spurr and Barnes, 1980). As a result, the amount of dissolved nutrients entering the stream following harvesting by clearcutting typically increases. However, it tends to return in a relatively short time to preharvest level (Johnson and Swank, 1973; Fredriksen et al., 1975; Hornbeck et al., 1975). Nitrate N is usually found in high concentrations following harvesting. Rapid revegetation of the cut area and nutrient uptake by this new growth minimizes loss and acts to restore nutrient cycling to the preharvest level (Marks and Bormann, 1972; Likens et al., 1978).

The Hubbard Brook Experimental Forest in New Hampshire is an excellent example of measuring potential losses of nutrients (Likens et al., 1970). On a small watershed all trees and shrubs were cut but not removed. Regrowth was inhibited by herbicide spray in each of three years following cutting. The nutrient cycle was disrupted, stream runoff increased, and percolating rain water flushed substantial amounts of nutrients from the system during the three years following cutting while vegetation was suppressed. Average stream water concentrations increased over four times for Ca and Mg and over 15 times for K. Nitrate concentration increased 41-fold the first year and

56-fold the second, above undisturbed conditions. This experiment is of great value in illustrating the rapid nutrient loss after deforestation and the rapid recovery of the system following three years of denudation.

Complete tree harvesting and ultrashort rotations (2 to 8 years) mean much greater removal of nutrients than conventional harvesting procedures. The new logging systems remove the whole tree to a central point for delimbing and chipping so that what residue remains is not spread evenly over the site. Besides the stem, branches, leaves, and roots may be utilized, and all standing trees and brush are often removed from the site (Spurr and Barnes, 1980). Under these conditions, nutrient removal may be two or more times that removed by conventional harvesting methods.

Nutrient Composition

By analyzing the mineral content of the tree it is possible to determine the quantity of elements that have been incorporated. The leaves of pine trees are particularly responsive to nutrient supply, and foliar analysis has long been popular as a means of assessing soil fertility. In particular, the current year's foliage of the terminal shoot is especially indicative of soil conditions (Leyton and Armson, 1955; Leaf, 1968). The season of the year should also be considered, since the mineral content of the leaves change as the season progresses.

Plants tend to take up soluble minerals as they are supplied to the roots (Wells and Jorgensen, 1975). The amounts of a given element in the leaves at a given time are not clearly related to the amount available in the soil or to the nutritive requirements of the species.

There have been many comparisons between the mineral concentration of the foliage of trees of the same species growing on different soils. In a study of white oak (Quercus alba L.) growing on different soil types in Illinois (McVickar, 1949), differences in the chemical composition of the leaf were significant only when trees growing on the poorest soils were compared to those growing on the best. Again, in New York, when several hardwood species were compared on three soil types of varying limestone content, the Ca content of the foliage was found to be more dependent upon the inherent capacity of each species to absorb the nutrient rather than upon the Ca level of the soil itself (Bard, 1946).

The ability of different species to absorb nutrients has been studied in many parts of the world. In the northeastern United States, basswood (Tilia americana L.), yellow-poplar (Liriodendron tulipifera L.), dogwood (Cornus florida L.), and red cedar (Juniperus virginiana L.) are among the trees that concentrate large amounts of Ca in their foliage; while beech (Fagus spp.), red spruce (Picea rubens Sarg.), pines (Pinus spp.), and hemlock (Tsuga spp.) are low in their uptake (Bard, 1946). By putting together data for the mineral content of roots, bark, branches, leaves, and bole wood, it is possible to determine the annual uptake of nutrients by forest trees.

The effect of nutrients on tree growth has been thoroughly researched. Reviews of the nutrient requirements of forest stands (Tamm, 1964), the mineral nutrition of conifers (Morrison, 1974), the deficiencies of K, Mn, and S in forest trees (Leaf, 1968), and the microelement nutrition of trees (Fortescue and Marten, 1970; Stone, 1968) provide entry into the literature. Besides foliar analysis, other methods of diagnosing the nutrient status of forests include experimental field, greenhouse, or hydroponic studies (Ingestad, 1962), visual deficiency symptoms (Hacskaylo et al., 1969), and soil analysis (Tamm, 1964; Leaf, 1968).

The minerals that are taken up into forest trees are eventually returned to the forest floor except for the amount carried out of the forest in logs and other forest products. Minerals are returned to the surface of the soil by litterfall and through the washing and leaching effects of rain. Minerals are also added to the soil by the belowground dying and decaying of roots.

Rates of nutrient cycling and the accumulation of nutrients within the naturally occurring loblolly pine forests are being altered as the demand for wood increases and intensive management develops. Genetic improvement, site preparation, weed control, fertilization, and complete tree harvest alter the nutrient cycle. Studies of nutrient cycling in loblolly pine will help resolve problems associated with increased production, efficient use of fertilizer, soil productivity and overall quality of the environment (Wells and Jorgensen, 1975).

Litterfall

Litter is defined as the organic remains of plants and animals that are found either on the soil surface or buried in the mineral soil itself. This includes large woody debris, such as whole tree trunks, in addition to leaves, twigs, fruits and the like, that may occur in abundance on the soil surface. Belowground litter includes dead roots, large and fine. Roots decompose and are an important source of nutrients although we have tended to think only in terms of the surface litter layer (Wells and Jorgensen, 1975).

Litterfall is made up of leaves, small twigs, bark, and fruits. Bray and Gorham (1964) estimate that between 1,500 to 5,000 kilograms of oven-dry organic material is added to the surface of a fully stocked hectare in a single year. Leaf litter accounts for roughly 70 percent of the total. Under open conifer stands the weight of litterfall may drop below 100 kg/ha, and in the tropical rain forest as much as

10,000 kg may be accumulated (Lutz and Chandler, 1946; Bray and Gorham, 1964).

Several studies have been conducted in loblolly pine stands to look at the variation in litterfall. Litterfall varies from year to year but tends to increase as the forest canopy closes. Wells and Jorgensen (1975) conducted an experiment in three different loblolly pine plantations. The amount of litterfall, including branches, was related to basal area and age of the plantation (Table I). Thinning also influenced litterfall. Plantation 3 was a productive site, yet, as long as 14 years after it was thinned at age 25, the litterfall and the needle component in its litterfall were still below that of plantation 1 for the five years before it was initially thinned at age 16. Similarly, in plantation 2, litterfall six years after the last thinning had not reached the level of plantation 1 before thinning.

Needle fall in plantation 3 during the nine years of data collection averaged 4,500 kg/ha/yr, with a range from 3,100 to 5,700. In plantation 1 during the five years before it was thinned, needle fall averaged 6,134 kg/ha/year. Besides the needles and branches, pieces of bark and fine, unidentified material fell from the trees. This material amounted to approximately 5 % of the litter weight, but contained 20 % of the N, 12 % of the P, 5 % of the K, 3 % of the Ca, and 10 % of the Mg.

TABLE I

ANNUAL RATES OF LITTERFALL OF LOBLOLLY PINE PLANTATIONS BEFORE AND AFTER THINNING

Plantation No. and Age at Latest Thinning	Plantation Age (yrs) When Measurements Were Made	Average Basal Area	Litterfall (kg/ha)
		m^2/ha	
1 16 yrs.	11-15	49.2	7,749
	16-17	22.2	3,374
2 27 yrs.	24-27	33.8	5,129
	28-29	21.0	2,213
3 25 yrs.	31-39	31.6	6,033

Source. Wells and Jorgensen, (1975).

Litterfall in pine stands also contributes substantially to the forest fuel load. Sackett (1975) reported that litter accounted for 86 % of the total fuel weight of a 1-year-old loblolly and longleaf pine site in Florida and South Carolina, with the remaining 14 % made up of pine branches and miscellaneous material. In 4-year-old and 12-year-old stands, litter accounted for 74 and 55 % of the fuel weight, respectively, with pine branches and miscellaneous material accounting for the remainder. Lockaby and Boyd (1986) reported that average annual litterfall for a 2-year period was 7178 kg/ha/yr in an 18-year-old loblolly pine stand (Table II). Likewise, Curtis et. al, (1977), reported annual litterfall reached 7,802 kg/ha in a 40-year-old loblolly pine stand in South Carolina, but with a lower BA of 21.8 m^2/ha. More studies concerning litterfall have been located in North and South Carolina, primarily because these states are well within the natural range for loblolly pine. As BA increased, so did litterfall, stand age didn't seem to have an influence on the amount of litterfall that fell during a certain time period.

Metz (1952) studied litterfall in nine forest stands in the South Carolina Piedmont, one of which was a 10-year-old loblolly pine plantation, and found that hardwood forest stands return larger quantities of N, Ca, and Mg than loblolly or shortleaf pine (*Pinus echinata* Mill.) stands. Metz et al. (1970) noted that the forest floor under

TABLE II

ANNUAL LITTERFALL RATES IN LOBLOLLY PINE STANDS OF SOUTHEASTERN UNITED STATES

Source	Location	Stand Age	Basal Area	Litter Component: Pine Foliage	Litter Component: Total
		years	m^2/ha	-----kg/ha------	
Metz 1954	North Carolina	10	23.7	4,227	4,550
Wells et al. 1972	South Carolina	62	22.0	3,241	4,587
Nemeth 1973	North Carolina	8	7.9	2,640	
		9-10	24.5	3,590	
		11	26.0	3,700	
Wells et al. 1975	North Carolina	11-15	49.2	6,134	7,749
		24-27	33.8		5,129
		31-39	31.6	4,500	6.033
Wells et al. 1972	North Carolina	14-17	30.0	4,943	6,094
Gresham 1982	South Carolina	20	25.7	4,370	7,799
Curtis et al. 1977	South Carolina	40	21.8		7,802
Lockaby and Boyd 1986	Louisiana	18	31.0		7,178
Rachal 1986	Oklahoma	11	5.74	2,696	3,150
		11	11.47	4,323	4,685
		11	22.94	6,923	8,013

loblolly plantations in the Virginia Piedmont was thicker than under other species of pine, although content of mineral elements tended to be higher in litter from white pine (Pinus strobus L.). Wells et al. (1972) stated that litterfall plays a more dominant role in the cycling of elements between trees and soil than does throughfall water or stemflow in southeastern hardwood and natural loblolly stands. The mass of the forest floor in loblolly pine plantations is thought to approach stability in approximately 15-20 years (Switzer and Nelson, 1972).

Seasonal Litterfall Patterns

Litterfall occurs throughout the year, but there are seasonal peaks for many types of tissue. The greatest amounts of pine needles fall in the fall and winter months. Lockaby and Boyd (1986) reported that in an 18-year-old loblolly stand, 48 % of the yearly total fell during the peak months of October, November, and December (Figure 3). Boyer and Fahnestock (1966), also reported that 47 percent of the annual total of litter deposition fell during September, October, and November. The litterfall averaged about 6 % for all other months. Wells et al. (1972) reported a single peak of litterfall during September, October, and November for a natural loblolly pine stand in the Piedmont of North Carolina, with low rates the rest of the year. Likewise Van Lear and Goebel

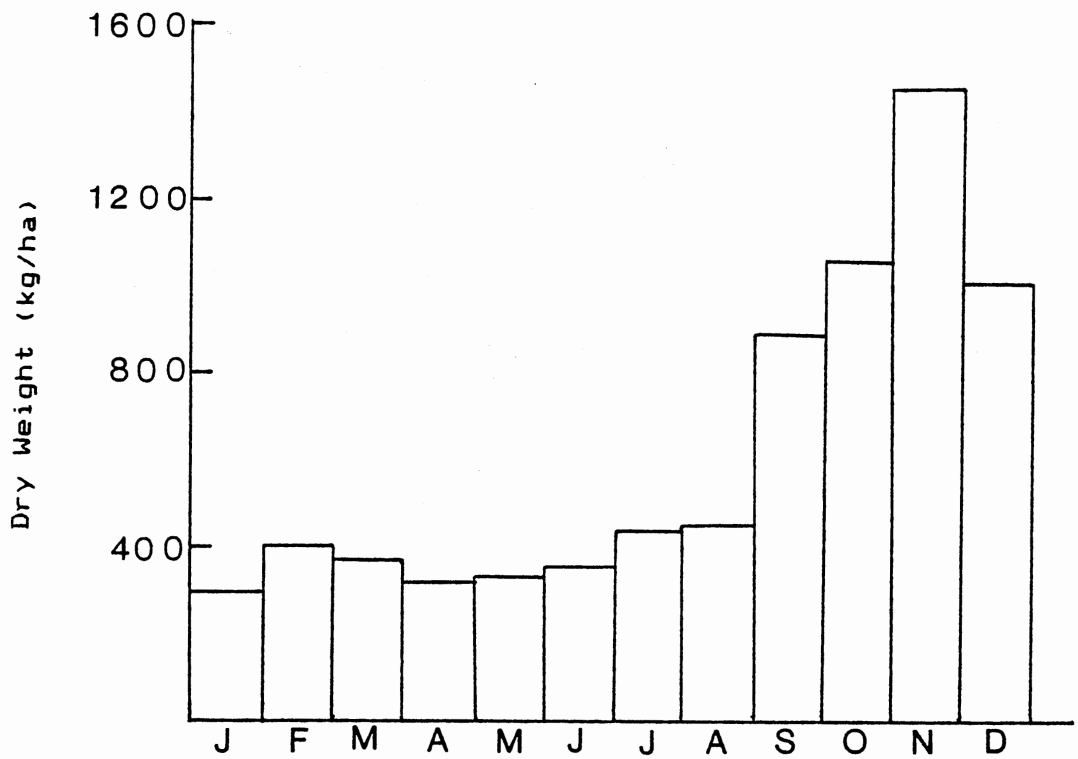

Figure 3. Source: Lockaby; 1986. Seasonal Trends in Litterfall for an Unthinned Loblolly Pine Stand in North Louisiana

(1976) reported that the greatest amounts of needles fell in the fall and winter months in three loblolly plantations in South Carolina.

Switzer and Nelson (1972) estimate that 40 and 54 percent of the annual N and Ca requirements of 20-year-old loblolly pine plantations are derived from litter decomposition. In addition to serving as a storehouse for nutrients, the forest floor modifies the effect of climate on soil temperature and moisture flow (McColl, 1973).

Storms have a large influence on the amount and timing of litterfall. The mobile nutrients, N, P, and K which are capable of rapid redistribution within the plant, are influenced the most. These elements are usually translocated out of tissues which are becoming senescent or dormant. The effect of storms is to remove plant tissue prematurely, thus, a large quantity of these mobile elements are returned to the forest floor in litter before the natural translocation processes can occur (Gosz et al., 1972). The immobile elements, Ca and Mg, are affected differently since premature litterfall results in a decrease in the return of these elements to the forest floor.

Yearly litter and nutrient fall must be thought of as a dynamic, everchanging process. Yearly or seasonal differences in litterfall affect subsequent processes of decomposition, mineralization, and immobilization. There can be any number of combinations of monthly and yearly periods of abundant or sparse litter and nutrient fall with monthly or yearly periods of rapid or negligible decomposition (Gosz and others, 1972).

Understory Vegetation

Understory vegetation plays an important role in the circulation of nutrients. Its contribution tends to be strongest in the early and late stages of stand development, when the amount of light reaching the understory is greatest. Under relatively open conditions understory vegetation may contribute up to 28 percent of the total litter (Bray and Gorham, 1964). Under white pine and mixed hardwood forests in Connecticut, Scott (1955) found that subordinate vegetation accounted for about 15 percent of the annual weight of the litter. The shrubs and herbs contained higher percentages of many nutrient elements than did the tree foliage, so that as much as one-quarter of the annual return of nutrients to the soil came through the lesser plants.

Litter Removal

Since nutrients in the litter and even in the semi-decomposed humus are not in a form immediately available to trees, the removal of litter or humus may have no immediate effect on site quality. In parts of Europe where litter and humus were removed repeatedly for livestock bedding, mulching, and other purposes, however, litter removal resulted in severe deterioration of the site (Lutz and Chandler, 1946). German investigations indicate that the deficiency of N in soils subject to litter removal plays an important part in the impoverishment of the soil.

The losses in nutrients resulting from litter removal may be more than counterbalanced by improved soil properties. The removal of litter from uplands may result in warming the soil, reducing soil acidity, stimulating soil biota, and generally improving site conditions (Lutz and Chandler, 1946).

CHAPTER III

METHODS AND MATERIALS

Study Area

The study site was located in a 12-year-old loblolly pine plantation in southeastern McCurtain County, near Broken Bow, Oklahoma, owned by the Weyerhaeuser Company. The stand of loblolly pine was planted in 1976. Hardwood species associated with loblolly are sweetgum (*Liquidamber styraciflua* L.), black tupelo (*Nyssa sylvatica* Marsh), hickories (*Carya spp*.), and water oak (*Quercus nigra* L.).

The U.S. Soil Conservation Service mapped the area as Cahaba fine sandy loam (Typic Hapludult, fine-loamy, siliceous, thermic), with 0 to 1 % slopes (USDA, 1974). The Cahaba series consist of deep, nearly level, well-drained soils on terraces and uplands. These soils formed in loam sediment under a cover of pines and hardwoods. The site is on the upper coastal plain in close proximity to the Mountain Fork and Little Rivers (Gray and Galloway, 1959).

McCurtain County has a warm, moist temperate climate. The spring and autumn months are mild, with cool nights and warm days. Summers are hot, and the high humidity causes high temperatures to be unpleasant (USDA, 1974). The average daily maximum temperatures in McCurtain County range from 12 ^{o}C. in January to 34 ^{o}C. in July and August. Average daily minimum temperatures range from 1 ^{o}C. in January to 20 ^{o}C in July. Precipitation averages 119 cm per year and is well distributed throughout the year. Spring is the wettest season, receiving 31 % of the average yearly precipitation (USDA, 1974).

Experimental Design and Treatment Applications

The study design included three blocks with two treatments on each block. The two treatments were three levels of thinning with each level including a fertilized and an unfertilized treatment (Figure 4). However, only the unfertilized plots are reported on in this study. Three 0.10 ha square plots were randomly located within each block. The thinning treatments were applied in March, 1984 and were:

1) thinned to 25 % of the original basal area (25 BA) (7.79 m^2/ha) (33.94 ft^2/ac)

2) thinned to 50 % of the original basal area (50 BA) (12.58 m^2/ha) (54.52 ft^2/ac)

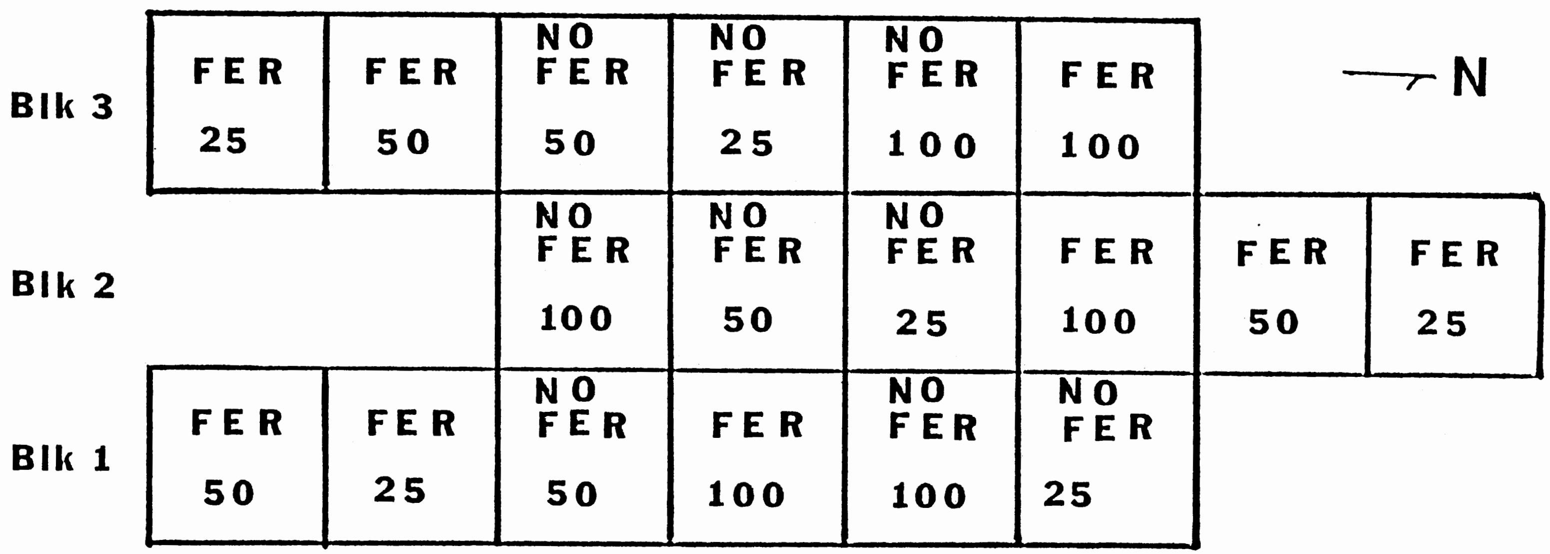

Figure 4. Experimental Design of the Present Study

3) unthinned (100 BA) (26.61 m^2/ha) (115.97 ft^2/ac) Since the treatments were set up to simulate precommercial thinning, all slash was left where it lie on the site. Stand characteristics following thinning can be found in Appendix A.

Sample and Data Collection

Litterfall

To obtain an estimate of litterfall, five litter traps were randomly placed on each plot that was not fertilized. Each trap was 0.49 meters square and had wooden sides 15.0 cm deep. The screen that lined the bottom of the boxes was a mesh of 0.32 cm in size. The traps were placed on site in mid September, 1984.

Placement of litter traps was achieved by randomly drawing two-digit numbers from the table of random numbers found in Steele and Torrie (1980). Using the northeast corner as a starting point, the first number drawn represented the number of paces into the plot heading west. From this point, the second randomly selected number of paces was used to locate the position of the box by heading south (Rachal, 1984).

Litterfall collection began in October of 1984 and continued to April of 1987. At this time the traps were taken up and the stands were thinned back to their original density levels. Litterfall was collected on a monthly basis and each collection period was carried out on the same day of every month to reduce variation among samples. When the material was taken from the traps, it was placed in paper sacks with trap and plot number marked on the bag.

Litterfall was then separated into three categories: 1) pine foliage, 2) pine bark and branches, and 3) miscellaneous. The miscellaneous category was mainly comprised of hardwood leaves and twigs. After separation, the litterfall samples were placed in ovens and dried at 70 °C until a constant weight was obtained. After drying, all samples were weighed to the nearest 0.01 gram.
The pine foliage was then ground to pass through a 1-mm sieve. A composite sample from each plot was analyzed for N, P, K, Ca, and Mg.

Rachal (1986), collected litterfall data on this study from October, 1984 through October, 1985. Rachal determined litterfall weights (pine foliage, pine branches, and misc. material), for this period and also performed N analysis on pine foliage from fertilized and unfertilized plots. Starting May, 1986 and continuing to April, 1987, the present study determined litterfall weights (pine foliage, pine branches, and misc. material), and nutrient concentrations on the pine foliage for the elements N, P, K, Ca, and Mg.

Digestion

The method used for wet digestion is a modification of a method described by O'Neill and Webb (1970), that used Se powder as a catalyst. Scientists at the Southern Forest Experiment Station found that selenium tended to interfere with the P determination and used copper sulfate instead.[1]

Approximately 0.25 grams of plant material was carefully weighed, placed into a 250 ml digestion tube and 2.5 ml of copper sulfate solution were added. The copper sulfate solution consist of 62.5 grams of $CuSO_4 \cdot 5H_2O$ in 500 ml of water. Concentrated sulfuric acid (25 ml) was added to the digestion tube which was placed into the block and heated according to the following temperatures and time.

Temperature, °C	Time at the temp., hrs.
150	1
200	0.5
250	0.5
300	0.5
350	2.0
370	1.0

1 Personal communication, Allen Tiarks, Southern Forest Experiment Station, Alexandria, LA.

The total digestion process takes 5 and 1/2 hours to complete. The color of the digested sample should be light green. The tubes are taken out of the block after digestion is complete and allowed to cool. After cooling, about 50 ml of distilled water is added. After cooling again, the tubes are shaken, cooled, filled to the 250 ml mark with distilled water, mixed again and aliquots are taken for determination of N, P, K, Ca, and Mg. The method has been compared to conventional methods and good agreement was found.

Nitrogen Analysis

Nitrogen concentrations were determined by utilizing the Labconco 65000 Rapid Kjeldahl distillation unit which is designed to conform with standard micro-Kjeldahl distillation techniques. Known samples were tested and accurate results were obtained. For methods and procedures, refer to Appendix B.

Phosphorus Analysis

Phosphorus concentrations were determined by using the ascorbic acid colormetric procedure (Adams et. al., 1981). The concentrations were determined by using the spectrophotometer set on a wavelength of 885 nm. For methods and procedures, refer to Appendix C.

Potassium, Calcium, and Magnesium Analysis

Potassium, Ca, and Mg concentrations were determined by atomic absorption spectrophotometry (AA). Before the samples are run through the AA, all samples must be filtered through a size 47 mm filtering system.

A standard curve must be generated in order to evaluate the samples. Two EPA samples were also ran to make sure the AA is set up correctly. If a sample's concentration is higher than the standards that were used to develop the standard curve, higher standards must be prepared and the samples analyzed again.

Analysis of the Data

The data were analyzed for statistically significant differences among the thinning treatments. All monthly data were averaged for each treatment, and the treatment means were compared using the Duncan's New Multiple Range Test. Significance was declared at the 0.05 level of probability. Sources of variation used in the Analysis of Variance (AOV) for this study were as follows: (1) among blocks, and (2) among treatments. The AOV's generated mean squares that were used to test hypotheses concerning treatment means.

Duplicate samples were run for each element to test reliability. Also, plant material received from the

Southern Forest Experiment Station was used to test our methods and procedures. After analyzing the samples, we found close agreement in concentration levels for each element as shown in Appendix D.

CHAPTER IV

RESULTS AND DISCUSSION

Litterfall

Most pine foliage fell between August and December, although some was collected in every month (Figure 5). The peak period of annual leaf fall occurred between August and December, when about 63-72 % of the needles were cast. These amounts and percentages are in close agreement with Gresham (1982) (Table III), and Lockaby and Boyd (1987), (Table II). The total quantity of litterfall (pine foliage, pine branches, and misc. material), differed significantly from the 25 BA plots and the unthinned plots, i.e., the total collected in the 25 BA plots totaled 2,943.8 kg/ha, the 50 BA plots totaled 3,899.8 kg/ha, and the unthinned plots totaled 5,054.5 kg/ha (Table IV). Rachal (1986) reported pine foliage weights of 2696.9 kg/ha/yr for the 25 BA plots during the first year after thinning and 4323.2 kg/ha/yr and 6,923.8 kg/ha/yr for the 50 BA and 100 BA plots, respectively. Results found in this study represent a decrease of 13.4 %, 31.3 %, and 73.8 % for the 25 BA, 50 BA, and 100 BA plots, respectively compared to Rachal's data. However, the figures for total

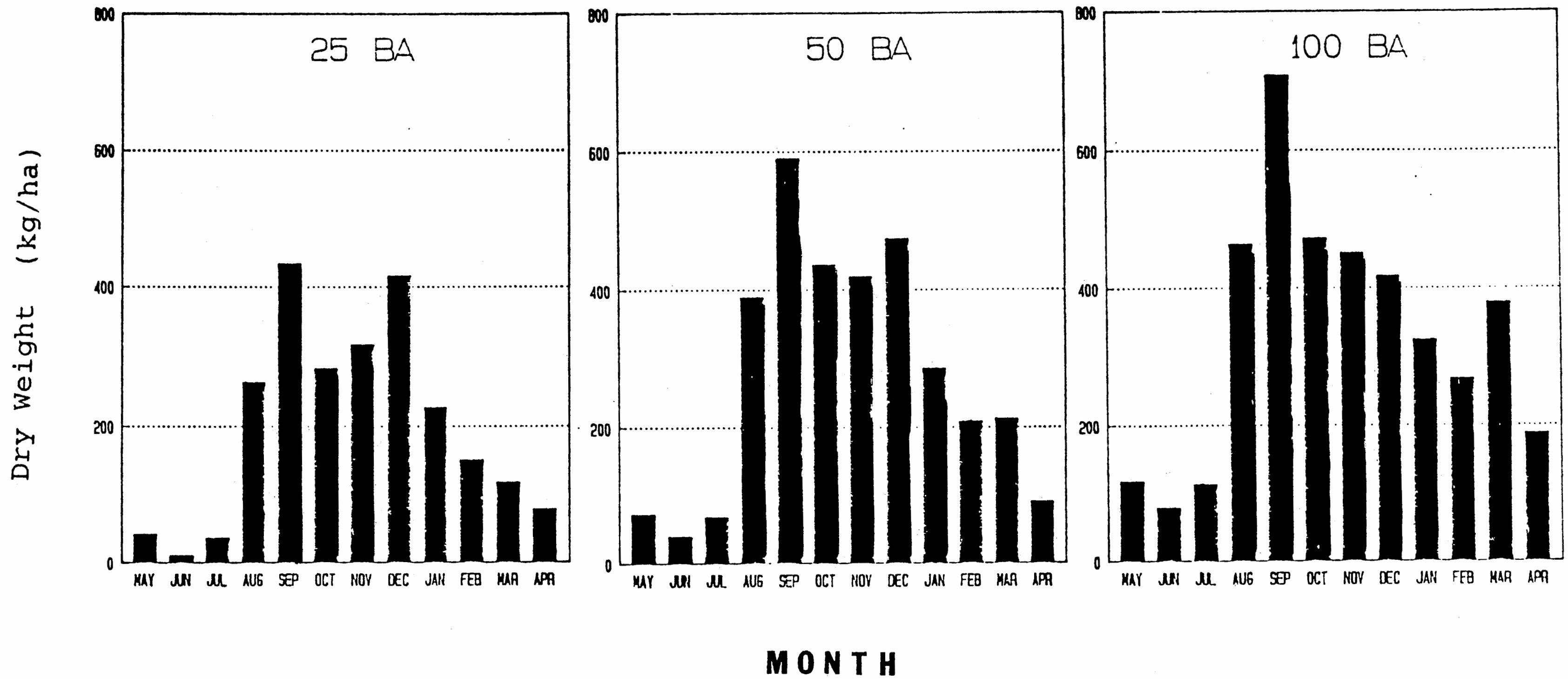

Figure 5. Seasonal Trends in Litterfall at Each Level of Stand Density.

TABLE III

ANNUAL LITTERFALL (kg/ha) OF AN
UNTHINNED LOBLOLLY PINE STAND

Component	1976-77	1977-78	1978-79	1979-80	1976-80
Litterfall	4119	4339	3984	5038	4370
Total Fol.	5221	5392	4873	6011	5374

Source: Gresham, 1982. Litterfall Patterns in Mature Loblolly and Longleaf Pine Stands in Coastal South Carolina.

TABLE IV

PATTERNS OF ACCUMULATION AND ANNUAL PRODUCTION OF LITTERFALL FOR EACH LEVEL OF STAND DENSITY

Date	Thinning Level	Litterfall Component: Pine Foliage	Pine Branches	Misc.	Total
		--------kg/ha--------			
5/86	25	41.97 B*	4.15	4.96	51.08
	50	73.06 AB	5.10	3.40	81.56
	100	118.03 A	13.81	10.48	142.32
6/86	25	10.41 A	7.55	16.94	34.90
	50	39.93 A	18.43	11.36	69.72
	100	78.98 A	14.63	18.44	112.05
7/86	25	36.19 B	1.97	25.44	63.60
	50	68.91 AB	3.81	11.77	84.49
	100	113.13 A	7.42	13.74	134.29
8/86	25	263.26 A	12.65	80.00	355.91
	50	389.73 A	15.10	48.91	453.74
	100	463.81 A	75.85	57.96	597.62
9/86	25	434.01 A	24.15	53.27	511.43
	50	590.40 A	12.18	28.30	630.88
	100	707.07 A	141.02	35.10	883.19
10/86	25	283.26 A	14.90	44.69	342.85
	50	436.53 A	92.65	24.70	553.88
	100	472.24 A	29.12	78.85	580.21
11/86	25	317.28 A	1.50	53.20	371.98
	50	419.75 A	2.38	32.04	454.17
	100	450.81 A	65.24	53.54	569.59
12/86	25	416.26 A	7.75	28.50	452.51
	50	474.49 A	8.64	33.54	516.67
	100	417.48 A	37.21	37.69	492.38
1/87	25	227.00 A	2.24	33.13	262.37
	50	286.12 A	5.17	7.82	299.11
	100	324.83 A	10.82	24.22	359.87
2/87	25	150.88 B	9.32	12.31	172.51
	50	208.71 AB	8.10	7.89	224.70
	100	268.57 A	81.29	20.55	370.41

* Letters show comparisons among thinning levels for each month and for the annual totals. Weights followed by the same letter are not significantly different based on Duncan's NMR test at the 0.05 level.

TABLE IV (Continued)

Date	Thinning Level	Pine Foliage	Pine Branches	Misc.	Total
		Litterfall Component			
		----------------kg/ha	-------------		
3/87	25	117.89 A*	3.88	5.92	127.69
	50	212.79 B	160.40	12.04	385.23
	100	379.18 C	58.10	53.27	490.55
4/87	25	78.50 B	89.80	28.71	197.01
	50	91.15 AB	19.86	34.69	145.70
	100	187.82 A	72.45	61.77	322.04
Annual Totals	25	2376.91B	179.86C	387.07B	2943.84C
	50	3291.57AB	351.82B	256.46C	3899.85B
	100	3981.95A	606.96A	465.61A	5054.52A

* Letters show comparisons among thinning levels for each month and for the annual totals. Weights followed by the same letter are not significantly different based on Duncan's NMR test at the 0.05 level.

litterfall collected is somewhat lower. This is probably due to low amounts of precipitation (137.79 cm) during the year (1985), when the needles were produced, compared to 183.54 cm of precipitation which fell during 1984.
Total litterfall decreased from 1984 to 1987 by 7 %, 20 %, and 58 % on the 25 BA, 50 BA, and 100 BA plots, respectively.

Yearly pine foliage deposition ranged from 2,377 kg/ha in the 25 BA plots to 3,982 kg/ha in the unthinned plots. Pine foliage made up approximately 81 % of the total litter, while pine branches accounted for 9 %, and miscellaneous material, on the average, produced 10 %. In the 25 BA plots, the miscellaneous component was 13.2 % of the total, the 50 BA plots averaged 6.6 %, and the unthinned plots totaled 9.2 %. The difference is due to a large amount of understory vegetation in the thinned plots. Pine branches accounted for 6.1 % of the total on the 25 BA plots and 9.0 % and 12.0 % on the 50 BA and unthinned plots, respectively. The higher percentage in the unthinned plots is usually accounted for by increased natural pruning.

Nitrogen Content

Every month in which samples were collected, ANOVA results indicated that thinning had no apparent effect on the concentrations of N found in the litter (Table V). Nitrogen concentrations were consistently lower in the 25 and 50 BA plots during the dormant season. The concentrations reported here are similar to those presented by Rachal (1986) who also found that N concentrations were lower during the months of September through January. The results are also similar to those Rachal (1986) reported on N concentrations during the growing season. The 25 BA and 50 BA plots showed higher concentrations than the 100 BA plots.

Creighton (1984) stated that thinning results in higher soil temperatures and increased moisture conditions allowing for higher microbial populations and activity to increase decomposition rates. With this in mind, it may be assumed that litter is broken down more quickly on the 25 BA plots, which would increase the rate of N release from the litter while reducing N concentrations and enhancing N availability.

The amount of N transferred to the forest floor via litterfall was directly related to stand density and is controlled by the amount of litterfall accumulated under each level of thinning (Table VI). The amount of N transferred to the forest floor was 12.64 kg/ha/yr, 17.38 kg/ha/yr, and 21.50 kg/ha/yr for the 25 BA, 50 BA and 100 BA, respectively.

TABLE V

NITROGEN CONCENTRATIONS OF THE LITTER AS AFFECTED BY THINNING

Date	Thinning Level 25 BA	50 BA	100 BA
	------------------	%N	------------------
5/86	0.60 A*	0.56 A	0.60 A
6/86	0.59 A	0.56 A	0.59 A
7/86	0.57 A	0.55 A	0.58 A
8/86	0.55 A	0.53 A	0.57 A
9/86	0.51 A	0.50 A	0.54 A
10/86	0.51 A	0.50 A	0.54 A
11/86	0.49 A	0.48 A	0.53 A
12/86	0.52 A	0.51 A	0.54 A
1/87	0.57 A	0.55 A	0.54 A
2/87	0.57 A	0.57 A	0.56 A
3/87	0.57 A	0.57 A	0.56 A
4/87	0.58 A	0.57 A	0.56 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

TABLE VI

NITROGEN CONTENT OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	-----------kg/ha (N)-----------		
5/86	0.25 C*	0.41 B	0.68 A
6/86	0.06 B	0.40 A	0.45 A
7/86	0.20 B	0.38 B	0.64 A
8/86	1.46 A	2.09 A	2.57 A
9/86	2.21 C	2.96 B	3.69 A
10/86	1.45 A	2.18 A	2.45 A
11/86	1.55 A	2.04 A	2.29 A
12/86	2.19 A	2.42 A	2.20 A
1/87	1.29 A	1.58 A	1.79 A
2/87	0.86 B	1.19 AB	1.52 A
3/87	0.67 B	1.21 AB	2.14 A
4/87	0.45 B	0.52 B	1.08 A
Annual Totals	12.64 B	17.38 AB	21.50 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

Annual quantities of N transferred in unthinned plots in this study are similar to those presented by Switzer and Nelson (1972), and Van Lear and Goebel (1976), who reported 27.9 kg/ha/yr and 27.3 kg/ha/yr, respectively. However, the amount reported here is lower than the amounts presented by Lockaby and Boyd (1986) and Rachal (1986), who reported 41.4 kg/ha/yr and 48.39 kg/ha/yr. This difference is a result of the varying amount of litterfall that was transferred to the forest floor.

Phosphorus Content

Just as in N concentrations, ANOVA results showed that there were no significant differences in P concentrations between thinning treatments at the .05 level (Table VII). There were no visible trends during the growing season or the dormant season, P concentration remained stable throughout the year at approximately 0.05 %.

Content of P was related to the quantity of litterfall, with the greatest amounts transferred during September through December. The quantities of P were 1.22, 1.72, and 2.37 kg/ha/yr for the 25 BA, 50 BA, and unthinned plots, respectively (Table VIII). The average annual quantities reported here for the unthinned plots are similar to those reported by Van Lear and Goebel (1976) who reported 3.6 kg/ha/yr. However, Lockaby and Boyd (1986) reported a

TABLE VII

PHOSPHORUS CONCENTRATIONS OF THE LITTER
AS AFFECTED BY THINNING

	Thinning Level		
Date	25 BA	50 BA	100 BA
	--------------- %P ---------------		
5/86	0.05 A*	0.07 A	0.08 A
6/86	0.06 A	0.07 A	0.05 A
7/86	0.07 A	0.04 A	0.06 A
8/86	0.06 A	0.06 A	0.07 A
9/86	0.05 A	0.06 A	0.06 A
10/86	0.04 A	0.04 A	0.06 A
11/86	0.04 A	0.04 A	0.05 A
12/86	0.04 A	0.04 A	0.04 A
1/87	0.04 A	0.04 A	0.05 A
2/87	0.04 A	0.04 A	0.05 A
3/87	0.05 A	0.05 A	0.05 A
4/87	0.06 A	0.05 A	0.06 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

TABLE VIII

PHOSPHORUS CONTENT OF THE LITTER AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	---------------kg/ha (P)--------------		
5/86	0.02 B*	0.05 AB	0.10 A
6/86	0.04 A	0.04 A	0.05 A
7/86	0.02 B	0.03 B	0.07 A
8/86	0.16 A	0.24 A	0.32 A
9/86	0.28 A	0.37 A	0.45 A
10/86	0.12 A	0.18 A	0.29 A
11/86	0.13 A	0.19 A	0.25 A
12/86	0.20 A	0.23 A	0.19 A
1/87	0.09 B	0.13 AB	0.17 A
2/87	0.06 B	0.09 B	0.15 A
3/87	0.06 B	0.12 B	0.22 A
4/87	0.04 A	0.05 A	0.11 A
Annual Totals	1.22 B	1.72 AB	2.37 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

higher value of 5.6 kg/ha/yr. This is a result of higher litterfall rates.

Potassium Content

The highest concentrations of K occurred during the summer months of Aug. and Sept. (Table IX). This increase in K is thought to be a result of low precipitation leaching during these dry months. The K concentrations remained stable at approximately 0.06 % from December through June. Lockaby and Boyd (1986) reported similar results, with the exception of December at the 0.06 % level.

Average annual quantities of K transferred to the forest floor via litterfall for the 25 BA, 50 BA, and 100 BA plots were 1.65, 2.38, and 2.85 kg/ha/yr, respectively (Table X). ANOVA results indicate that the quantities are statistically equivalent at the 0.05 level.

The greatest deposition of K for each level of stand density followed the pattern of litterfall, with the greatest amounts showing up during September through December. These months accounted for 76, 76, and 70% of K deposition for the 25 BA, 50 BA, and 100 BA plots, respectively. The annual quantities for the unthinned plots reported here are similar to those reported by Van Lear and Goebel (1976), who reported 3.1 kg/ha/yr. Lockaby

TABLE IX

POTASSIUM CONCENTRATIONS OF THE LITTER AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	%K		
5/86	0.06 A*	0.05 A	0.06 A
6/86	0.04 A	0.05 A	0.05 A
7/86	0.06 A	0.07 A	0.07 A
8/86	0.09 A	0.10 A	0.09 A
9/86	0.08 A	0.09 A	0.09 A
10/86	0.07 A	0.07 A	0.08 A
11/86	0.07 A	0.07 A	0.07 A
12/86	0.05 A	0.05 A	0.05 A
1/87	0.05 A	0.05 A	0.05 A
2/87	0.06 A	0.06 A	0.06 A
3/87	0.06 A	0.05 A	0.04 A
4/87	0.06 A	0.06 A	0.05 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

TABLE X

POTASSIUM CONCENT OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level 25 BA	50 BA	100 BA
	kg/ha (K)		
5/86	0.02 A*	0.04 A	0.07 A
6/86	0.01 A	0.03 A	0.04 A
7/86	0.02 B	0.04 B	0.08 A
8/86	0.24 A	0.40 A	0.43 A
9/86	0.37 A	0.54 A	0.63 A
10/86	0.22 A	0.34 A	0.39 A
11/86	0.22 A	0.31 A	0.34 A
12/86	0.21 A	0.25 A	0.23 A
1/87	0.13 A	0.15 A	0.19 A
2/87	0.09 A	0.12 A	0.17 A
3/87	0.07 A	0.11 A	0.18 A
4/87	0.05 A	0.05 A	0.10 A
Annual Totals	1.65 A	2.38 A	2.85 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

and Boyd (1986), and Switzer and Nelson (1972), reported slightly higher amounts with 5.5 and 5.2 kg/ha/yr, respectively.

Calcium and Magnesium Content

Fluctuations in Ca and Mg concentrations followed the same pattern, with increased concentrations occurring in August and decreasing concentrations in December. The Ca concentrations remained stable at approximately 0.46 % from December through July. Thinning density had no effect on this seasonal trend. ANOVA results showed no significant differences between thinning levels at the 5 % level (Table XI).

The average amounts of Ca returned to the forest floor via litterfall are 12.11, 16.21, and 19.20 kg/ha/yr on the 25 BA, 50 BA, and 100 BA plots, respectively (Table XII). These numbers are very similar to those reported by Van Lear and Goebel (1976), who reported 16.8 kg/ha/yr of Ca was returned to the forest floor on unthinned plots by litterfall. Lockaby and Boyd (1986), on the other hand reported an average of 42.4 kg/ha/yr of Ca returned by litterfall on unthinned plots. This figure is 45% higher than the amount found in this study. The higher figure is a result of the greater quantity of litterfall that fell on the unthinned plots. The months of August through December accounted for 73 % of the Ca returned on the 25 BA plots

TABLE XI

CALCIUM CONCENTRATIONS OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level 25 BA	50 BA	100 BA
	%Ca		
5/86	0.45 A*	0.45 A	0.44 A
6/86	0.46 A	0.45 A	0.45 A
7/86	0.46 A	0.46 A	0.47 A
8/86	0.52 A	0.49 A	0.48 A
9/86	0.53 A	0.49 A	0.50 A
10/86	0.49 A	0.47 A	0.48 A
11/86	0.55 A	0.54 A	0.54 A
12/86	0.51 A	0.48 A	0.47 A
1/87	0.49 A	0.48 A	0.47 A
2/87	0.49 A	0.47 A	0.46 A
3/87	0.47 A	0.47 A	0.45 A
4/87	0.46 A	0.45 A	0.44 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

TABLE XII

CALCIUM CONTENT OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	---------------kg/ha (Ca)-------------		
5/86	0.19 B*	0.32 B	0.53 A
6/86	0.04 B	0.33 A	0.36 A
7/86	0.16 B	0.31 AB	0.53 A
8/86	1.37 A	1.92 A	2.24 A
9/86	2.31 B	2.94 AB	3.55 A
10/86	1.39 A	2.06 A	2.28 A
11/86	1.74 A	2.28 A	2.44 A
12/86	2.16 A	2.29 A	1.97 A
1/87	1.11 A	1.37 A	1.52 A
2/87	0.73 A	0.98 A	1.25 A
3/87	0.55 B	1.00 AB	1.71 A
4/87	0.36 B	0.41 B	0.82 A
Annual Totals	12.11 B	16.21 AB	19.20 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

while 70 and 65 % was returned on the 50 BA and 100 BA plots, respectively.

Mg concentrations followed the same pattern as Ca with an increase occurring in September through November. The rest of the year, Mg concentrations remained stable at approximately 0.04 %. ANOVA tests showed thinning density had no effect on Mg concentrations at the 5 % level (Table XIII).

Mg content totaled 1.06, 1.51, and 1.78 kg/ha/yr for the 25 BA, 50 BA, and unthinned plots, respectively (Table XIV). The results for the unthinned plots are slightly lower than those reported by Lockaby and Boyd (1986) and Van Lear and Goebel (1976), who reported 3.0 and 3.1 kg/ha/yr, respectively.

TABLE XIII

MAGNESIUM CONCENTRATIONS OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	%Mg		
5/86	0.03 A*	0.03 A	0.03 A
6/86	0.03 A	0.03 A	0.04 A
7/86	0.03 A	0.03 A	0.04 A
8/86	0.04 A	0.04 A	0.04 A
9/86	0.04 A	0.04 A	0.04 A
10/86	0.04 A	0.04 A	0.04 A
11/86	0.05 A	0.07 A	0.05 A
12/86	0.04 A	0.04 A	0.04 A
1/87	0.04 A	0.04 A	0.04 A
2/87	0.04 A	0.04 A	0.04 A
3/87	0.04 A	0.04 A	0.04 A
4/87	0.03 A	0.03 A	0.03 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

TABLE XIV

MAGNESIUM CONTENT OF THE LITTER
AS AFFECTED BY THINNING

Date	Thinning Level		
	25 BA	50 BA	100 BA
	----------------kg/ha (Mg)-------------		
5/86	0.01 A*	0.02 A	0.04 A
6/86	0.00 A	0.02 A	0.03 A
7/86	0.01 A	0.02 A	0.04 A
8/86	0.12 A	0.18 A	0.22 A
9/86	0.20 A	0.24 A	0.32 A
10/86	0.13 A	0.19 A	0.22 A
11/86	0.17 A	0.31 A	0.24 A
12/86	0.18 A	0.21 A	0.19 A
1/87	0.10 A	0.12 A	0.14 A
2/87	0.06 A	0.09 A	0.11 A
3/87	0.05 A	0.08 A	0.16 A
4/87	0.03 A	0.03 A	0.07 A
Annual Totals	1.06 A	1.51 A	1.78 A

* Letters following means show comparisons between thinning levels within a date. Means followed by the same letter are not significantly different based on Duncan's NMR test at the .05 level.

CHAPTER V

SUMMARY AND CONCLUSIONS

Litterfall varied from season to season and increased as the forest canopy closed. The peak period of annual leaf fall occurred between August and December, when about 63-72 % of the needles were cast. Pine foliage weights found in this study and those Rachal (1986) reported on the same site one year previous, are significantly different. This large variation is a result of the amount of precipitation that fell during the year when pine needles were produced. Rachal reported pine foliage litterfall weights that were 13.4 %, 31.3 %, and 73.8 % higher than those found in this study for the 25, 50 and 100 BA plots, respectively. The pine foliage litterfall Rachal collected was produced when the site received 183.4 cm of precipitation. However, the following year when this study began, only 137.8 cm of rainfall was received on the site. This factor is probably the major reason for the large difference in pine foliage weights during the different years.

The average rainfall amount for this area is estimated to be 119 cm per year. If this is the case, Rachal's study and this study were performed when an above average rainfall amount occurred. Rachal's study experienced an unusual wet year, while the rainfall influencing this study was closer to the average, yet still above normal. During an average year of precipitation (119 cm), lower pine foliage weights should be expected. These conditions and occurrences are highly variable from year to year. Bray and Gorham (1964), summarized the situation well when they wrote, "Much of the litterfall is dependent on growth processes, and environmental conditions which change plant-tissue production therefore indirectly affect litterfall and are partly responsible for the year-to-year variation."

The nutrient content of litterfall is also variable from year-to-year as a result of the natural variation of nutrient concentrations in plant parts. Timing of litterfall may also magnify nutrient content variation. Most of the nutrient content results were similar to those reported by Van Lear and Goebel (1976). Their study was performed on a site with low productivity potential. Our results are probably similar, due to the fact that the site is located on the extreme outer border for the natural range of loblolly pine. The physiological makeup of loblolly pine in the current study could differ from that of loblolly located well within its natural range. It has been reported that 50 % of the N and P and 60 % of the K is transferred back into the branch before needle abscission occurs. The percentages for this site could be slightly higher, resulting in greater use of elements by the tree and less returned to the forest floor to be recycled. Ca and Mg contents show no visible differences between green and dead needles. If this is the case here, whole tree harvesting could have a drastic impact on the site in terms of nutrient depletion. The only nutrients that would be available for remaining trees are those remaining in undecomposed needles lying on the forest floor. But, once this reserve is used up the availability of nutrients will have to come from some other source, such as fertilizer. With fertilizer cost what they are, some other means of managing site fertility should be implemented, such as selection harvesting or clear cutting with the branches and needles spread evenly over the cut area.

Rachal (1986) reported that elemental dynamics were much more sensitive to changes in stand density than to additions of fertilizer. This is because elemental capital of the site was, and is, at a level sufficient for pine growth. After statistical analysis, the null hypothesis was rejected and it is concluded that different thinning densities do have an effect on the amounts of pine foliage litter produced and foliar nutrient concentrations.

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APPENDIX

APPENDIX A

STAND DENSITY LEVELS FOUR YEARS AFTER THINNING

STAND CHARACTERISTICS

BA	Spring '84	Spring '85 m^2/ha	Spring '86	Spring '87
25	7.79	9.69	12.14	15.26
50	12.58	15.48	18.00	21.94
100	26.61	29.68	32.45	35.32

APPENDIX B

NITROGEN DETERMINATION METHODS

Nitrogen Analysis:

The following reagents will have to be mixed or collected before the distillation process can begin.

1) Sodium hydroxide / Potassium sulfide -- Dissolve 450 grams of solid NaOH in water. While still warm, dissolve 10 grams of K_2S in the NaOH solution, cool and dilute to one liter.

2) Methyl red indicator -- Dissolve one gram methyl red in 200 ml ethyl alcohol.

3) Sodium hydroxide standard solution -- 0.01 Normal.

4) Sulfuric acid standard solution -- 0.02 Normal.

Using a 25 ml buret, prepare the sulfuric acid receiving solution by adding the calculated amount of 0.02 N sulfuric acid standard solution to a 125 ml Erlenmeyer flask. Add 5-7 drops of methyl red indicator (see calculation section for amount of standard solution to add). Dilute volume with water to approximately 70-75 ml.

Pipet 20 ml aliquot of sample solution to sample addition funnel on the Rapid Distillation apparatus. Distillation rate must be between 4-5 ml/minute. Adjust water flow control valve to keep water level in the steam reservoir approximately 2/3 full. Introduce sample into sample chamber. Rinse funnel with 3-4 ml portions of water. Raise 125 ml Erlenmeyer flask, containing the receiving solution, into position under the condensate tube of the still. Correct position is where the top of the outlet tube is completely submerged below the receiving solution liquid level. Add 10 ml plus or minus 1 ml of sodium hydroxide / potassium sulfide to the addition funnel. Slowly add alkali to the sample chamber. It is very important to add the caustic slowly, while visually monitoring the standard acid solution to see that the solution does not siphon back through the condenser and into the steam reservoir. Leave column of caustic in the funnel stem at act as a liquid seal. Distill for 3-5 minutes, lower receiving flask and allow distillation to continue for approximately one minute. Titrate excess standard acid with 0.01 N sodium hydroxide standard solution.

Calculations:

Standard acid to add to receiving flask (ml);

$$\frac{(\%\ \text{nitrogen expected in sample}) \times (\text{sample aliquot taken}) \times (\text{g sample wt.})}{(\text{normality of standard acid}) \times 1.4007 \times 250} + 2$$

% Nitrogen;

$$\frac{(\text{ml standard acid} \times \text{normality}) - (\text{ml standard base} \times \text{normality})}{\text{effective sample weight}} \times 1.4007$$

where: effective sample weight = $\frac{\text{weight of sample in grams}}{250}$ X sample aliquot

APPENDIX C

PHOSPHORUS DETERMINATION METHODS

Phosphorus Analysis:

The following reagents must be mixed before total phosphorous can be run.

1) 5 N H_2SO_4 - Add approximately 600 ml of deionized distilled water (ddw) to a clean 1000 ml volumetric flask. Carefully pour 140 ml of concentrated H_2SO_4 into the volumetric flask. Stir, cover flask and set the flask aside until it cools to room temperature. Add ddw until solution is at the 1000 ml calibration mark.

2) Armstrong Reagent - Add 122 ml of concentrated H_2SO_4 to 800 ml of ddw. While solution is hot, add 10.5 grams ammonium molybdate. Add 0.3 grams of antimony potassium tartrate and apply heat to dissolve. Dilute to 1000 ml calibration mark.

3) Ascorbic Acid Solution - Dissolve 3 grams of ascorbic acid in 10 ml of ddw. Dilute to exactly 100 ml and store in refrigerator. Ascorbic acid solution is only stable for one week.

Measure out 10 ml of digested sample and place in a 125 ml Ehrlenmeyer flask. Add ddw until diluted to the 50 ml mark. Add one drop of phenolphtalein indicator to each flask. Adjust the pH of the solution (from acidic to basic) by adding dropwise 6 N NaOH. The proper pH (8.3) is reached when a faint pink color develops. If too much sodium hydroxide is added (solution a very dark pink), apply a few drops of 5 N H_2SO_4 to lower pH. Add 5 ml of Armstrong reagent and 1 ml of ascorbic acid; swirl to mix. Allow a 20 minute reaction period and then read absorbance of solution on the spectrophotometer.

APPENDIX D

COMPARISON OF LABORATORY RESULTS FOR U.S. FOREST SERVICE SAMPLE MATERIAL

Louisiana pine foliage:

Element	Amount Detected mg/g	Our method: mg/g
N	9.4 *	8.9
P	0.91 *	0.87
K	6.27 *	6.36

* Amounts reached at Southern Forest Experiment Station, Louisiana.

VITA

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Master of Science

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