TRIAZINE HERBICIDES AND THE MINERAL NUTRITION OF CONIFERS

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
BOBBY JOE CONNER
1969

This is to certify that the

thesis entitled

TRIAZINE HERBICIDES AND THE

MINERAL NUTRITION OF CONIFERS

presented by

Bobby Joe Conner

has been accepted towards fulfillment
of the requirements for

Ph.D degree in Forestry

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Date February 7, 1969

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ABSTRACT

TRIAZINE HERBICIDES AND THE MINERAL
NUTRITION OF CONIFERS

By

Bobby Joe Conner

In controlled environment experiments, low level soil applications of 2-chloro-4,6 bis (ethylamino)-s-triazine (simazine) and 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine), and their interaction with ammonium and nitrate sources of N, influenced the growth and foliar N nutrition of newly germinated slash (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.) seedlings.

Herbicidal rates of pre-emergence applied simazine and atrazine did not significantly influence the foliar mineral nutrition of Scotch pine (*Pinus sylvestris* L.), white spruce (*Picea glauca* (Moench) Voss), or balsam fir (*Abies balsamea* (L.) Mill.) nursery transplants, except for the foliar concentration of Mg.

Simazine (0.05 - 0.8 ppm) applied without supplemental N increased the foliar N concentration (% N in needles) of 10- and 12-week-old slash pine seedlings grown under controlled environment. The maximum increase was 43.8 percent at the highest rate of simazine. Simazine

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applied at 0.8 ppm with both ammonium and nitrate sources of N (84 ppm N) increased the foliar N concentration of seedlings more than the N sources applied alone. Green and dry foliage weights were increased by simazine treatments of 0.4 ppm, but decreased by 0.8 ppm.

Soil applied atrazine (0.4 ppm) increased the foliar N concentration of 11-week-old slash and loblolly pine seedlings. However, atrazine (0.1 and 0.4 ppm) treatments depressed both the growth and foliar N accumulation of loblolly pine seedlings.

In the greenhouse, soil applications of 0.5, 1.0, and 2.0 ppm simazine increased the foliar N concentration of 16-week-old slash pine seedlings. The maximum increase was 91 percent at the highest simazine level. This increase was greater than where 84 ppm N of either ammonium or nitrate sources of N was supplemented in the nutrient solution. The foliar N concentration of seedlings treated with simazine (0.5 - 2.0 ppm) and both levels (28 and 84 ppm N) of either ammonium or nitrate N was greater than where these N sources were applied alone.

Simazine applied at 0.5 and 1.0 ppm did not affect the foliar N accumulation of seedlings. Decreases in both green and dry seedling weights were found when simazine was applied at concentrations of 0.5 to 2.0 ppm. When a herbicidal rate of simazine (2.0 ppm) was applied to slash pine seedlings, the significant increase in foliar N

concentration was primarily a function of growth reduction. Simazine treatment depressed root weight more than foliage weight.

Simazine treatment at 2.0 ppm increased foliar nitrates. No differences were found in foliar nitrates between ammonium and nitrate treated seedlings, either alone or with simazine. This implies that possibly the ammonium ion was as effectively utilized with simazine as was the nitrate source of N.

In the field, the lower rate of soil applied atrazine (2.25 kg/ha) increased the foilar Mg concentration of Scotch pine, white spruce, and balsam fir over the control. Simazine applied at herbicidal rates (4.50 and 9.00 kg/ha) did not significantly alter the foliar concentration of any element for either species the first growing season. Neither did simazine treatment affect the foliar N concentration of seedlings the second year.

A greater herbicidal injury and mortality occurred in white spruce than the other species. Since the phytotoxic effect of triazine treatment on this species appeared greater when the herbicides were applied alone, it is possible that supplemental N to the triazine plots might have counteracted herbicide phytotoxicity.

Ammonium nitrate applied to simazine plots significantly decreased the foliar concentrations of P, Ca, Cu, Zn, and B for various species. Supplemental N applied with

atrazine significantly decreased foliar P and B, and increased foliage Mg and Mn for some species. Ammonium nitrate applied with simazine and atrazine the first year did not affect the foliar concentrations of N, K, Na, Ca, Fe, or Al for either species. Neither did N applied to simazine plots affect foliar Mg or Mn, or N applied with atrazine affect foliar Cu or Zn of any seedlings.

TRIAZINE HERBICIDES AND THE MINERAL NUTRITION OF CONIFERS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1969

GJ79253
9-3-69

ACKNOWLEDGMENTS

The author is indebted to the Chairman of his Guidance Committee, Dr. D. P. White, for his sustained encouragement and guidance throughout the course of this study. He is also grateful to the other members of the Guidance Committee--Drs. H. D. Foth, J. W. Hanover, and S. K. Ries--for their valuable assistance and suggestions during the course of this work.

The author extends his appreciation to Dr. C. E. Cress for his guidance and assistance with the statistical aspects of the project.

Acknowledgment is made to Geigy Agricultural Chemicals, Ardsley, New York, for their financial support and continued interest in this study.

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Final Examination: February 7, 1969

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CHAPTER I

INTRODUCTION

Triazine herbicides have certain characteristics such as selectivity, persistence, low hazard and economy that have promoted their wide acceptance as herbicides in many forestry operations.

Early forestry research in chemical weed control in this country dates back to at least the 1920's when Toumey and Korstian (1942) were experimenting with sulfuric acid and copper and zinc sulfates. During the period preceding the second World War the scarcity of labor and successful use of volatile oils for weed control in vegetable crops resulted in the introduction of these materials for use in forestry (Eliason, 1954).

In recent years, researchers have found 2-chloro-4,6 bis (ethylamino)-s-triazine (simazine) and 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine) very effective in eliminating a broad spectrum of grasses and broad-leaved weeds in forestry operations. These herbicides are classified as mono-chloro triazines and are the most important triazines from the standpoint of commercial use. Simazine and atrazine are widely used for pre- and post-emergence weed control in forestry operations. The selectivity and long residual action of simazine are desirable traits which lend themselves well to tree plantation establishment and maintenance. However, many species do not show complete tolerance to this chemical, particularly at a young age, and its use is not recommended on 1-0 seedlings (Winget et al., 1963). Although the triazines have only very limited application in tree nursery seedbeds, they have been used for weed control in nursery transplant areas.

The major uptake of triazines is by root absorption and therefore good soil moisture is essential to insure their effectiveness. Simazine has a water solubility of 5 ppm and atrazine 70 ppm (Gysin, 1962). The leaves of plants are unable to absorb measurable amounts of simazine while atrazine shows a considerable effect through the leaves. Affected plants first show chlorosis of the foliage, followed by death of the affected tissue, and with seedlings, death of the plant.

Vigorous tree growth following the use of these compounds in tree plantations has been generally attributed to a reduction in competition (White, 1960). There is now evidence that other physiological processes may be involved in growth stimulation by these compounds (Ries et al., 1967).

In the early 1960's, White (1960) observed improved growth and foliar color following triazine treatment in coniferous plantations. Research by Ries et al. (1963) with

fruit trees and agricultural crops seems to substantiate a "fertilizer effect" following the control of weeds with triazine compounds. The effect manifests itself in improved plant vigor, foliage color, and N nutrition over and above that observed with similar weed control by mechanical means or other types of herbicides. Other workers have reported a "bonus effect" of growth stimulation from triazine treatment (DeVries, 1963; Ries and Gast, 1965; Tweedy and Ries, 1967).

This study attempted to define the growth stimulating effect of triazine treatments on coniferous tree species grown under growth chamber, greenhouse, and field conditions.

Under controlled environment, the growth and nitrogen nutrition effects from low level applications of simazine and atrazine and their interactions with nitrogen were measured on slash (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.) seedling.

In the field, herbicidal levels of triazines were applied both with and without supplemental nitrogen in attempt to detect their influence on coniferous plant nutrition. Three species, Scotch pine (*Pinus sylvestris* L.), white spruce (*Picea glauca* (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill), representing three different genera, were used.

CHAPTER II

LITERATURE REVIEW

Background

Triazine compounds were first synthesized in Switzerland in 1952. No group of herbicides has been more extensively studied or more widely used.

The structure of triazine herbicides is based on cyanuric chloride, the starting material from which these compounds are made (Gysin, 1962). Simazine and atrazine are classified as mono-chloro-s-triazine derivatives and are synthesized by replacing two of the three chlorine atoms of cyanuric chloride with two aliphatic amino-groups. The only structural difference between these two compounds is that atrazine has one ethylamino and one isopropylamino-substituent, where simazine has two ethylamino-substituents. However, this small change in structure causes a drastic difference in the physical and biological properties of simazine and atrazine (Gysin, 1962). The high biological effectiveness of these substituted symmetrical triazines against a wide spectrum of plants has aroused much interest in their use. While they have been found useful as soil

sterilents, they are particularly valuable as selective herbicides on a number of crops.

Triazine Herbicides--Plant Growth and Mineral Nutrition

Triazine herbicides have the unusual property of influencing the growth and N content of some plants when applied at sub-toxic levels (Ries *et al*., 1967). Ries *et al*. (1963) reported that both peach (*Prunus* sp.) and apple (*Malus* sp.) trees treated with simazine had a higher leaf N and more growth than trees where weeds were controlled by other means. Bartley (1957) found that corn (*Zea mays* L.) treated with rates of simazine up to 17.9 kg/ha was greener and taller than where no simazine was used. Tweedy and Ries (1967) found simazine applications increased the dry weight and N content of corn grown at sub-optimal temperature in low levels of nitrate. They found nitrate reductase activity in corn growing on sub-optimal levels of nitrate to increase with simazine concentration. Gramlich and Davis (1967) reported from field studies that corn and Johnsongrass (*Sorghum halepense*) treated pre-emergence with atrazine were smaller and contained a higher percentage N than untreated plants. Plants treated with high rates of atrazine (17.9 kg/ha) had less N uptake (mg N/plant) than the untreated controls. Freney (1965) reported applications of 1 to 5 ppm simazine to the soil of greenhouse pots, increased the dry matter yields and N uptake in corn only

when additional N was applied to the soil. He found simazine applied at 0.06 ppm in solution culture increased the yield of corn tops by 36 percent, the uptake of N by 37 percent, P by 25 percent, Mg by 24 percent, and K by 41 percent. Simazine treatment had no effect on the yield of roots. DeVries (1963) found that simazine applications generally reduced the dry weight of corn and Monterey pine (*Pinus radiata* D. Don), but increased the N content of the shoot. Kozlowski and Kuntz (1963) reported that preemergence soil spray of simazine and atrazine at 1.1 kg/ha to red (*Pinus resinosa* Ait.) and white pine (*Pinus strobus* L.) seedlings in greenhouse flats cause more injury and reduction in dry weight than a delayed herbicide application. Conner and White (1968) found low level soil applications of simazine (0.8 ppm) increased the foliar N content of slash pine seedlings grown in the growth chamber. The dry weight of seedling tops was not changed by simazine applications but a reduction in dry root weight was observed.

Ries *et al*. (1967) reported that rye plants (*Secale cereale* L.) receiving a 0.10 μM (0.02 ppm) application of simazine contained 45 percent more water-extractable protein per plant than controls. The fresh weight per plant was not changed, but there was a progressive decrease in percent dry weight with increasing simazine concentration. Simazine treatments increased the respiration rate more than 10 percent without affecting the respiratory quotient. Increased

respiration may account for the decrease in dry weight. The increased rate of respiration combined with the lower rate of carbohydrate accumulation suggests a greater energy requirement in simazine treated plants. They found simazine applications increased protein accumulation in plants grown with nitrate, but not in plants grown with ammonium as a N source. This response implies that the action of simazine involves some step in the reduction of nitrate to ammonia, or perhaps earlier in the uptake of nitrate but no step in the further conversion of ammonia. The fact that the effect of simazine decreased as the nitrate level approached the optimum suggests that simazine treatment enhances nitrate utilization by the plant (Ries et al., 1967). Gramlich and Davis (1967) found in nutrient culture studies with corn that 4 and 8 ppm of atrazine added to the nutrient solution increased the percentage foliar nitrates without an accompanying decrease in free ammonia as might be expected if atrazine inhibited the enzymatic conversion of nitrate to ammonia. They also concluded that the increased percentage total N of atrazine treated plants was primarily due to increased nitrate.

Triazine Absorption, Translocation, and Metabolism

Various workers have shown by the use of radioactive-labelled triazines that the chloro-triazines are absorbed

through the roots and migrate to the leaves through the xylem in the transpiration stream (Davis et al., 1959; Sheets, 1961). Davis et al. (1959) have shown ^{14}C-labelled simazine applied in nutrient culture moved from the roots to leaves of cucumber (Cucumis sp.) plants in less than 30 minutes. Simazine moved rapidly into the roots but almost no absorption occurred through intact leaves, however, simazine did enter when the cuticle was broken. Ragab et al. (1961) found from labelled $^{14}CO_2$ studies with corn and cucumber seedlings that more radioactivity was present in roots than leaves and stems, and more activity from cucumber extracts than from corn. Sheets (1961) observed that ^{14}C-ring labelled simazine was absorbed by both oat (Avena sativa L.) and cotton (Gossypium hirsutum L.) seedling roots and the ^{14}C was distributed throughout seedling oats within three hours. Absorption and translocation of simazine upward through the treated seedlings was greater at 37°C than at 26°C, and with temperature constant at 37°C, absorption and translocation were greater in plants which were grown in a 66 percent relative humidity. The ^{14}C in leaves of oats was approximately three times that in the leaves of cotton when both species were treated alike. They found the amount of ^{14}C in leaves to be dependent on transpiration and the simazine molecule was apparently changed more rapidly in roots than in leaves. Montgomery and Freed (1961) demonstrated using 2.25 and 9.0 kg/ha of

^{14}C-labelled simazine and atrazine that the total concentration of ^{14}C in corn plants decreased after about 30 days. They confirmed these findings with ion exchange and paper chromatography studies by showing that only trace amounts, if any, of these materials remained unchanged in the plant. In later work, Montgomery and Freed (1964) concluded that although there was a good correlation between resistance and extent of metabolism, even the highly susceptible plants have a limited capacity for degrading these chemicals. Negi *et al*. (1964) studying the metabolism of ^{14}C-labelled and unlabelled atrazine in soybeans (*Glycine max* Merr.), beans (*Phaseolus* sp.), and oats (susceptible), peanuts (*Arachis hypogaea* L.) and cotton (intermediate), and Johnsongrass, grain sorghum (*Sorghum vulgare*), and corn (resistant), found atrazine residues in all plants 11 days after a pre-emergence application of 1.12 kg/ha. Unaltered atrazine found in the plants was roughly correlated with plant susceptibility. All plants converted some atrazine to hydroxy-atrazine and the amount of this material formed was somewhat correlated with resistance as the three resistant species converted at least twice as much atrazine to hydroxy-atrazine as did the susceptible soybeans and oats. Although triazines have been found to be absorbed by plants rather rapidly, only a small portion of the herbicide applied is actually taken up by the plant. For example, if maize seedlings were grown in nutrient solution containing 2 ppm

simazine, between 0.25 and 0.75 ppm simazine would probably be recovered in the leaves (Gysin, 1962).

Triazine Herbicides--Mechanism of Action

Once an absorbed triazine molecule reaches the leaves, it enters the living cell and causes a drastic change in the plants metabolism in the presence of light. Ashton *et al*. (1960) found with kidney beans (*Phaseolus vulgaris* L.) that treatments of simazine and related triazines drastically inhibited CO_2 fixation in the light. The degree of inhibition increased with higher herbicide concentration and longer exposure time. This is undoubtedly an important factor in the phytotoxic characteristics of the triazine compounds. Zweig and Ashton (1962) showed that 0.1 ppm of atrazine applied to kidney beans did not influence CO_2 fixation, while 1 ppm caused 90 percent inhibition after 2 days. From chromatography work, these authors showed that high concentrations (10 ppm) of applied atrazine greatly changed the synthesis of various organic acids in kidney bean leaves. While glycine practically disappeared from the leaves a great increase of aspartic acid formation occurred. These investigators are of the opinion that atrazine affects products of the tricarboxylic acid cycle and interpret the disappearance of sucrose and glyceric acid and the formation of aspartic and malic acid as a result of phosphoenolpyruvic carboxylase activity. In addition, Roth (1958) has shown that plants with high peroxidase activity are relatively resistant to the effects of simazine and other chloro-triazines. He extracted from maize what he called a polyphenol fraction which was able to break dowm simazine _in vitro_ and showed that simazine detoxification was of non-enzymatic nature. He also reported a high catalase activity in these simazine treated plants. Later, Eastin _et al_. (1964) reported a significant increase in the catalase activity of a resistant strand of corn treated with atrazine, where the catalase activity of a susceptible strand decreased with atrazine treatment.

The phytotoxic effects of triazines are due, at least in part, to an interference in the photosynthetic process. Moreland _et al_. (1959) have shown that the conversion of sugar to starches can continue in the presence of triazines but that formation of the sugar is blocked. They demonstrated that by feeding carbohydrates to an entire living barley plant (_Hordeum vulgare_ L.) through severed leaf tips the phytotoxicity of simazine could be reduced. Gast (1958) also showed that the accumulation of starch is inhibited by simazine treatment to coleus (_Coleus blumei_) plants. He also demonstrated that starch-free coleus chloroplasts kept in the dark in a saccharose solution were able to form starch in the presence of simazine, which proves that triazines inhibit sugar formation. The reduction of the photochemical activity by triazine treatment can be measured using isolated chloroplasts in

the presence of redox-dyes (with the so-called Hill reaction). Exer (1958) showed that the triazines inhibit the Hill reaction in the same order of magnitude as the urea herbicides of the CMU type, findings which were confirmed later by Moreland et al. (1959). Moreland et al. (1959) found simazine treatment reduced the photochemical activity (Hill reaction) of isolated barley chloroplasts by 50 percent at 4.6×10^{-6} $\underline{M}$. Within the group of the active chlorotriazines, atrazine inhibits photolysis at a lower concentration than simazine. There is, however, not always a correlation between ability to interfere with the Hill reaction and herbicidal activity. Although the interference with photosynthesis may not be the only mode of action, it is thought to be a principal one. Ashton et al. (1963), studying the structural changes in kidney beans induced by applications of atrazine, found that chloroplasts of both developing and mature primary leaves were ultimately disintegrated in plants treated with atrazine in the light. Comprehensive reviews of the literature on the nature of the triazines in relation to their phytotoxicity and effect upon biological plant processes has been provided by Gramlich and Davis (1967), Gysin (1962), Hamilton (1964), and Montgomery and Freed (1964).

Some crops, notably corn, show a high level of tolerance to assimilated simazine and atrazine through detoxication of the parent molecule (Montgomery and Freed,

1961). The rate of plant metabolism must be rapid enough to prevent accumulation of the lethal concentration of the triazine in the plant, and the pathway of metabolism must alter the parent molecule to a less or non-phytotoxic form. Montgomery and Freed (1960) found that atrazine undergoes extensive conversion to a new compound in the plant. On the basis of the chromatographic behavior of this compound, it was suggested that the product was the hydroxy analog of atrazine, the chlorine atom having been replaced with a hydroxyl group. These observations were confirmed by Castelfranco et al. (1961), who characterized the constituent responsible for the conversion. The properties of the active constituent were subsequently isolated and identified by Roth and Knulsi (1961), and independently by Hamilton and Moreland (1962). It was found to be the cyclic hydroxamate, 2,4-dihydroxy-3-keto-7 methoxy-1,4-benzoxazine. Hamilton and Moreland (1962) showed that the triazine tolerant corn could convert simazine to 2-hydroxy-4,6-bis(ethylamino)-s-triazine (hydroxy-simazine) which is non-toxic. Later, Ries and Gast (1965) reported hydroxy-simazine treatment did not affect the N content in corn plants. Funderburk and Davis (1963) found corn to metabolize both ring and side-chained labelled simazine. Paper chromatography of the extracts of treated plants indicated that hydroxy-simazine and an unidentified ^{14}C product are formed with either type of labelled herbicide. They concluded that all portions of

the triazine ring are subject to complete oxidation by corn, cotton, and soybean plants and appreciable amounts of radioactive $^{14}CO_2$ is given off showing that these plants can completely metabolize a portion of the absorbed triazine. Hamilton (1964) reported the tolerance of several species of Gramineae to atrazine was not related to the ability of their excised roots to metabolize ^{14}C-simazine. He found the content of benzoxazinone derivatives to be directly related to the ability of excised roots to form hydroxy-simazine.

Shimabukuro (1967) found atrazine in corn is rapidly detoxified by hydroxylation, whereas susceptible species such as soybeans and intermediately susceptible species such as peas (*Pisum sativum* L.), dealkylate atrazine to produce still a somewhat toxic product. Even though simazine may be dealkylated by susceptible species, there is still sufficient activity to affect the protein content (Ries *et al.*, 1967).

Although the mechanism whereby triazine herbicides may affect the increase in foliar N and protein content has not been fully established, recent research has provided some of the physical and biochemical changes that occur when various plants are treated with very low concentrations of triazines (Ries *et al.*, 1967; Ries and Gast, 1965; Tweedy and Ries, 1967).

CHAPTER III

METHODS OF INVESTIGATION

Growth Chamber

The influence of varying levels of triazine on slash and loblolly pine seedlings was measured in three controlled environment chamber (Sherer CEL 512-37) studies. Seedlings were grown in 236 ml plastic containers containing 700 g of equal parts Spinks loamy sand (A_1 horizon) and quartz sand (Figure 1). The original mineral soil was obtained from Baker Woodlot, Michigan State University, air-dried and screened through a 2 mm mesh prior to mixing. A sample of this mixture was analyzed for NO_3-N by the Brucine method. P was determined by the Bray P_1 technique, and K, Ca, and Mg, by the flame photometer. pH was read with a pH meter using a 1:1 soil-water ratio and organic matter was determined by loss on ignition at 500°C. Soil analyses by the Michigan State University Soil Testing Laboratory showed the following soil characteristics:

		Available Nutrients (ppm)				
pH	Organic Matter %	NO_3-N	P	K	Ca	Mg
5.6	1.3	15	20	4	323	29

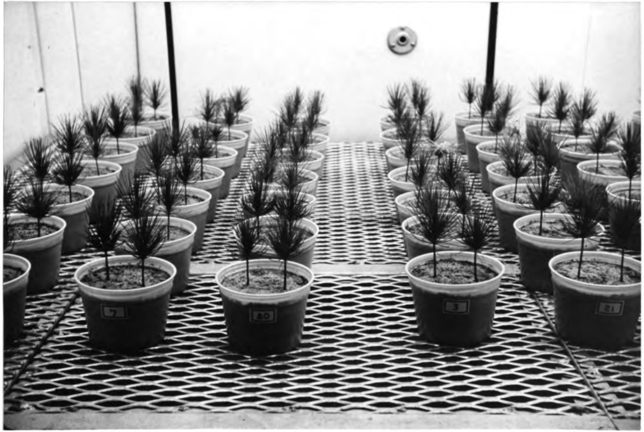

Figure 1. General view of 9-week-old slash pine seedlings in the growth chamber.

The environmental conditions maintained throughout these experiments were a 16 hour light period at 28°C, an 8 hour dark period at 22.5°C, and a relative humidity of approximately 70 percent. The light intensity was approximately 3148 foot candles at the plant foliage level (76.2 cm).

Slash (Dodge G-4) and loblolly pine (Meriwether G-6) seeds were obtained from the Forest Science Laboratory, Southern Forest Experiment Station, Athens, Georgia. These seeds were dry stratified for 2 months in the refrigerator at 2°C prior to germinating in the growth chamber (approximately 7 days) in a glass dish containing a 7.6 cm layer of quartz sand. The seedlings were transplanted 3 days following emergence.

Experiment 1.--Newly transplanted slash pine seedlings were grown for 4 weeks (May 23 to June 20, 1967) in the growth chamber prior to treatment (Tables 1 and 2). The pots were treated with several low levels of simazine (0, 0.05, and 0.1 ppm) and N was supplied at both 14 and 42 ppm N. The herbicide was included in a slightly modified nutrient solution (Table 3) prepared according to solution No. 1 of Hoagland and Arnon (1938). To obtain a solution of simazine that would mix with the nutrient solution, 25 mg of pure simazine[1] (99.2 percent) was dissolved in 50 ml of chloroform. Ten milliliters of this solution

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[1]Obtained from Geigy Agricultural Chemicals, Ardsley, New York.

Table 1.--Nitrogen and simazine treatments used in Experiment 1.

No.	Treatment
1	Control (all nutrients except N)
2	Nitrate nitrogen (14 ppm N)
3	Nitrate nitrogen (42 ppm N)
4	Ammonium nitrogen (14 ppm N)
5	Ammonium nitrogen (14 ppm N) + N-Serve (1.4 ppm)
6	Ammonium nitrogen (42 ppm N)
7	Ammonium nitrogen (42 ppm N) + N-Serve (4.2 ppm)
8	Simazine (0.05 ppm)
9	Simazine (0.05 ppm) + Nitrate nitrogen (14 ppm N)
10	Simazine (0.05 ppm) + Nitrate nitrogen (42 ppm N)
11	Simazine (0.05 ppm) + Ammonium nitrogen (14 ppm N)
12	Simazine (0.05 ppm) + Ammonium nitrogen (14 ppm N) + N-Serve (1.4 ppm)
13	Simazine (0.05 ppm) + Ammonium nitrogen (42 ppm N)
14	Simazine (0.05 ppm) + Ammonium nitrogen (42 ppm N) + N-Serve (4.2 ppm)
15	Simazine (0.10 ppm)
16	Simazine (0.10 ppm) + Nitrate nitrogen (14 ppm N)
17	Simazine (0.10 ppm) + Nitrate nitrogen (42 ppm N)
18	Simazine (0.10 ppm) + Ammonium nitrogen (14 ppm N)
19	Simazine (0.10 ppm) + Ammonium nitrogen (14 ppm N) + N-Serve (1.4 ppm)
20	Simazine (0.10 ppm) + Ammonium nitrogen (42 ppm N)
21	Simazine (0.10 ppm) + Ammonium nitrogen (42 ppm N) + N-Serve (4.2 ppm)

Table 2.--Preparation of nutrient solution treatments used in Experiment 1.

No.[1]	Nitrogen Source		Simazine (5 ppm)	N-Serve (50 ppm)
	1$\underline{M}$ KNO_3	.5$\underline{M}$ $(NH_4)_2SO_4$		
	ml/l			
1	-	-	-	-
2	1	-	-	-
3	3	-	-	-
4	-	1	-	-
5	-	1	-	28
6	-	3	-	-
7	-	3	-	84
8	-	-	10	-
9	1	-	10	-
10	3	-	10	-
11	-	1	10	-
12	-	1	10	28
13	-	3	10	-
14	-	3	10	84
15	-	-	20	-
16	1	-	20	-
17	3	-	20	-
18	-	1	20	-
19	-	1	20	28
20	-	3	20	-
21	-	3	20	84

[1]All treatments contained the following nutrients (1$\underline{M}$ solution, ml/liter: $MgSO_4 \cdot 7H_2O$, 2.0: $CaCl_2 \cdot 2H_2O$, 5.0; KH_2PO_4, 1.0; K_2SO_4, 5.0; KOH, 0.2; Fe-EDTA, 5.0; Minor elements, 1.0 (See Table 3).

Table 3.--Basic nutrient solution.[1]

Reagent	Concentration	Stock	Nitrate	Ammonium
	M	g/l	------ml/l-------	
KNO_3	1	101.0	2.0	-
$(NH_4)_2SO_4$	1	132.0	-	1.0
$MgSO_4 \cdot 7H_2O$	1	246.0	2.0	2.0
$CaCl_2 \cdot 2H_2O$	1	147.0	5.0	5.0
KH_2PO_4	1	136.0	1.0	1.0
K_2SO_4	1	87.0	5.0	5.0
KOH	1	100.0	0.2	0.2
Fe-EDTA	1	0.25	5.0	5.0
Minor Elements[2]			1.0	1.0
H_3BO_3		2.86		
$MnCl_2 \cdot 4H_2O$		1.81		
$ZnSO_4 \cdot 7H_2O$		0.22		
$CuSO_4 \cdot 5H_2O$		0.08		
$H_2Mo_4 \cdot H_2O$		0.02		

[1]The amount of KNO_3 and $(NH_4)_2SO_4$ stock solution used varied with the N level desired. The amounts above represent 28 ppm N.

[2]Minor element stock solution was prepared by adding the listed amount of each element and making the total volume to 1 liter with distilled water.

was mixed with 1 liter of distilled water in a 2 liter round bottom evaporating flask. The chloroform was evaporated from the mixture in 30 minutes using a rotary film evaporator with a water bath temperature of 50°C. The remaining solution was made up to a volume of 1 liter with distilled water to obtain a 5 ppm stock solution. N was supplied with KNO_3 as the nitrate source, and $(NH_4)_2SO_4$ as the ammonium source. The pH of all nutrient solution treatments was adjusted with KOH to pH 6.3. Since ammonium was compared to nitrate as a N source, 2-chloro-6-(trichloromethyl)pyridine[1] (N-Serve) was used to prevent oxidation of ammonium by Nitrosomonas sp. (Goring, 1962). Since N-Serve is relatively insoluble in water, 50 mg of pure N-Serve (99 percent) was dissolved in 50 ml of benzene. This solution was mixed with 1 liter of distilled water in a 2 liter round bottom evaporating flask. The benzene was evaporated from the mixture in 30 minutes using a rotary film evaporator with a water bath temperature of 50°C. The remaining solution was made up to a volume of 1 liter with distilled water to obtain a 50 ppm stock solution. The N-Serve was included in the ammonium treatments at a rate of 10 percent of the respective N level. The treatments were pipetted onto the soil surface at a rate of 100 ml per week (2-50 ml applications) for 6 weeks (June 20 to August 1, 1967).

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[1]Obtained from Dow Chemical Company, Midland, Michigan

Approximately 550 ml per container of treating solution was applied during this period. The pots were periodically watered with distilled water to adjust soil moisture to approximately 15 percent by weight as determined by weighing the pots.

The experiment was arranged in a randomized complete block design with 4 replications. After 10 weeks, green and dry weight measurements were made of seedling foliage, stems, and roots (2 seedlings per pot). The plants were dried at 70°C for 48 hours in a mechanical convection oven, ground in a Wiley mill, and total N was determined on the foliage by the micro-Kjeldahl method. The data was subjected to analysis of variance and treatment means were compared using planned orthogonal contrasts and Tukey's w-procedure.

Experiment 2.--The experimental methods and materials used in this study were the same as that described previously with the following exceptions: Newly transplanted slash pine seedlings were grown in the growth chamber for 3 weeks (August 4 to August 25, 1967) prior to treatment (Tables 4 and 5). Higher levels of both simazine and N were used and the plants were treated for 9 weeks at a rate of 100 ml per week (2-50 ml applications). Approximately 900 ml per container of treating solution was applied during this period. Simazine (0, 0.2, 0.4,

Table 4.--Nitrogen and simazine treatments used in Experiment 2.

No.	Treatment
1	Control (all nutrients except N)
2	Nitrate nitrogen (28 ppm N)
3	Nitrate nitrogen (84 ppm N)
4	Ammonium nitrogen (28 ppm N) + N-Serve (2.8 ppm)
5	Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)
6	Simazine (0.2 ppm)
7	Simazine (0.2 ppm) + Nitrate nitrogen (28 ppm N)
8	Simazine (0.2 ppm) + Nitrate nitrogen (84 ppm N)
9	Simazine (0.2 ppm) + Ammonium nitrogen (28 ppm N) + N-Serve (2.8 ppm)
10	Simazine (0.2 ppm) + Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)
11	Simazine (0.4 ppm)
12	Simazine (0.4 ppm) + Nitrate nitrogen (28 ppm N)
13	Simazine (0.4 ppm) + Nitrate nitrogen (84 ppm N)
14	Simazine (0.4 ppm) + Ammonium nitrogen (28 ppm N) + N-Serve (2.8 ppm)
15	Simazine (0.4 ppm) + Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)
16	Simazine (0.8 ppm)
17	Simazine (0.8 ppm) + Nitrate nitrogen (28 ppm N)
18	Simazine (0.8 ppm) + Nitrate nitrogen (84 ppm N)
19	Simazine (0.8 ppm) + Ammonium nitrogen (28 ppm N) + N-Serve (2.8 ppm)
20	Simazine (0.8 ppm) + Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)

Table 5.--Preparation of nutrient solution treatments used in Experiment 2.

No.[1]	Nitrogen Source: 1$\underline{M}$ KNO_3	Nitrogen Source: .5$\underline{M}$ $(NH_4)_2SO_4$	Simazine (5 ppm)	N-Serve (50 ppm)
	ml/l			
1	-	-	-	-
2	2	-	-	-
3	6	-	-	-
4	-	2	-	56
5	-	6	-	168
6	-	-	40	-
7	2	-	40	-
8	6	-	40	-
9	-	2	40	56
10	-	6	40	168
11	-	-	80	-
12	2	-	80	-
13	6	-	80	-
14	-	2	80	56
15	-	6	80	168
16	-	-	160	-
17	2	-	160	-
18	6	-	160	-
19	-	2	160	56
20	-	6	160	168

[1]All treatments contained the following nutrients (1$\underline{M}$ solution, ml/liter): $MgSO_4 \cdot 7H_2O$, 2.0; $CaCl_2 \cdot 2H_2O$, 5.0; KH_2PO_4, 1.0; K_2SO_4, 5.0; KOH, 0.2; Fe-EDTA, 5.0; Minor elements, 1.0 (See Table 3).

and 0.8 ppm) was included in a slightly modified mutrient solution prepared according to solution No. 1 of Hoagland and Arnon (1938) as described in Experiment 1. Nitrate (KNO_3) and ammonium ($(NH_4)_2SO_4$) sources were supplemented in the nutrient solution at both 28 and 84 ppm N. N-Serve was used in the ammonium treatments as described previously. The experimental design, physical growth measurements, plant chemical analyses, and tests for significance among treatment means were the same as described previously.

Experiment 3.--This experiment was similar to Experiment 2 except a second species, loblolly pine, was included, and atrazine was substituted for simazine as the herbicide. Slash and loblolly pine seedlings were transplanted into each pot on August 4, and 8 respectively. The seedlings were grown in the growth chamber for 3 weeks until treatments were begun on August 25, 1967 (Tables 6 and 7). Treatments were applied for 8 weeks at a rate of 150 ml per container per week (3-50 ml applications) with a total volume of 1150 ml per container being applied during the treatment period. Atrazine (0, 0.1, and 0.4 ppm) was included in a slightly modified solution prepared according to solution No. 1 of Hoagland and Arnon (1938) as described previously. Nitrate (KNO_3) and ammonium ($(NH_4)_2SO_4$) sources were supplemented in the nutrient solution treatments at 0 and 84 ppm N. N-Serve was used in the ammonium treatments as described previously and the physical growth

Table 6.--Nitrogen and atrazine treatments used in Experiment 3.

No.	Treatment
1	Control (all nutrients except N)
2	Nitrate nitrogen (84 ppm N)
3	Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)
4	Atrazine (0.1 ppm)
5	Atrazine (0.1 ppm) + Nitrate nitrogen (84 ppm N)
6	Atrazine (0.1 ppm) + Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm N)
7	Atrazine (0.4 ppm)
8	Atrazine (0.4 ppm) + Nitrate nitrogen (84 ppm N)
9	Atrazine (0.4 ppm) + Ammonium nitrogen (84 ppm N) + N-Serve (8.4 ppm)

Table 7.--Preparation of nutrient solution treatments used in Experiment 3.

No.[1]	Nitrogen Source		Atrazine (5 ppm)	N-Serve (50 ppm)
	1<u>M</u> KNO_3	.5<u>M</u> $(NH_4)_2SO_4$		
	ml/l			
1	-	-	-	-
2	6	-	-	-
3	-	6	-	168
4	-	-	20	-
5	6	-	20	-
6	-	6	20	168
7	-	-	80	-
8	6	-	80	-
9	-	6	80	168

[1]All treatments contained the following nutrients (1M solution, ml/liter: $MgSO_4 \cdot 7H_2O$, 2.0; $CaCl_2 \cdot 2H_2O$, 5.0; KH_2PO_4, 1.0; K_2SO_4, 5.0; KOH, 0.2; Fe-EDTA, 5.0; Minor elements, 1.0 (See Table 3).

measurements, plant chemical analyses, and tests for significance among treatment means were the same as described for Experiment 1. The experiment was arranged in a split-plot design with 4 replications.

Greenhouse

Newly germinated slash pine seedlings were grown for 16 weeks (April 1 to July 22, 1968) in 3.78 liter plastic greenhouse containers containing 3200 g of equal parts Spinks loamy sand (A_1 horizon) and quartz sand. A sample of this soil mixture analyzed by the Michigan State University Soil Testing Laboratory using the techniques described previously (except for organic matter, which was determined by a Leco Carbon Analyzer using high induction combustion with thermal conductivity quantitation) showed the following characteristics:

pH	Organic Matter %	Available Nutrients (ppm)				
		NO_3-N	P	K	Ca	Mg
5.5	2.4	10	1	24	322	24

The same slash pine seed source was used as described for the growth chamber studies. Drainage was provided in each container by 3 holes (1.27 cm diameter) equally spaced around the outer bottom circumferences of the container. The seedlings were transplanted in

greenhouse pots 3 days after emergence and grown for 3 weeks prior to treatment (Tables 8 and 9). Treatments were applied to the soil surface for 13 weeks. A 5 ppm stock solution of simazine in water was prepared as described in Experiment 1. Weekly applications of simazine at rates of 0, 0.5, 1, and 2 ppm were applied independent of the nutrient solution treatments in a single application of 200 ml per container. Approximately 2600 ml per container of simazine solution was applied during this 13 week period. The soil moisture level in each pot was periodically adjusted with distilled water to approximately 15 percent by weight as determined by weighing the pots. Nitrate (KNO_3) and ammonium ($(NH_4)_2SO_4$) sources at both 28 and 84 ppm N were supplemented in a slightly modified nutrient solution prepared according to solution No. 1 of Hoagland and Arnon (1938) as described in Experiment 1. These treatments were applied on alternate weeks in a single application at a rate of 200 ml per container. Approximately 1300 ml per container of nutrient solution treatments were applied during the 13 week period. A stock solution of N-Serve in water was prepared as described previously. This material was included in all nutrient solution treatments at a rate of 10 percent of the 84 ppm N level. Several pairs of fluorescent lights were arranged parallel in the center of the plant bed 63.5 cm from the plant foliage level. These lights were automatically controlled and

Table 8. Nitrogen and simazine treatments used in Greenhouse Experiment.

No.	Treatment[1]
1	Control (all nutrients except N)
2	Nitrate nitrogen (28 ppm N)
3	Nitrate nitrogen (84 ppm N)
4	Ammonium nitrogen (28 ppm N)
5	Ammonium nitrogen (84 ppm N)
6	Simazine (0.5 ppm)
7	Simazine (0.5 ppm) + Nitrate nitrogen (28 ppm N)
8	Simazine (0.5 ppm) + Nitrate nitrogen (84 ppm N)
9	Simazine (0.5 ppm) + Ammonium nitrogen (28 ppm N)
10	Simazine (0.5 ppm) + Ammonium nitrogen (84 ppm N)
11	Simazine (1.0 ppm)
12	Simazine (1.0 ppm) + Nitrate nitrogen (28 ppm N)
13	Simazine (1.0 ppm) + Nitrate nitrogen (84 ppm N)
14	Simazine (1.0 ppm) + Ammonium nitrogen (28 ppm N)
15	Simazine (1.0 ppm) + Ammonium nitrogen (84 ppm N)
16	Simazine (2.0 ppm)
17	Simazine (2.0 ppm) + Nitrate nitrogen (28 ppm N)
18	Simazine (2.0 ppm) + Nitrate nitrogen (84 ppm N)
19	Simazine (2.0 ppm) + Ammonium nitrogen (28 ppm N)
20	Simazine (2.0 ppm) + Ammonium nitrogen (84 ppm N)

[1]All treatments contained N-Serve at a rate of 10% of the 84 ppm N level.

Table 9.--Preparation of nutrient solution treatments used in Greenhouse Experiment.

No.[1]	Nitrogen Source: 1$\underline{M}$ KNO_3	Nitrogen Source: .5$\underline{M}$ $(NH_4)_2SO_4$	Simazine (5 ppm)
	ml/l		
1	-	-	-
2	2	-	-
3	6	-	-
4	-	2	-
5	-	6	-
6	-	-	100
7	2	-	100
8	6	-	100
9	-	2	100
10	-	6	100
11	-	-	200
12	2	-	200
13	6	-	200
14	-	2	200
15	-	6	200
16	-	-	400
17	2	-	400
18	6	-	400
19	-	2	400
20	-	6	400

[1]All treatments contained the following nutrients: (1$\underline{M}$ solution, ml/liter): $MgSO_4 \cdot 7H_2O$, 2.0; $CaCl_2 \cdot 2H_2O$, 5.0; KH_2PO_4, 1.0; K_2SO_4, 5.0; KOH, 0.2; Fe-EDTA, 5.0; Minor elements, 1.0 (See Table 3). All treatments contained N-Serve at a rate of 10% of the 84 ppm N level (168 ml/l of 50 ppm stock solution).

synchronized with the daily photoperiod to provide artificial light for a 16 hour period per day. The experiment was arranged in a randomized complete block design with 4 replications. After 16 weeks, seedling height (measured from soil surface), diameter (measured 2 cm above root collar), and green and dry weights of seedling foliage, stems and roots were recorded (3 seedlings per container). The plants were dried at 70°C for 48 hours in a mechanical convection oven, ground in a Wiley mill and total N was determined on the foliage by the micro-Kjeldahl method. Foliar nitrates were determined by the method of Lowe and Hamilton (1967). The data was subjected to analysis of variance and means were compared by Tukey's w-procedure.

Field

Field plots were located at the Michigan State University Tree Research Center (Figure 2). The soils (Kalamazoo and Spink series) were well-drained with sandy loam plow layers. Soil samples taken from the control plots within each replication were analyzed by the Michigan State University Soil Testing Laboratory using the same techniques as described for the growth chamber. The general fertility level of these soils is described below:

			Available Nutrients (kg/ha)				
pH	Organic Matter %	Lime Requirement (metric tons/ha)	NO_3-N	P	K	Ca	Mg
5.1	2.1	6.3	13.2	24.2	83.2	548.1	84.1

Figure 2. General view of Field Experiment at the Tree Research Center. Sub-plots are 1.67 sq m; mulch is from fresh hardwood chips.

The experimental area was covered by a sown timothy-bromegrass sod and various weed species common to the area. No fertilizer or herbicide treatments had been applied to the area during the past five years. On April 5, 1967, the site was prepared for experimental planting by plowing, discing, and packing lightly.

The experiment was arranged in a split-plot design with 5 replications. Individual plots within each replication contained 1.67 sq m of area (0.91 m x 1.83 m), and each plot was separated from the adjacent plot by a 0.61 m buffer strip. The replications were separated by a 1.07 m strip or walkway.

One plant each of Scotch pine, white spruce, and balsam fir was handplanted in each plot on April 22, 1967. The spruce and fir were 2-3 nursery stock from a northern Wisconsin seed source and the Scotch pine was a 2-0 nursery stock from a southern France source.

The fertilizer and weed control treatments including simazine, atrazine and wood chip mulch were applied on April 29, 1967 (Table 10). Ammonium nitrate (33.5%N) was the only fertilizer used as a variable in the study and was broadcast by hand at rates of 0, 112, and 336 kgN/ha. Additional applications of ammonium nitrate were applied on July 7, 1967, and April 10, 1968, at the same rate. Superphosphate (8.8%P) and sulfate of potash (44.8%K) were broadcast by hand over all plots (except controls) at

Table 10. Fertilizer and weed control treatments used in Field Experiment.[1]

No.	Treatment[2]
1	Control
2	Wood chip mulch
3	Ammonium nitrate (112 kgN/ha)
4	Ammonium nitrate (112 kgN/ha) + wood chip mulch
5	Ammonium nitrate (336 kgN/ha)
6	Ammonium nitrate (336 kgN/ha) + wood chip mulch
7	Simazine 80W (4.50 kg/ha)
8	Simazine 80W (4.50 kg/ha) + Ammonium nitrate (112 kgN/ha)
9	Simazine 80W (4.50 kg/ha) + Ammonium nitrate (336 kgN/ha)
10	Simazine 80W (9.00 kg/ha)
11	Simazine 80W (9.00 kg/ha) + Ammonium nitrate (112 kgN/ha)
12	Simazine 80W (9.00 kg/ha) + Ammonium nitrate (336 kgN/ha)
13	Atrazine 80W (2.25 kg/ha)
14	Atrazine 80W (2.25 kg/ha) + Ammonium nitrate (112 kgN/ha)
15	Atrazine 80W (2.25 kg/ha) + Ammonium nitrate (336 kgN/ha)
16	Atrazine 80W (4.50 kg/ha)
17	Atrazine 80W (4.50 kg/ha) + Ammonium nitrate (112 kgN/ha)
18	Atrazine 80W (4.50 kg/ha) + Ammonium nitrate (336 kgN/ha)

[1]Ammonium nitrate (33.5%N) was fertilizer grade. Herbicide rates refer to active ingredient. Wood chip mulch was applied uniformly over the plots at a depth of 7.6 cm.

[2]All plots (except Treatments 1 and 2) received superphosphate (8.8%P) and sulfate of potash (44.8%K) at rates of 28 kgP/ha and 149 kgK/ha, respectively.

rates of 28 kgP/ha and 149 kgK/ha, respectively.

Atrazine 80W and simazine 80W were applied pre-emergence both alone and in combination with the three N levels. Atrazine was applied at rates of 0, 2.25, and 4.50 kg/ha, and simazine at 0, 4.50, and 9.00 kg/ha active ingredient. Additional applications of simazine and atrazine were applied on April 15, 1968, at the same rate. All materials were sprayed uniformly over the plots and seedlings using a calibrated hand sprayer. A fresh hardwood chip mulch was used as a non-phytotoxic weed control treatment. This material was applied uniformly over the plots at a depth of 7.6 cm. Although triazine treatments provided excellent weed control, plots not receiving these herbicides required sanitation weed control to provide more uniform growing conditions. Sanitation herbicide and insecticide treatments were applied to the experimental area on the following dates:

May 23, 1967 - Applied chlordane (40%) @ 3.4 kg/ha to soil surface.

June 6, 1967 - Sprayed Amitrol-T (21.1%) @ 18.7 liters/ha around border and in walkways.

July 6 and September 1, 1967, and June 3, 1968 - Sprayed paraquat (42%) @ 4.7 liters/ha around border and in plots and walkways.

June 8, 1968 - Foliar spray of Lindane @ 4.7 liters/ha.

August 27, 1968 - Sprayed Amitrol-T (21.1%) @ 18.7 liters/ha around border and in plots and walkways.

Total precipitation at the field plot site for the 1967 growing season was normal as compared to the period of record. However, early spring precipitation was particularly heavy, followed by a dry period in May and another above normal period in June. Total precipitation for the 1968 growing season was above normal as compared to the period of record. Heavy precipitation was recorded in May and June, followed by a normal period in July. Above normal precipitation was again measured in the late growing season during August and September. A comparison between the experimental seasons (1967 and 1968) and the period of record is shown below:

	Growing Season Precipitation (cm)						
	April	May	June	July	August	Sept.	Total
Period of Record (1921-1950)	7.2	9.5	8.6	5.8	6.8	7.8	45.7
1967 Growing Season	9.4	2.9	15.7	2.0	8.4	7.9	46.3
1968 Growing Season	5.5	11.1	20.5	5.9	7.6	9.6	60.2

On September 19, 1967, and October 4, 1968, needles of the current years lateral growth were taken from each tree for nutrient analysis. The samples were dried in a mechanical convection oven at 70°C for 48 hours and ground in a Wiley mill. Total N was determined by the micro-Kjeldahl method. Potassium was determined by the flame photometer and all other elements (P, Na, Ca, Mg, Mn, Fe, Cu, B, Zn, and Al) by a direct reading spectrograph. The data was subjected to analysis of variance and means were compared by planned orthogonal contrasts.

CHAPTER IV

RESULTS AND DISCUSSION

An unusual characteristic of triazine herbicides is that they have been found to increase the growth and N content of some plants when applied at sub-toxic levels (Ries et al., 1967). Although similar effects have been postulated previously in the N nutrition of conifers, this research presents experimental evidence that triazine treatment significantly affects the growth and mineral nutrition of conifers. Experimental results from growth chamber, greenhouse, and field experiments are discussed.

Growth Chamber

Experiment 1.--Neither the foliar N concentration (% N in needles) nor the foliar N accumulation (mg N/top) of 10-week-old slash pine seedlings raised on a soil-quartz sand mixture in a growth chamber were significantly altered by soil applications of non-phytotoxic levels (0.05 or 0.10 ppm) of simazine (Table 11 and Appendix A). However, a trend of increasing foliar N concentration and N accumulation was observed with increasing simazine applied. The maximum increase in foliar N concentration was 11.1 percent

Table 11.--Significance of experimental factors on the foliar nitrogen content and foliar percent dry weight of slash pine seedlings grown in the growth chamber for 10 weeks (Experiment 1).[1]

Source	df		% N	mg N/top	% Dry Wt.
Rep	3				
Simazine (S)	2		NS	NS	NS
Nitrogen (N)[2]	6		**	**	*
Control vs N		1	**	**	**
NO_3 (14 vs 42 ppm N)		1	NS	NS	NS
NH_4 (14 vs 42 ppm N)		1	NS	NS	NS
NO_3 vs NH_4		1	NS	NS	NS
N-Serve		1	NS	NS	NS
NH_4 x N-Serve		1	NS	NS	NS
S x N	12		**	**	*
Error	60				
CV (%)			5.6	14.1	2.9

[1]See Appendix A for data.

[2]Orthogonal contrasts.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

(1.35 to 1.50%N) with 0.10 ppm simazine. This increase in foliar N concentration was approximately one-third that obtained when either nitrate or ammonium sources were supplemented in the nutrient solution at a rate of 42 ppm N. The maximum increase in foliar N accumulation from simazine application (0.10 ppm) was one-half that obtained where 42 ppm N as either nitrate or ammonium forms were supplied in the nutrient solution. The increased N accumulation with increasing simazine applied appears to be a result of an increase in both foliar N concentration and dry weight (Appendix A). Thus, it appears that simazine concentrations up to 0.10 ppm under these experimental conditions provides a stimulating effect upon both the growth and foliar N content of slash pine seedlings. Similarly, Tweedy and Ries (1967) found low levels of simazine applied to the root zone of corn plants grown under both sub-optimal temperature and low nitrate levels increased the N content and dry weight of plants 20 to 25 percent.

When simazine was applied in combination with the lower level of nitrate (14 ppm N) in the nutrient solution, the foliar N concentration of seedlings was greater than where an equivalent rate of N was applied alone (Appendix A). The foliar N concentration of seedlings treated with the ammonium source (14 and 42 ppm N) was greater than the nitrate, particularly where the lower level of N was applied with 0.10 ppm simazine. Simazine (0.10 ppm) applied with

both levels of ammonium N (14 and 42 ppm N) enhanced the foliar N concentration of seedlings more than did nitrate N and simazine at similar levels. Both levels of ammonium N applied with 0.10 ppm simazine significantly increased the foliar N concentration over the control. The maximum increase in foliar N concentration was 45.9 percent where 0.10 ppm simazine and 42 ppm N as ammonium N were applied. No differences in foliar N concentration were found between the ammonium and nitrate sources (at either 14 or 42 ppm N) applied with 0.05 ppm simazine. Nitrate N at 42 ppm and ammonium N at both 14 and 42 ppm N applied with 0.05 ppm simazine significantly increased the foliar N concentration over the control.

N-Serve supplemented in the ammonium treatments had no significant effect upon the foliar N concentration of slash pine seedlings (Table 11). This implies that possibly ammonium N is as effectively utilized with simazine as is the nitrate source, or that N-Serve did not effectively control nitrification. It is also possible that the seedlings were fulfilling their N requirements from an endogenous nitrate supply contained in the unsterilized soil mixture. Sabey (1968) reported that a fall application of N-Serve to soil buried in plastic bags under field conditions and allowed to incubate over winter, effectively delayed nitrification for about one month in the spring. Thus, it is possible that under our experimental conditions

where the N-Serve was applied with the nutrient solution, there was an insufficient incubation period for nitrification suppression.

Simazine applied with both 14 and 42 ppm N as either nitrate or ammonium N in the nutrient solution did not significantly alter the foliar N accumulation of seedlings over where nitrate or ammonium forms were supplemented alone. The maximum increase in foliar N accumulation in simazine treated pots was 65.3 percent where 0.05 ppm simazine and 42 ppm N as nitrate N were applied (Appendix A). However, when 42 ppm N as ammonium N (with N-Serve) was used alone, a foliar N accumulation of 76.4 percent was observed. Since both the 14 and 42 ppm N levels of the ammonium source alone significantly increased N accumulation over the control, and no differences were observed between these levels of N and where the same N levels were applied with simazine, the stimulating effect of simazine applied with N in this experiment on foliar N accumulation is probably very slight.

The effect of simazine on seedling growth is shown in Table 12 and Appendix A. Although increasing soil applied simazine (0.05 and 0.10 ppm) did not significantly affect either green or dry seedling weights, the 0.10 ppm simazine application increased both the green and dry foliage weights of seedlings 22.0 and 19.4 percent, respectively, over the control. The total green and dry

Table 12.--Significance of experimental factors on the green and dry weights of slash pine seedlings grown in the growth chamber for 10 weeks (Experiment 1).[1]

		Green Weight (g)					Dry Weight (g)				
Source	df	Foliage	Stem	Root	Total	Foliage/ Root	Foliage	Stem	Root	Total	Foliage/ Root
Rep	3										
Simazine	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen	6	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S x N	12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error	60										
CV (%)		15.7	19.3	24.6	15.8	19.7	14.8	23.4	24.6	15.7	24.1

[1]See Appendix A for data.

NS Factor is not significant.

seedling weights were increased 22.6 and 14.0 percent, respectively, when 0.10 ppm simazine was applied. These increases in both foliage and total seedling weights were greater than when 42 ppm nitrate N was supplemented in the nutrient solution. Freney (1965) also reported that 0.06 ppm simazine in solution culture increased the yield of corn tops 36 percent and N uptake by 37 percent without affecting root growth.

Experiment 2.--In this experiment, higher non-phytotoxic levels of simazine were used than in the previous experiment. The foliar N concentration (% N in needles) of slash pine seedlings grown on a soil-quartz sand mixture in the growth chamber was increased by simazine treatments of 0.2, 0.4, and 0.8 ppm (Table 13, Figure 3). The maximum increase was 43.8 percent (1.30 vs 1.87%N) at the highest rate (0.8 ppm) of simazine. This increase was almost equivalent to adding 84 ppm N of either ammonium or nitrate N to the nutrient solution (Appendix B).

N accumulation (mg N/top) was increased 26.2 percent over the control when 0.4 ppm simazine was used in the nutrient solution. Increased foliar N as a result of simazine treatment at sub-toxic levels has also been shown for other crops (Ries et al., 1967; Tweedy and Ries, 1967). The decrease in N accumulation between the 0.4 and 0.8 ppm simazine treatments, although an increase over the control, is probably a result of a reduction in foliar dry weight

Table 13.--Significance of experimental factors on the foliar nitrogen content and foliar percent dry weight of slash pine seedlings grown in the growth chamber for 12 weeks (Experiment 2).[1]

Source	df	% N	mg N/top	% Dry Wt.
Rep	3			
Simazine (S)[2]	3	**	*	**
Control vs S	1	**	*	**
0.2 vs 0.4 and 0.8 ppm	1	**	*	NS
0.4 vs 0.8 ppm	1	**	NS	*
Nitrogen (N)[2]	4	**	NS	**
Control vs N	1	**		NS
NO_3 (28 vs 84 ppm N)	1	**		NS
NH_4 (28 vs 84 ppm N)	1	**		*
NO_3 vs NH_4	1	NS		**
S x N	12	*	NS	NS
Error	57			
CV (%)		5.2	18.7	3.5

[1]See Appendix B for data.

[2]Orthogonal contrasts.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

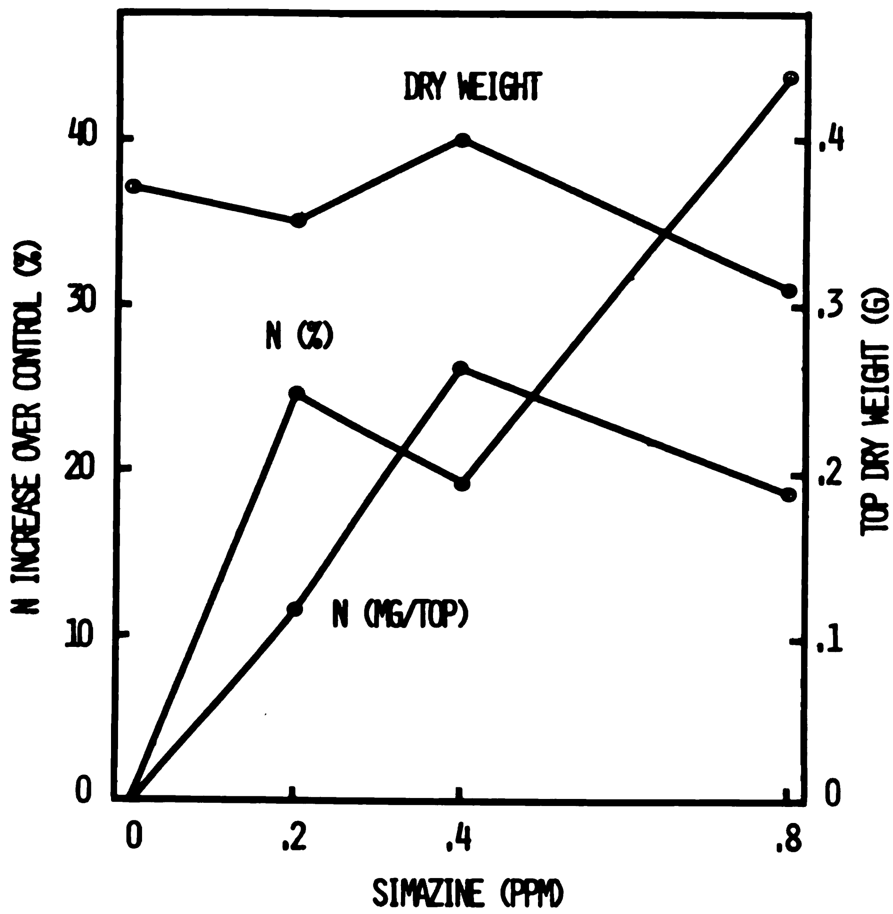

Figure 3. Relationship between simazine application rate and the top dry weight and N content of 12-week-old slash pine seedlings grown in the growth chamber without supplemental N (Experiment 2).

at the 0.8 ppm simazine level (Figure 3). A decrease in seedling dry weight from simazine treatment has also been reported by other workers (DeVries, 1963; Kozlowski and Kuntz, 1963).

Ammonium and nitrate N at a concentration of 84 ppm N, when applied both alone and with simazine in the nutrient solution, increased the percent foliar N over an equivalent 28 ppm N treatment, except where 0.4 ppm simazine and 84 ppm N as ammonium N were applied (Figure 4). Simazine treatment appears to enhance N accumulation in seedling foliage. Both nitrate and ammonium additions at 84 ppm N increased the foliar N concentration by as much as 70.8 and 65.4 percent, respectively, when 0.8 ppm simazine was added to the soil (Figure 4). It was established early by Addoms (1937) that loblolly pine seedlings grown in sand culture for 29 months were capable of utilizing both nitrate and ammonium forms of N at concentrations of 136 and 195 ppm, respectively.

The trend of N accumulation in Figure 4 suggests that the 84 ppm N treatment used in this experiment lies below the optimal level for this species. However, according to Fowells and Krauss (1959) this level of N should be sufficient to maintain adequate growth. They found the maximum growth of one-year-old loblolly and Virginia pine seedlings grown in sand culture occurred between 25 and 100 ppm N. Tweedy and Ries (1967) found the addition of

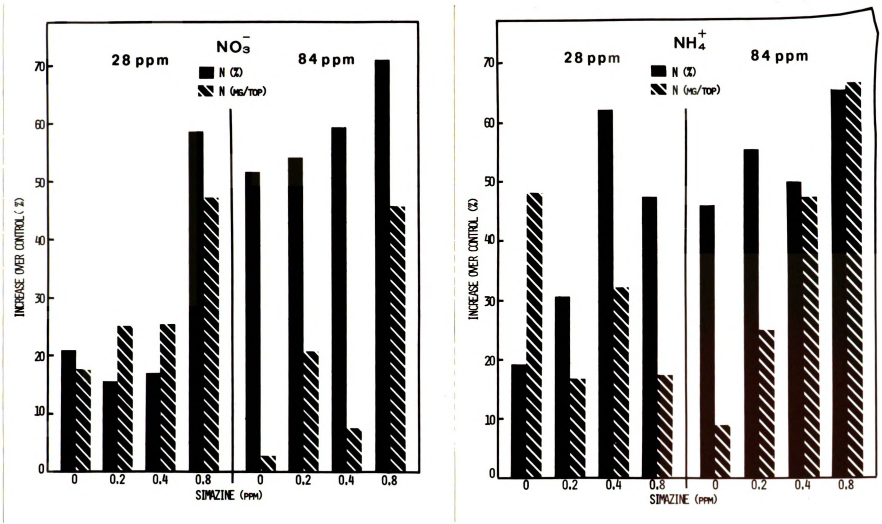

Figure 4. Increase in foliar N over the control for slash pine seedlings treated with combinations of simazine and nitrate or ammonium sources (ppm N) and grown in a growth chamber (Experiment 2).

simazine to the root-zone area of corn plants grown under both sub-optimal temperatures and low nitrate levels increased the N content and dry weight of the plants by 20 to 25 percent. This increase is thought to be associated with an effect on nitrate reductase. They did not find any increase from simazine treatment when an ammonium source was added.

In contrast to the findings of Tweedy and Ries (1967), simazine treatment in this experiment increased the foliar N content of slash pine seedlings grown on ammonium as well as nitrate N. However, it is possible that either the N-Serve did not effectively control nitrification or the seedlings utilized an endogenous supply of nitrate contained in the unsterilized soil mixture as discussed in Experiment 1. Ries et al. (1967) also found the effect of simazine on protein accumulation in rye plants decreased as the nitrate level approached the optimum. A similar N accumulation response was found for seedlings in this study where simazine was applied with nitrate N. A greater foliar N accumulation was found in slash pine seedlings treated with the lower (28 vs 84 ppm N) nitrate level, applied either alone or with increasing simazine in the nutrient solution (Figure 4). For example, 0.8 ppm simazine and 28 ppm N as nitrate applied in combination increased foliar N accumulation 46.9 percent (Table 14).

Table 14.--Significance of experimental factors on the green and dry weights of slash pine seedlings grown in the growth chamber for 12 weeks (Experiment 2).[1]

Source	df	Green Weight (g) Foliage	Green Weight (g) Stem	Green Weight (g) Root	Green Weight (g) Total	Green Weight (g) Foliage/Root	Dry Weight (g) Foliage	Dry Weight (g) Stem	Dry Weight (g) Root	Dry Weight (g) Total	Dry Weight (g) Foliage/Root
Rep	3										
Simazine (S)[2]	3	NS	NS	NS	NS	**	NS	NS	NS	NS	**
Control vs S	1					*					NS
0.2 vs 0.4 and 0.8 ppm	1					NS					NS
0.4 vs 0.8 ppm	1					**					**
Nitrogen (N)[2]	4	**	NS	NS	*	*	**	NS	*	**	NS
Control vs N	1	NS			NS	NS	NS		NS	NS	
NO_3 (28 vs 84 ppm N)	1	**			**	NS	**		**	**	
NH_4 (28 vs 84 ppm N)	1	NS			NS	NS	NS		NS	NS	
NO_3 vs NH_4	1	NS			NS	**	NS		NS	NS	
S x N	12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error	57										
CV (%)		18.3	23.4	26.2	19.6	19.0	19.8	21.6	26.8	20.0	18.1

[1]See Appendix B for data.

[2]Orthogonal contrasts.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

At the high rate of N application, without any herbicide added, there is the expected development of highly succulent tissue with a relatively high concentration of N in the tissue, but a low actual N accumulation (Figure 4). In these same high N treatments the addition of increasing amount of herbicide results in a large increase in N accumulation with a small but linear increase in N concentration. In contrast to the low nitrate treatments where simazine increased N assimilation, the herbicide seemed to depress N assimilation in pots treated with a low level of ammonium N. However, the N accumulation of slash pine seedlings was greatest when the highest levels of both ammonium N (84 ppm N) and simazine (0.8 ppm) were applied in combination. This increase in foliar N with increasing herbicide application occurs without any significant change in seedling mass (Table 14 and Appendix B).

Increasing soil applied simazine (0.2 to 0.8 ppm) did not significantly alter either green or dry seedling weights. However, simazine applied at 0.4 ppm increased both green and dry foliage weights 9.6 and 8.1 percent, respectively, over the control. Although the total dry seedling weight was not increased when 0.4 ppm simazine was applied, total green seedling weight was increased 23.0 percent. These increases in both green and dry foliage and total seedling weights were greater than when 84 ppm N of either nitrate or ammonium N was supplemented in the

nutrient solution. When the concentration of soil applied simazine was increased to 0.8 ppm, both green and dry foliage, stem, root, and total seedling weights were decreased. The depressing effect of simazine treatment on seedling root weight is shown by the increasing foliage/root ratio with increasing simazine concentration.

Experiment 3.--This experiment was similar to the previous study except a second species, loblolly pine, was included and atrazine was substituted for simazine as the herbicide. Non-phytotoxic levels of soil applied atrazine (0.4 ppm) increased the foliar N concentration of 11-week-old slash and loblolly pine seedlings grown in a soil-quartz sand mixture in the growth chamber (Table 15). However, the maximum increase was 3.2 and 13.0 percent for slash and loblolly pine seedlings, respectively (Appendix C). This increase was considerably less than where either nitrate or ammonium (84 ppm N) sources were used alone.

Atrazine at 0.1 and 0.4 ppm applied in combination with both nitrate and ammonium (84 ppm N) sources, significantly increased the foliar N concentration of both slash and loblolly pine seedlings over the control (Table 15 and Appendix C). The maximum increase was 53.4 percent for loblolly pine seedlings when 0.4 ppm atrazine and 84 ppm N as nitrate N were applied. Since both nitrate and ammonium forms alone significantly increased the foliar N concentration of both species, the effect of atrazine on the

Table 15.--Significance of experimental factors on the foliar nitrogen content and foliar percent dry weight of slash and loblolly pine seedlings grown in the growth chamber for 11 weeks (Experiment 3).[1]

Source	df	% N	mg N/top	% Dry Wt.
Rep	3			
Atrazine (A)[2]	2	**	*	NS
Control vs A	1	**	NS	
0.1 vs 0.4 ppm	1	**	**	
Nitrogen (N)[2]	2	**	**	**
Control vs N	1	**	**	NS
NO_3 vs NH_4 (84 ppm N)	1	*	**	**
A x N	4	NS	NS	NS
Error (a)	24			
Species (S)	1	NS	**	NS
A x S	2	NS	NS	*
N x S	2	NS	*	NS
A x N x S	4	NS	NS	NS
Error (b)	27			
CV (%)				
Error (a)		3.9	23.7	4.7
Error (b)		5.3	24.6	3.3

[1]See Appendix C for data.

[2]Orthogonal contrasts.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

enhancement of foliar N in these seedlings is very slight. However, it appears that a combination of atrazine and supplemental N to the soil generally increased the foliar N concentration more than when N was applied alone.

The foliar N accumulation in slash pine seedlings was increased by 0.4 ppm atrazine applied both alone or with supplemental N in the nutrient solution. For example, when 0.4 ppm atrazine was applied with ammonium N (84 ppm N), the foliar N accumulation of slash pine seedlings was increased 80.6 percent over the control (Appendix C). Except for the previous example, the increase in foliar N accumulation in slash pine from nitrate or ammonium sources applied with atrazine did not exceed that where N was applied alone. In loblolly pine, all N and herbicide treatments decreased foliar N accumulation, except where 0.4 ppm atrazine was applied with either nitrate or ammonium forms (84 ppm N). This decrease in foliar N accumulation in loblolly pine seedlings was probably due to the depressive effect of both atrazine and N on the foliage dry weight of seedlings (Appendix C). No differences in the foliage dry weight of slash pine seedlings were found when these same atrazine and N treatments were used. Gramlich and Davis (1967) found similar results from field experiments in which atrazine treated corn plants were smaller and contained a higher N concentration, but less N accumulation, than untreated plants.

The effect of atrazine on the growth of both slash and loblolly pine seedlings can be observed in Table 16. Although no significant differences were found in either green or dry foliage, root, or total seedling weights when atrazine was applied to either species, the green and dry foliage and total weights of slash pine seedlings were increased when 0.4 ppm atrazine was applied to the soil (Appendix C). In contrast to slash pine, both the green and dry foliage, root, and total weights of loblolly pine seedlings were decreased with increasing concentrations of atrazine applied.

Greenhouse

Foliar Nitrogen Content.--The foliar N concentration (% N in needles) of 16-week-old slash pine seedlings raised in the greenhouse was increased by soil applications of 0.5, 1, and 2 ppm simazine (Table 17 and Figure 5). The maximum increase was 91 percent (1.26 vs 2.41 % N) at the highest simazine level. This increase in foliar N concentration was greater than where 84 ppm N of either nitrate or ammonium N was used in the nutrient solution (Appendix D). In fact, 1 ppm simazine applied to the soil was equivalent to supplying 84 ppm N of either nitrate or ammonium N in the nutrient solution. This stimulating effect of simazine applications on the N concentration in other crops has also been shown by other investigators (DeVries, 1963; Ries *et al*., 1963).

Table 16.--Significance of experimental factors on the green and dry weights of slash and loblolly pine seedlings grown in the growth chamber for 11 weeks (Experiment 3).[1]

Source	df	Green Weight (g) Foliage	Stem	Root	Total	Foliage/Root	Dry Weight (g) Foliage	Stem	Root	Total	Foliage/Root
Rep	3										
Atrazine (A)[2]	2	NS	*	NS	NS	NS	NS	*	NS	NS	NS
Control vs A	1		*					*			
0.1 vs 0.4 ppm	1		NS					NS			
Nitrogen (N)[2]	2	NS	NS	*	NS	**	*	*	*	*	*
Control vs N	1			*		NS	*	NS	NS	NS	NS
NO_3 vs NH_4 (84 ppm N)	1			NS		**	**	*	**	**	**
A x N	4	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
Error (a)	24										
Species (S)	1	**	**	**	**	**	**	**	**	**	NS
A x S	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x S	2	NS	NS	NS	NS	NS	*	*	NS	NS	NS
A x N x S	4	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Error (b)	27										
CV (%)											
Error (a)		26.8	81.8	36.3	27.6	15.3	25.5	27.2	32.1	26.2	16.3
Error (b)		25.4	24.9	39.1	27.3	17.4	23.5	28.5	33.5	24.0	19.6

[1] See Appendix C for data.

[2] Orthogonal contrasts.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

Table 17.--Significance of experimental factors on the foliar nitrogen content, foliar percent dry weight, height, and stem diameter of slash pine seedlings grown in the greenhouse for 16 weeks.[1]

Source	df	% N	mg N/top	NO_3^--N	% Dry Weight	Height	Stem Diameter
Rep	3						
Simazine	3	**	**	**	**	**	**
Nitrogen	4	**	**	NS	NS	*	*
S x N	12	NS	NS	NS	NS	NS	NS
Error	57						
CV (%)		4.1	14.9	15.0	2.7	6.5	6.9

[1]See Appendix D for data.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

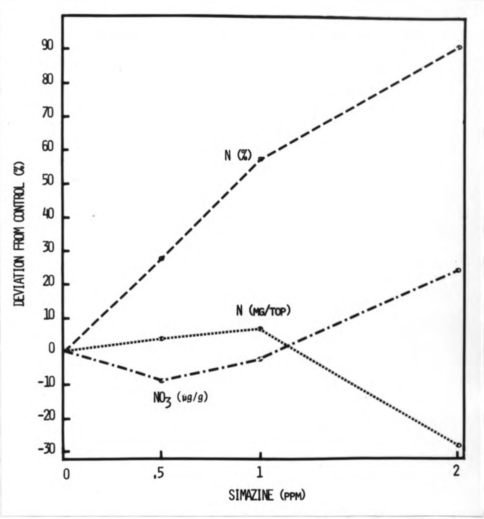

Figure 5. Relationship between simazine application rate and the N content of 16-week-old slash pine seedlings grown in the greenhouse without supplemental N.

An increase in foliar N concentration was also found with increasing levels of simazine applied with both 28 and 84 ppm N as either nitrate or ammonium sources (Figure 6). The maximum increase was 118 percent where 2 ppm simazine was applied in combination with 84 ppm N as ammonium N.

Simazine applied without supplemental N did not significantly increase foliar N accumulation (mg N/top) over the control (Figure 5). However, a trend of increasing foliar N accumulation was observed in plants treated with both 0.5 and 1 ppm simazine. An additive effect on foliar N accumulation was observed where 0.5 ppm simazine and 84 ppm N as ammonium were applied in combination. This treatment increased foliar N accumulation 80 percent and was greater than supplying 84 ppm N of either nitrate or ammonium N in the nutrient solution (Figure 6). When simazine was applied at a standard herbicidal rate (2 ppm) both alone and in combination with either nitrate or ammonium N, there was a significant depressing effect upon N accumulation. This decrease in foliar N accumulation is probably due to the reduction in foliar dry weight where 2 ppm simazine was used (Figure 7). Thus, the 2 ppm simazine concentration applied to slash pine seedlings at this stage of development was probably phytotoxic. Similar effects were observed on red pine seedlings by Winget et al. (1963). From the depressive effect of simazine on

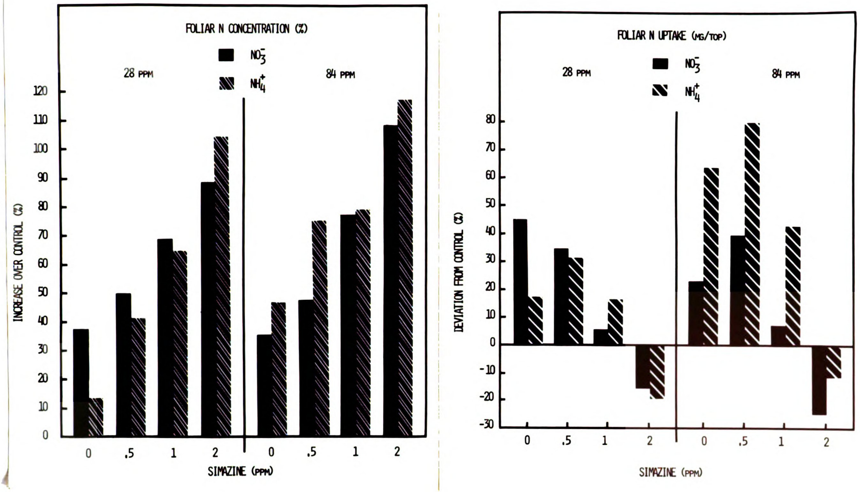

Figure 6. Changes in the foliar N concentration (%) and N uptake (mg N/top) from the control for slash pine seedlings grown in the greenhouse and treated with combinations of simazine and nitrate or ammonium sources (ppm N).

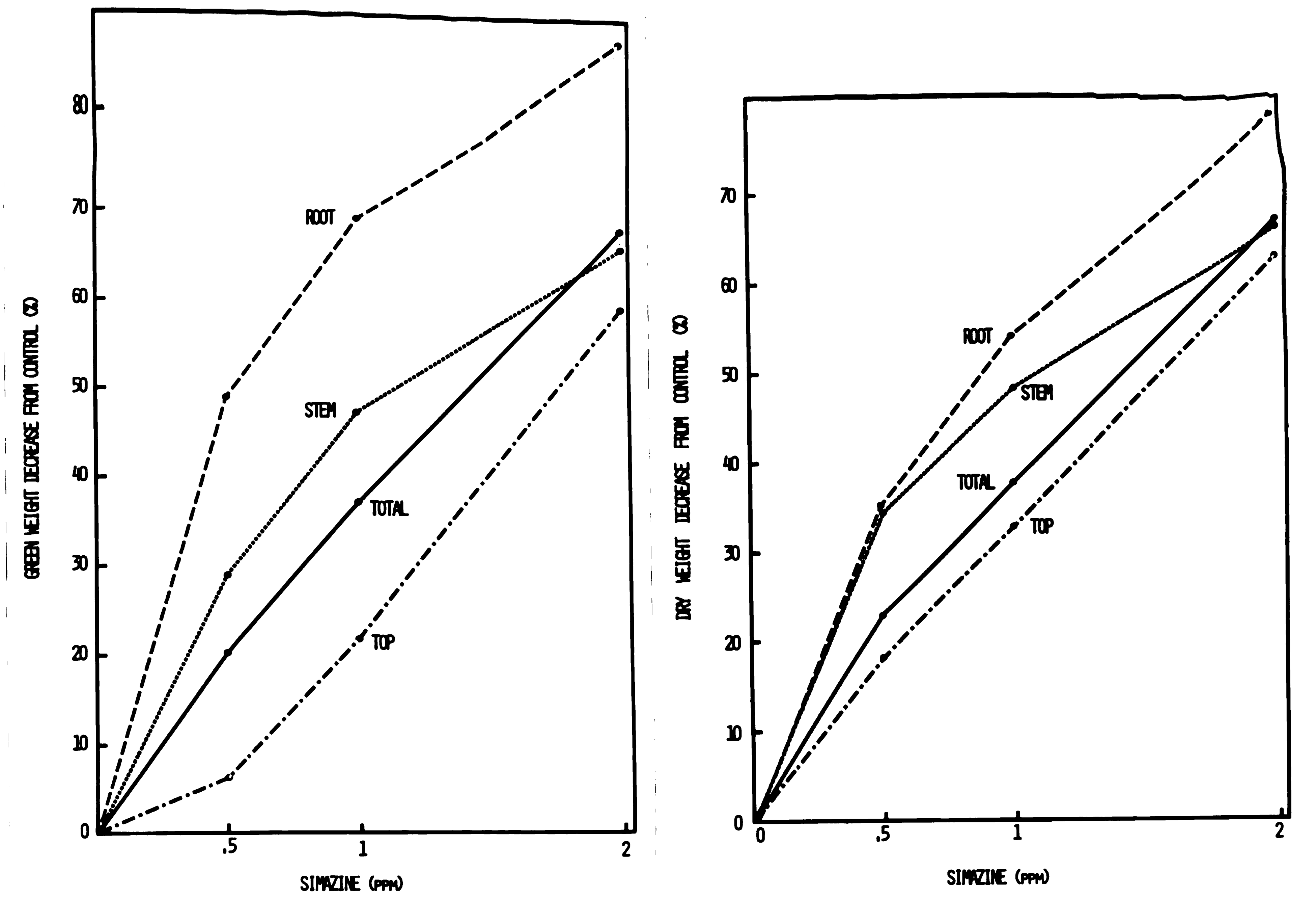

Figure 7. Relationship between simazine application rate and the decrease in green (left) and dry (right) weights from the control for slash pine seedlings grown in the greenhouse without supplemental N.

the growth and N accumulation of seedlings in this study, it is apparent that the increased foliar N concentration from increasing simazine applied was primarily a function of decreased dry weight. Gramlich and Davis (1967) found corn treated pre-emergence with high rates of atrazine (17.9 kg/ha) also had less N uptake than the untreated controls.

Accumulation of Foliar Nitrates.--Simazine applied at 2 ppm without supplemental N increased the foliar nitrates (μg NO_3/g dry weight) of slash pine seedlings (Figure 5). However, a maximum increase of 25.4 percent was obtained where 2 ppm simazine and 84 ppm N as ammonium were applied in combination. No differences were found in foliar nitrates of seedlings supplied with nitrate and ammonium sources, either with or without simazine. According to the technique of Low and Hamilton (1967) for the determination of nitrates in plant extracts, no nitrates should have been found in the ammonium treated seedlings if only the ammonium ion was utilized. The fact that foliar nitrates were found in ammonium treated seedlings indicates that either: (1) the N-Serve did not effectively control nitrification, (2) the seedlings were utilizing an endogenous supply of nitrate contained in the unsterilized soil mixture, or (3) the ammonium source was as effectively utilized with simazine as was the nitrate source. If the latter is true, then the effect of simazine on

foliar N accumulation is not necessarily a function of increased nitrate reductase activity accelerating nitrate uptake by the plant as suggested by Ries et al. (1967). Tweedy and Ries (1967) found in experiments with corn, that responses to simazine occurred in plants grown with nitrate, but not ammonium as the N source. They found nitrate reductase activity to increase almost ten-fold in plants exposed to simazine for 7 days. Also, Gramlich and Davis (1967) found in nutrient culture studies with corn that atrazine treatment at 4 and 8 ppm increased the percentage foliar nitrates without an accompanying decrease in free ammonia as might be expected if atrazine inhibited the enzymatic conversion of nitrate to ammonia. They concluded that the increased percentage total N of atrazine treated plants was primarily due to increased nitrate. However, it has been shown that conifers receive most of their N in the form of ammonium as little nitrification occurs under acid forest conditions (Addoms, 1937). Bengtson[1] found that slash pine seedlings grown in the greenhouse for 270 days had the highest N uptake and dry matter production when fertilized with ammonium sulfate at 600 mg N/pot. Also, Tiedjens (1934) found that the ammonium ion was assimilated most satisfactorily in tomato and apple plants from nutrient solutions having a pH of 5.0 to 6.5

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[1] G. W. Bengtson, TVA, personal communication, 1968.

Since the acid forest soil mixture used in our studies had a pH of 5.6 and the nutrient solution treatments had a pH of 6.3, conditions appear favorable for ammonium ion absorption by the seedlings.

Simazine and Growth Reduction.--The effect of simazine on the growth of 16-week-old slash pine seedlings is shown in Table 18 and Figure 7. In contrast to the growth chamber studies where low levels of simazine (0.05 - 0.8 ppm) did not affect green or dry weights of slash pine seedlings, decreases in both green and dry foliage, stem, root, and total seedling weights were found where slightly higher concentrations of simazine (1 to 2 ppm) were applied in the greenhouse. In fact, 1 ppm simazine significantly lowered both the green and dry foliage, stem, root, and total seedling weights (Figure 7). This decrease in seedling growth may be a result of increased respiration. Ries et al. (1967) have shown that increasing applications of simazine progressively decreased the percent dry weight of rye plants. Simazine also increased the respiration rate of the plants more than 10 percent without affecting the respiratory quotient, which they thought accounted for the decrease in dry weight.

A 10.7 percent increase in seedling height was found where 0.5 ppm simazine was applied (Figure 8). Plants treated with 0.5 ppm simazine were taller than where 84 ppm

Table 18.--Significance of experimental factors on the green and dry weights of slash pine seedlings grown in the greenhouse for 16 week.[1]

		Green Weight (g)					Dry Weight (g)				
Source	df	Foliage	Stem	Root	Total	Foliage/ Root	Foliage	Stem	Root	Total	Foliage/ Root
Rep	3										
Simazine	3	**	**	**	**	**	**	**	**	**	**
Nitrogen	4	**	*	NS	**	NS	**	*	NS	**	NS
S x N	12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error	57										
CV (%)		12.8	16.8	22.8	13.4	16.5	11.6	18.7	17.4	11.6	16.3

[1]See Appendix D for data.

* Factor is significant at .05 level.
** Factor is significant at .01 level.
NS Factor is not significant.

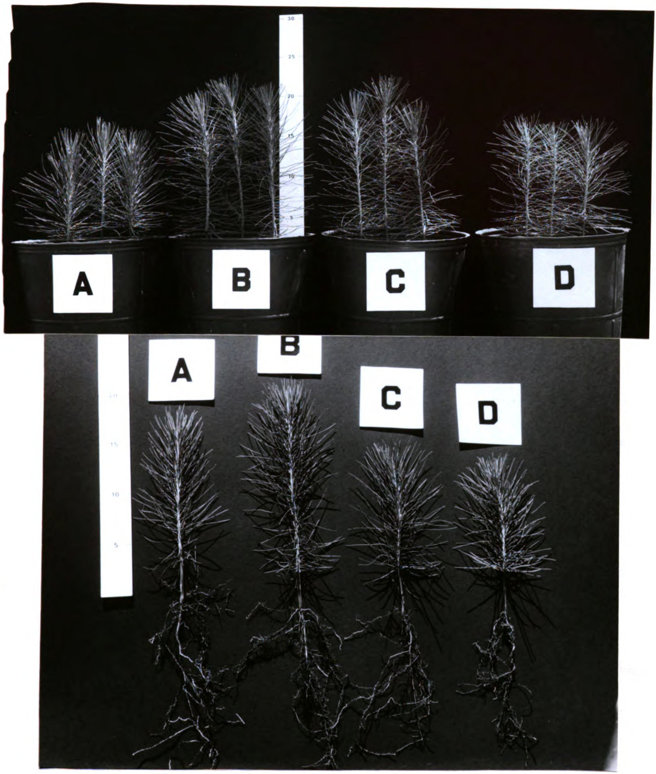

Figure 8. Effect of simazine application rate on the top (upper) and root (lower) growth of 16-week-old slash pine seedlings grown in the greenhouse without supplemental N (Treatments: A=Control, B=Simazine @ 0.5 ppm, C=Simazine @ 1 ppm, D= Simazine @ 2 ppm).

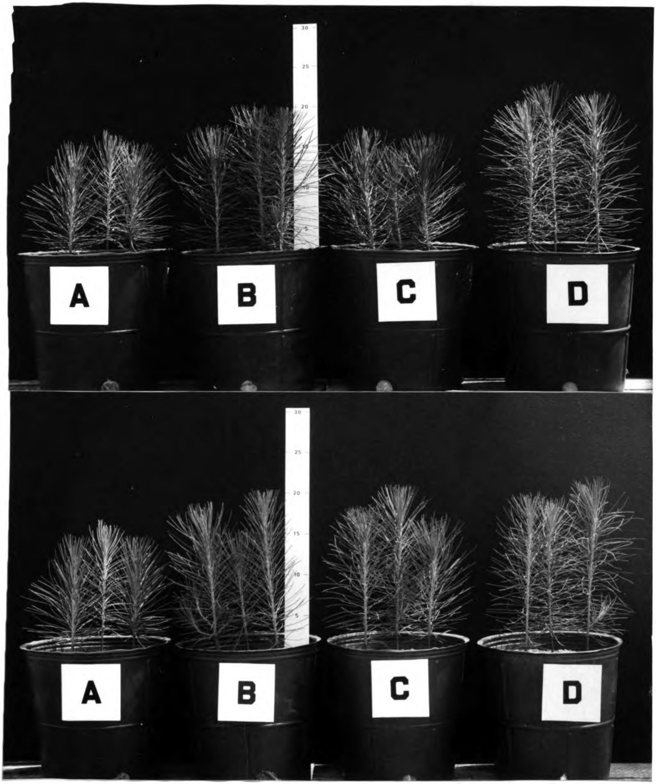

Figure 9. Effect of simazine and nitrate (upper) and ammonium (lower) treatments on the top growth of 16-week-old slash pine seedlings grown in the greenhouse (Treatments: Upper, A=Control, B=NO_3-N @ 28 ppm N, C=NO_3-N @ 84 ppm N, D=Simazine @ 0.5 ppm; Lower, A=Control, B=NH_4-N @ 28 ppm N, C=NH4-N @ 84 ppm N, D=Simazine @ 0.5 ppm).

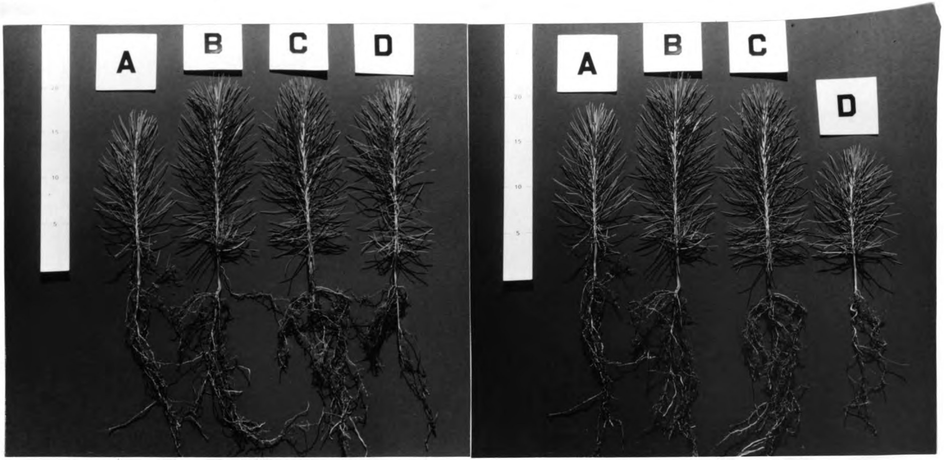

Figure 10. Effect of simazine and nitrate and ammonium treatments on the top and root growth of 16-week-old slash pine seedlings grown in the greenhouse (Treatments: Left, A=Control, B=NO_3-N @ 84 ppm N, C=NH_4-N @ 84 ppm N, D=Simazine @ 0.5 ppm; Right, A=Control, B=NO_3-N @ 84 ppm N, C=NH_4-N @ 84 ppm N, D=Simazine @ 2 ppm).

It is possible that the mycorrhizal habit in conifers may alter uptake of simazine by degradation within the fungal mantle or by altering the absorption pattern. Freeman *et al.* (1964) suggest the presence of mycorrhizae may enhance the resistance of white pine seedlings to simazine. They found the uptake of ^{14}C-labeled simazine in noninoculated plants was more than double that of inoculated ones. Since the slash pine seedlings in these studies had well-developed mycorrhizae, the influence of these fungi upon simazine absorption and degradation is a possibility.

Field

Foliar Mineral Nutrition.--Simazine applied pre-emergence at herbicidal rates without supplemental N did not significantly alter the foliar mineral nutrition of field planted Scotch pine, white spruce, or balsam fir nursery transplants (Tables 19, 20 and 21; Appendix E).

The lower rate of soil applied atrazine (2.25 kg/ha) increased the foliar Mg concentration of all species over the control. Earlier, DeVries (1963) reported significant increases in the Mg uptake of corn plants grown on limed soils treated with simazine. Freney (1965) also found simazine applied at 0.06 ppm in solution culture increased the Mg uptake of corn by 24 percent, N by 37 percent, P by 25 percent, and K by 41 percent. However, in this study simazine did not significantly affect either N, P, or K

Table 19.--Changes in the foliar mineral nutrition of field planted SCOTCH PINE from ammonium nitrate and weed control treatments.[1]

Treatment	Foliar Concentration[2]												
	N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control													
Mulch	+	0	0	+	(+)	-	-	0	-	0	(-)	0	0
NH_4NO_3 (112 kgN/ha)	0	0	(+)	-	(+)	0	0	0	(-)	(+)	-	0	0
NH_4NO_3 (336 kgN/ha)	+	+	(+)	-	(+)	(+)	0	(+)	(+)	(-)	-	(-)	0
Simazine (4.50 and 9.00 kg/ha)	0	0	(-)	0	(+)	0	(+)	0	0	0	0	0	(+)
Simazine + NH_4NO_3 (112 kgN/ha)	0	0	(-)	0	(+)	0	0	(+)	0	(+)	0	0	(+)
Simazine + NH_4NO_3 (336 kgN/ha)	0	+	0	-	(+)	0	0	(-)	(-)	(-)	-	-	0
Atrazine (2.25 and 4.50 kg/ha)	0	0	(-)	(+)	0	0	-	(+)	0	(+)	(+)	(+)	0
Atrazine + NH_4NO_3 (112 kgN/ha)	0	0	0	0	(+)	0	0	(+)	(+)	(+)	0	0	(+)
Atrazine + NH_4NO_3 (336 kgN/ha)	0	+	(+)	-	(+)	0	0	0	0	(+)	(-)	(-)	0

[1]From orthogonal contrasts (See Appendix E).

[2]Changes for: mulch and NH_4NO_3 levels are with respect to the control, simazine and atrazine (without N) are a result of increasing herbicide concentration, the herbicides + NH_4NO_3 are with respect to the respective herbicides alone. 1967 growing season foliage, except second N concentration value.

+ Significant increase at .05 level.
(+) Increasing trend.
- Significant decrease at .05 level.
(-) Decreasing trend.
0 No change

Trends determined only for non-significant treatments that changed in a single direction by ±10% of the value upon which the treatment was based.

Table 20.--Changes in the foliar mineral nutrition of field planted WHITE SPRUCE from ammonium nitrate and weed control treatments.[1]

Treatment	Foliar Concentration[2] N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Control													
Mulch	+	0	0	+	(+)	-	-	0	-	0	(-)	0	0
NH_4NO_3 (112 kgN/ha)	0	0	0	-	(-)	(+)	(+)	(-)	(+)	(-)	(-)	-	(-)
NH_4NO_3 (336 kgN/ha)	+	+	0	-	(-)	0	0	(+)	(+)	-	(+)	-	0
Simazine (4.50 and 9.00 kg/ha)	0	0	0	0	(+)	(-)	0	0	(-)	(+)	(-)	0	(-)
Simazine + NH_4NO_3 (112 kgN/ha)	0	0	0	0	0	(+)	(+)	0	0	(-)	(-)	(-)	(-)
Simazine + NH_4NO_3 (336 kgN/ha)	0	+	0	-	(-)	0	(+)	0	0	-	(-)	-	0
Atrazine (2.25 and 4.50 kg/ha)	0	-	0	0	0	0	-	0	0	0	(-)	0	0
Atrazine + NH_4NO_3 (112 kgN/ha)	0	0	0	-	0	0	0	0	(+)	0	(-)	0	(+)
Atrazine + NH_4NO_3 (336 kgN/ha)	0	+	(-)	-	0	0	0	+	0	0	(-)	0	0

[1]From orthogonal contrasts (See Appendix E).

[2]Changes for: mulch and NH_4NO_3 levels are with respect to the control, simazine and atrazine (without N) are a result of increasing herbicide concentration, the herbicides + NH_4NO_3 are with respect to the respective herbicides alone. 1967 growing season foliage, except second N concentration value.

+ Significant increase at .05 level.
(+) Increasing trend.
- Significant decrease at .05 level.
(-) Decreasing trend.
0 No change

Trends determined only for non-significant treatments that changed in a single direction by ±10% of the value upon which the treatment was based.

Table 21.--Changes in the foliar mineral nutrition of field planted BALSAM FIR from ammonium nitrate and weed control treatments.[1]

Treatment	N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
	Foliar Concentration[2]												
Control													
Mulch	+	0	0	+	(+)	-	-	0	-	0	(-)	0	0
NH_4NO_3 (112 kgN/ha)	0	0	(+)	-	(-)	0	0	0	0	0	-	-	-
NH_4NO_3 (336 kgN/ha)	+	0	(+)	-	(-)	(+)	(+)	+	(+)	-	-	-	-
Simazine (4.50 and 9.00 kg/ha)	0	0	0	0	0	0	0	(+)	0	(+)	0	(+)	0
Simazine + NH_4NO_3 (112 kgN/ha)	0	0	0	0	(+)	(+)	0	(+)	0	(+)	-	0	0
Simazine + NH_4NO_3 (336 kgN/ha)	0	0	(-)	0	(+)	0	0	(+)	(+)	(+)	(-)	0	(+)
Atrazine (2.25 and 4.50 kg/ha)	0	0	(+)	0	0	0	-	0	0	0	0	0	0
Atrazine + NH_4NO_3 (112 kgN/ha)	0	0	0	0	(-)	(+)	+	0	0	(-)	(-)	0	0
Atrazine + NH_4NO_3 (336 kgN/ha)	0	0	0	-	(-)	0	0	+	(+)	(-)	-	(-)	(+)

[1]From orthogonal contrasts (See Appendix E).

[2]Changes for: mulch and NH_4NO_3 levels are with respect to the control, simazine and atrazine (without N) are a result of increasing herbicide concentration, the herbicides + NH_4NO_3 are with respect to the respective herbicides alone.
1967 growing season foliage, except second N concentration value.

- \+ Significant increase at .05 level.
- (+) Increasing trend.
- \- Significant decrease at .05 level.
- (-) Decreasing trend.
- 0 No change.

Trends determined only for non-significant treatments that changed in a single direction by ±10% of the value upon which the treatment was based.

assimilation. Neither did atrazine applied pre-emergence at herbicidal rates to all species, have any significant effect upon the foliar content of any of the elements determined during the 1967 growing season other than Mg.

Approximately three months following herbicide treatment in the first growing season, a severe chlorosis was observed in white spruce seedlings. This foliar discoloration, followed by needle cast and eventually death, was associated more with simazine (particularly at the higher rate) than atrazine and was more severe when the herbicides were applied without supplemental N. The depression of N assimilation coupled with injury at the higher rates of simazine and atrazine suggests that white spruce may be more susceptible to these herbicides than the other two species. This phenomenon was also observed following a second application of the herbicides in the spring of 1968.

In the second growing season (1968), in which only foliar N was determined on the seedlings, again simazine treatment did not significantly change the foliar N concentration of either species (Tables 19, 20 and 21). However, in contrast to the previous year, a delayed increase in the foliar N of Scotch pine and white spruce was found from ammonium nitrate (336 kgN/ha) applied to the simazine plots. Freney (1965) reported similar results when applications of 1 to 5 ppm simazine to the soil of greenhouse

pots, increased the N uptake of corn only when additional N was supplied to the soil. In our study the higher rate of N (336 kgN/ha) applied with simazine also significantly increased the foliar N concentration of Scotch pine and white spruce seedlings over where the lower rate of N (112 kgN/ha) was applied similarly, or where simazine was applied alone. No differences were found in the foliar N of these species between the low level of ammonium nitrate (112 kgN/ha) applied with simazine and where simazine was applied without supplemental N. Ammonium nitrate applied to simazine treated balsam fir did not significantly alter its foliar N concentration during the second growing season.

Ammonium nitrate fertilizer (336 kgN/ha) applied alone (without herbicide) to Scotch pine, white spruce, and balsam fir seedlings in the early spring of 1967, significantly increased their foliar N concentration over where no N was applied (Tables 19, 20 and 21). No differences were found in the foliar N of Scotch pine and balsam fir between the two levels of supplemental N (112 vs 336 kgN/ha). However, the higher rate of ammonium nitrate (336 kgN/ha) significantly increased the foliar N concentration of white spruce over where the lower level of N (112 kgN/ha) was applied. In the second year, ammonium nitrate treatment significantly increased the foliar N concentration of only Scotch pine and white spruce seedlings over the control. The 336 kgN/ha ammonium nitrate application si

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application significantly increased the foliar N of these species over where 112 kgN/ha was applied. Supplemental N to balsam fir seedlings did not affect their foliage N concentration as was found in the previous year.

Although atrazine treatment did not significantly alter the foliar N concentration of seedlings during the first growing season, the low rate of herbicide (2.25 kg/ha) the second year significantly increased the foliar N concentration of white spruce seedlings over both the control and high herbicide (4.50 kg/ha) application (Table 20). No significant differences in foliar N of either Scotch pine or balsam fir were found between the two atrazine levels. However, the high rate of atrazine (4.50 kg/ha) applied to Scotch pine seedlings significantly decreased foliar N over the control (Table 19).

It is possible that degradation of the triazines by soil organisms (Burnside _et al_., 1961; Burschel, 1961; Reid, 1960) coupled with leaching by above normal precipitation at the test site during the early spring of both growing seasons, might reduce triazines to sub-toxic levels and thus contribute to the increased N assimilation in atrazine treated white spruce. The concentration of atrazine and simazine under these environmental conditions might have approached that used in the growth chamber or greenhouse where significant increases in the foliar N of slash pine were obtained with low level applications of simazine.

It is unusual that atrazine should significantly increase the foliar N concentration of white spruce seedlings during the second growing season as this species appeared more susceptible to herbicidal injury throughout both growing seasons. It is possible that differential uptake and/or distribution of both atrazine and simazine occurred among the three species. According to Freeman et al. (1964) using ^{14}C-labelled simazine, the ^{14}C was fairly evenly distributed throughout red pine seedlings after 40 days, but in white pine a much higher percentage was retained in the non-photosynthetic organs (roots and stems). The needles of red pine contained approximately three times more radioactive material than white pine. Although the uptake and distribution of the herbicides were not measured in our study, it is possible that the injury and mortality in white spruce from simazine and atrazine treatment was a result of greater absorption and/or accumulation of the chemicals in the photosynthetic areas of these seedlings. Since triazines are thought by some workers to kill by inhibiting the Hill reaction during photosynthesis (Moreland et al., 1959), if differential herbicide distribution did occur among these species, the fact that white spruce is less tolerant to these herbicides is not unreasonable.

The increased herbicidal injury and mortality that occurred in plots on the lower slope also suggests that

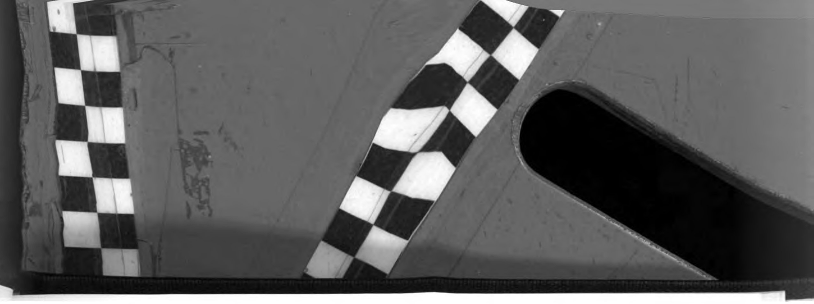
lateral soil movement of the herbicides probably occurred. Heavy precipitation following treatment application in the early spring of both growiñg seasons (See Chapter III) very likely contributed to herbicide movement and concentration on the lower slope.

Interaction of Nitrogen and Herbicide Treatments with Mineral Nutrition.--Broadcast applications of ammonium nitrate fertilizer (336 kgN/ha) to simazine and atrazine treated plots during the first growing season, significantly reduced the foliar P concentration of Scotch pine and white sprce seedlings over where the herbicides were applied alone (Tables 19 and 20; Appendix E). The depressive effect of N on foliar P has also been observed by other workers (Dumbroff and Michel, 1967). The high N level (336 kgN/ha) supplemented with atrazine also significantly decreased the foliar P of balsam fir, where N applied to simazine treated balsam fir did not affect its foliar P content (Table 21). The effect of ammonium nitrate applied with either simazine or atrazine on reducing the foliar P concentration of the affected species was greatest at the highest level of N (336 kgN/ha). Although no differences were found in the foliar P of either species between the two levels of ammonium nitrate applied with atrazine, the high rate of N (336 kgN/ha) applied to the simazine plots significantly reduced foliar P in both Scotch pine and white spruce seedlings over where the lower rate of N

(112 kgN/ha) was applied similarly (Tables 19 and 20). No differences were found in the foliar P of these seedlings between the lower rate of N (112 kgN/ha) applied with simazine and where simazine was used alone. However, the 112 kgN/ha application of ammonium nitrate applied with atrazine significantly decreased the foliar P of white spruce seedlings over where the herbicide was applied alone. Similar to where N was applied with simazine and atrazine, ammonium nitrate applied alone during the first year significantly lowered foliar P for all species over where no N was applied. This decrease in foliar P was greatest at the highest level of N (336 kgN/ha). Also, the high rate of supplemental N (336 kgN/ha) significantly reduced foliar P in balsam fir over the lower rate (112 kgN/ha).

The foliar Ca concentration of white spruce seedlings was significantly decreased by 336 kgN/ha of ammonium nitrate applied with simazine over where 112 kgN/ha was applied similarly (Table 20). N supplemented to the simazine plots did not affect the foliar Ca of either Scotch pine or balsam fir seedlings (Tables 19 and 21). Also, ammonium nitrate applied both alone and with atrazine did not significantly alter the foliar Ca concentration of the seedlings.

The lower rate of ammonium nitrate (112 kgN/ha) applied with atrazine significantly increased the foliar Mg concentration of both white spruce and balsam fir over



where the higher N rate (336 kgN/ha) was applied with atrazine (Tables 20 and 21). However, ammonium nitrate applied both alone and with simazine did not significantly alter the foliar Mg concentration of any species.

The high rate of ammonium nitrate (336 kgN/ha) applied with atrazine significantly increased the foliar Mn concentration of white spruce and balsam fir seedlings over where the herbicide was applied alone (Tables 20 and 21). The 336 kgN/ha ammonium nitrate treatment (without herbicide) significantly increased the foliar Mn concentration of balsam fir. A trend of increasing foliar Mn was observed in both Scotch pine and white sprce seedlings where this same rate of supplemental N (336 kgN/ha) was applied. Also, the 336 kgN/ha treatment significantly increased foliar Mn in these seedlings over the 112 kgN/ha application. Ammonium nitrate applied with simazine did not significantly affect the foliar Mn concentration of either species. However, a trend of increasing foliar Mn was observed in balsam fir with increasing N applied with simazine (Table 21).

Ammonium nitrate (336 kgN/ha) applied with simazine treated white spruce significantly lowered its foliar Cu concentration over where the herbicide was applied alone (Table 20). This same treatment combination significantly reduced the foliar Zn concentration of both Scotch pine and white spruce seedlings. These decrease in foliar Cu and Zn

were greatest at the higher level of N (336 kgN/ha). Similarly, ammonium nitrate applied alone (without herbicide) significantly reduced the foliar Zn of white spruce and balsam fir, and foliar Cu of balsam fir over the control. The high level of supplemental N (336 kgN/ha) was more effective in decreasing the foliar Cu of these seedlings. The foliar Cu and Zn concentrations of seedlings treated with ammonium nitrate and atrazine were not significantly affected.

Ammonium nitrate applied to simazine treated plots of Scotch pine and balsam fir in the first growing season significantly decreased their foliar B concentration over where simazine was applied without supplemental N (Tables 19 and 21). The decrease in the foliar B of Scotch pine was greatest at the higher rate of N (336 kgN/ha), where the lower level of N (112 kgN/ha) applied with the lower simazine level (4.50 kg/ha) was more effective in reducing the foliar B of balsam fir. The higher rate of ammonium nitrate (336 kgN/ha) applied with atrazine significantly lowered the foliar B concentration of balsam fir over where the herbicide was applied alone. N additions to the atrazine plots did not significantly alter the foliar B of either Scotch pine or white spruce, although a decreasing trend in foliar B was observed with increasing N applied (Tables 19 and 20). Supplemental N alone also significantly reduced the foliar B concentration of Scotch pine and balsam fir seedlings.

Broadcast applications of ammonium nitrate to simazine and atrazine treated seedlings during the first growing season did not significantly alter the foliar concentrations of N, K, Na, Ca, Fe, or Al for either species (Tables 19, 20 and 21). Similarly, as N applied to simazine plots did not significantly affect foliar Mg or Mn, N applied with atrazine did not affect the foliar Cu or Zn concentration of either species. Supplemental N alone (without herbicide) broadcast over the field plots did not significantly alter the foliar assimilation of K, Na, Ca, Mg, or Fe for either species in the first growing season. However, N additions alone to balsam fir seedlings significantly lowered their foliar Al concentration over the control (Table 21). This decrease in foliar Al was greatest at the lower level of N (112 kgN/ha).

It is apparent that combination herbicide and N treatments applied to the field plots significantly changed the concentration of many of the foliar elements. However, it should be noted that these changes in foliar mineral nutrition were primarily a response to added N and not herbicide. Although, no explanation is offered to describe the interaction effects of herbicide and N treatments on the changes in the foliar mineral concentrations in these species, these observations may prove useful to future researchers.

Mulching and Mineral Nutrition.--Mulching used as a non-phytotoxic weed control treatment, significantly increased foliar N and P and decreased foliar Ca, Mg, and Fe for all species during the first growing season (Tables 19, 20, and 21; Appendix E). Mulching had no significant effect upon the foliar concentrations of K, Na, Mn, Cu, B, Zn, or Al for either species. The effect of mulching on N concentration was not apparent in the second growing season. Concentrations of other foliar elements were not measured after the first year.

The lack of a greater gain in N assimilation in conifers from triazine compounds used under these field conditions may be a result of the high herbicide rates along with surface dispersion of herbicides by abnormal precipitation. It is possible that as triazine levels are further reduced by leaching and degradation with time, there may be a delayed nutritional gain in subsequent growing seasons.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objectives of this study were to determine: (1) the effect of low level soil applications of simazine and atrazine, and their interaction with ammonium and nitrate sources of N, on the growth and foliar N nutrition of slash and loblolly pine seedlings grown under controlled environment; (2) the effect of pre-emergence herbicidal applications of simazine and atrazine, and their interaction with ammonium nitrate fertilizer, on the foliar mineral nutrition of Scotch pine, white spruce, and balsam fir nursery transplants.

First Growth Chamber Study--Slash Pine with Simazine

Non-phytotoxic applications of simazine (0.05 and 0.10 ppm) did not significantly alter either the foliar N concentration (% N in needles) or foliar N accumulation (mg N/top) of 10-week-old slash pine seedlings raised on a soil-quartz sand mixture. However, simazine at 0.10 ppm appeared to enhance the growth and foliar N content of slash pine seedlings. Simazine (0.10 ppm) applied with the

ammonium source of N (14 and 42 ppm N) tended to increase the foliar N concentration of seedlings more than did nitrate N and simazine at similar levels. Simazine applied with both 14 and 42 ppm N of either nitrate or ammonium N did not significantly increase the foliar N accumulation of seedlings over where the N sources were applied alone. Simazine treatments (0.05 and 0.10 ppm) did not significantly affect either total green or dry seedling weights.

Second Growth Chamber Study--Slash Pine with Simazine

In this study slightly higher levels of simazine were used. The foliar N concentration of 12-week-old slash pine seedlings was increased by simazine applications of 0.2, 0.4, and 0.8 ppm. The maximum increase was 43.8 percent at the highest simazine level. This increase was almost equivalent to adding 84 ppm N of either nitrate or ammonium N in the nutrient solution. N accumulation was increased 26.2 percent when 0.4 ppm simazine was applied to the soil. Simazine appears to enhance N accumulation in seedling foliage. Increased foliar N content from subtoxic applications of simazine has also been shown for other crops (DeVries, 1963; Ries *et al.*, 1967). A decrease in foliar N accumulation between the 0.4 and 0.8 ppm simazine treatments (although an increase over the control) was a result of decreased foliage dry weight at the 0.8 ppm simazine level. Simazine applied at 0.8 ppm with both

nitrate and ammonium additions (84 ppm N) increased the foliar N concentration of seedlings 70.8 and 65.4 percent, respectively. The effect of simazine on foliar N accumulation decreased as the nitrate level approached the optimum. Conversely, at the higher levels of both ammonium N (84 ppm N) and simazine (0.8 ppm), N accumulation was greatest. This increase in foliar N with increasing herbicide application occurs without any significant change in seedling mass. Increasing concentrations of soil applied simazine (0.2 - 0.8 ppm) did not significantly alter either green or dry seedling weights. However, the higher simazine rate (0.8 ppm) decreased both the green and dry weights of all plant parts.

<u>Third Growth Chamber Study--Slash and Loblolly Pine with Atrazine</u>

In the final growth chamber study a second species, loblolly pine, was included and atrazine was substituted for simazine as the herbicide. Low level soil applications of atrazine (0.4 ppm) increased the foliar N concentration of 11-week-old slash and loblolly pine seedlings. However, this increase was considerably less than where either nitrate or ammonium (84 ppm N) sources of N were applied alone. The foliar N accumulation in slash pine seedlings was increased by 0.4 ppm atrazine applied both alone and with supplemental N in the nutrient solution. However, atrazine and N treatments depressed the foliar N accumulation

in loblolly pine seedling, except when 0.4 ppm atrazine was applied with either nitrate or ammonium sources of N (84 ppm N). Atrazine (0.4 ppm) treatment decreased the green and dry weights of loblolly pine seedlings.

Greenhouse Study--Slash Pine with Simazine

Foliar Nitrogen Content.--The foliar N concentration of 16-week-old slash pine seedlings was increased by applications of 0.5, 1, and 2 ppm simazine. The maximum increase was 91 percent at the highest simazine level. This increase in foliar N concentration was greater than when 84 ppm N of either nitrate or ammonium N was applied in the nutrient solution. The foliar N concentration of seedlings treated with simazine (0.5 - 2 ppm) and both levels (28 and 84 ppm N) of either nitrate or ammonium N was greater than when these N sources were applied alone.

Simazine treatment at 0.5 and 1 ppm did not affect the foliar N accumulation of seedlings. However, 2 ppm simazine applied both alone and with nitrate or ammonium sources of N significantly depressed N accumulation. Thus, simazine applied at this concentration to seedlings at this stage of development was probably phytotoxic. It is apparent that the significant increases in foliar N concentration from simazine treatment in this study were primarily a function of decreased seedling biomass.

Simazine treatment at 2 ppm increased foliar nitrates. No differences were found in foliar nitrates between nitrate and ammonium treated seedlings, either alone or with simazine. This implied that possibly the ammonium ion was as effectively utilized with simazine as was the nitrate source of N. If this is true, the effect of simazine on foliar N accumulation is not necessarily a function of increased nitrate reductase activity accelerating nitrate uptake by plants as suggested by Ries et al. (1967). However, it is possible that N-Serve added to inhibit nitrification of ammonium N was not effective and part of the growth and increased N from ammonium N and simazine was actually a nitrate response.

Simazine and Growth Reduction.--In contrast to the growth chamber where low levels of simazine (0.05 - 0.8 ppm) did not affect the green or dry weights of slash pine seedlings, decreases in both green and dry seedlings weights were found where slightly higher concentrations of simazine (1 - 2 ppm) were applied in the greenhouse. Simazine treatment depressed root weight more than foliage weight. For example, simazine applications at 0.5 ppm significantly reduced both green and dry root weights, but did not effect either green or dry foliage weights. Since N additions to simazine treated plants failed to significantly improve growth, simazine as these concentrations is probably interfering in some way with physiological growth processes.

Field Study--Simazine and Atrazine at Herbicidal Rates

Foliar Mineral Nutrition.--The lower rate of soil applied atrazine (2.25 kg/ha) increased the foliar Mg concentration of field planted Scotch pine, white spruce, and balsam fir over the control. Atrazine treatment did not affect the foliar concentration of any other elements the first season other than Mg. However, the 2.25 kg/ha atrazine application the second year significantly increased the foliar N concentration of white spruce over the control and 4.50 kg/ha treatment. Simazine applied at herbicidal rates (4.50 and 9.00 kg/ha) did not significantly alter the foliar concentration of any element for either species the first growing season. Neither did simazine treatment affect the foliar N concentration of seedlings the second year. A greater herbicidal injury and mortality occurred in white spruce than the other species. Since the phytotoxic effect of triazine treatment on this species appeared greater when the herbicides were applied alone, it is possible that supplemental N to the triazine plots might have counteracted herbicide phytotoxicity. It is also possible that differential uptake and/or distribution of the herbicides occurred among the three species as the white spruce was most significantly affected.

Ammonium nitrate fertilizer applied to simazine plots significantly decreased the foliar concentrations

Field Study--Simazine and Atrazine at Herbicidal Rates

Foliar Mineral Nutrition.--The [illegible] applied atrazine (2.25 kg/ha) [illegible] centration of field planted Scotch pine [illegible] balsam fir over the cont[illegible] affect the foliar concent[illegible] first season other than [illegible] zine application the second [illegible] the foliar N concentration [illegible] the control and 4.50 kg/ha treatment [illegible] applied at herbicidal rates (4.50 and 9.00 kg/ha) did not [illegible] the foliar concentration of any element for either [illegible] the first growing season. Neither did simazine treatment affect the foliar N concentration of seedlings the second year. A greater herbicidal injury and mortality occurred in white spruce than the other species. Since the phyto-toxic effect of triazine treatment on this species appeared greater when the herbicides were applied alone, it is possible that supplemental N to the triazine plots might have counteracted herbicide phytotoxicity. It is also possible that differential uptake and/or distribution of the herbicides occurred among the three species as the white spruce was most significantly affected.

Ammonium nitrate fertilizer applied to simazine plots significantly decreased the foliar concentrations of P, Ca, Cu, Zn, and B for various species. Supplemental N applied with atrazine significantly decreased foliar P and B, and increased foliar Mg and Mn for some species. Ammonium nitrate applied with simazine and atrazine the first year did not affect the foliar concentrations of N, K, Na, Ca, Fe, or Al for either species. Neither did N applied to simazine plots affect foliar Mg or Mn, or N applied with atrazine affect foliar Cu or Zn of any seedlings.

A fresh hardwood chip mulch, used as a non-phytotoxic weed control treatment, significantly increased the foliar concentrations of N and P, decreased foliar Ca, Mg, and Fe, and had no effect upon foliar K, Na, Cu, B, Zn, or Al for either species.

Silvicultural Implications

The majority of sites on which coniferous trees are planted are inherently low in fertility or degraded by past use. Nitrogen is one of the most important elements in plant nutrition and a commonly deficient element in trees growing on poor soils. From growth chamber results where non-phytotoxic levels of simazine (0.1 - 0.4 ppm) enhanced the foliar N accumulation of slash pine seedlings without significantly altering seedling biomass, it appears that a nutritional gain from low level applications of simazine might be an efficient way of supplying

available N to trees growing on low fertility soils. Also, low level applications of triazines to coniferous seed beds may provide some weed control in addition to a nutritional gain. However, the differential tolerance among various species to triazine compounds must be considered. At present, additional research is needed to further substantiate a "nutritional bonus" in addition to weed control from triazine compounds applied at sub-toxic levels. Low level applications of triazines and their interaction with both soil and applied nutrients should be tested in the field using a variety of species under different soil and climatic conditions.

When a herbicidal rate of simazine (2 ppm) was applied to seedlings in the greenhouse, the significant increase in foliar N concentration was primarily a function of growth reduction. Although foliar N concentration is not always correlated with growth, triazine treatment to coniferous trees at herbicidal rates may significantly influence: (1) resistance to disease, (2) resistance to insect attack, (3) seed production, and (4) frost resistance. In addition, the use of herbicidal rates of simazine and atrazine for weed control in young tree plantations may influence a delayed nutritional gain in subsequent growing seasons after triazine compounds are degraded to lower levels in the soil.

Although low level applications of triazines in this study were tested only under controlled environment, this research will provide some useful guidelines for other investigators.

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APPENDIX

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APPENDIX A

Appendix Table I.--Effect of simazine and nitrogen treatments on the foliar nitrogen concentration and accumulation of slash pine seedlings grown in the growth chamber for 10 weeks; Experiment 1 (means of 4 replications).

Treatment[1]				Foliar Nitrogen[2]		% N Increase over Control	
No.	Simazine	NO_3^-	NH_4^+	Conc.[3]	Accum.		
	ppm	--ppm	N--	%	mg/top	Conc.	Accum.
1	--	--	--	1.35	4.84	--	--
2	--	14	--	1.63	7.27	20.7	50.0
3	--	42	--	1.85*	7.31	37.0	51.0
4	--	--	14	1.88*	8.06**	39.3	66.5
5	--	--	14	1.77	7.47	31.1	54.5
6	--	--	42	1.95**	7.30	44.4	50.8
7	--	--	42	1.87*	8.54**	38.5	76.4
8	0.05	--	--	1.43	5.39	5.9	11.4
9	0.05	14	--	1.78	7.18	31.8	48.4
10	0.05	42	--	1.87*	7.99**	38.5	65.3
11	0.05	--	14	1.68	6.93	24.4	43.0
12	0.05	--	14	1.85*	7.44	37.0	53.7
13	0.05	--	42	1.93**	6.90	43.0	42.6
14	0.05	--	42	1.80	6.84	33.3	41.3
15	0.10	--	--	1.50	6.36	11.1	31.4
16	0.10	14	--	1.78	6.77	31.8	39.9
17	0.10	42	--	1.80	7.10	33.3	46.7
18	0.10	--	14	1.93**	7.96**	43.0	64.5
19	0.10	--	14	1.90*	7.05	40.7	45.7
20	0.10	--	42	1.97**	7.02	45.9	45.0
21	0.10	--	42	1.92**	7.49*	42.2	55.0
Tukey's w (.05)					2.65		
(.01)					3.04		

[1]Treatments 5, 7, 12, 14, 19, and 21 contained N-Serve at a rate of 10% of the respective N level.

[2]Determined on a dry weight basis. See Table 11 for statistical significance.

[3]Significance determined from transformed data (arcsin $\sqrt{\%}$), thus no Tukey's w shown.

* Significantly greater than control at 0.05 level.
** Significantly greater than control at 0.01 level.

Appendix Table II.--Effect of simazine and nitrogen treatments on the green weight of slash pine seedlings grown in the growth chamber for 10 weeks; Experiment 1 (means of 4 replications).

	Treatment[1]			Green Weight[2]				
No.	Simazine	NO_3^-	NH_4^+	Foliage	Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		-----------------g-----------------				
1	--	--	--	1.18	0.12	0.39	1.68	3.13
2	--	14	--	1.42	0.15	0.42	1.99	3.49
3	--	42	--	1.30	0.15	0.41	1.80	3.52
4	--	--	14	1.45	0.15	0.50	2.09	3.10
5	--	--	14	1.39	0.15	0.40	1.94	3.67
6	--	--	42	1.29	0.11	0.40	1.80	3.32
7	--	--	42	1.55	0.15	0.49	2.18	3.38
8	0.05	--	--	1.10	0.11	0.39	1.61	2.89
9	0.05	14	--	1.32	0.14	0.41	1.87	3.40
10	0.05	42	--	1.49	0.13	0.40	2.02	3.87
11	0.05	--	14	1.42	0.15	0.50	2.08	3.26
12	0.05	--	14	1.40	0.14	0.40	1.93	3.56
13	0.05	--	42	1.24	0.13	0.42	1.80	3.30
14	0.05	--	42	1.22	0.13	0.39	1.74	3.13
15	0.10	--	--	1.44	0.15	0.47	2.06	3.28
16	0.10	14	--	1.30	0.14	0.35	1.79	4.10
17	0.10	42	--	1.41	0.15	0.40	1.96	3.51
18	0.10	--	14	1.37	0.13	0.42	1.91	3.35
19	0.10	--	14	1.24	0.12	0.36	1.72	3.55
20	0.10	--	42	1.23	0.13	0.35	1.71	3.48
21	0.10	--	42	1.32	0.15	0.42	1.90	3.16

[1]Treatments 5, 7, 12,14, 19, and 21 contained N-Serve at a rate of 10% of the respective N level.

[2]See Table 12 for statistical significance.

Appendix Table III.--Effect of simazine and nitrogen treatments on the dry weight of slash pine seedlings grown in the growth chamber for 10 weeks; Experiment 1 (means of 4 replications).

Treatment[1]				Dry Weight[2]					
No.	Simazine	NO_3^-	NH_4^+	Foliage		Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		%	------------	---g---	------------		
1	--	--	--	30.1	0.36	0.04	0.17	0.57	2.17
2	--	14	--	32.0	0.45	0.05	0.17	0.67	2.70
3	--	42	--	31.2	0.40	0.05	0.14	0.59	3.02
4	--	--	14	29.6	0.43	0.05	0.15	0.63	3.05
5	--	--	14	30.6	0.42	0.05	0.15	0.62	2.93
6	--	--	42	29.3	0.37	0.03	0.15	0.56	2.57
7	--	--	42	29.8	0.46	0.04	0.18	0.68	2.60
8	0.05	--	--	34.1	0.38	0.04	0.16	0.58	2.44
9	0.05	14	--	30.7	0.41	0.05	0.16	0.61	2.79
10	0.05	42	--	29.2	0.44	0.05	0.15	0.63	3.01
11	0.05	--	14	28.7	0.41	0.05	0.18	0.63	2.53
12	0.05	--	14	29.4	0.41	0.05	0.17	0.62	2.65
13	0.05	--	42	29.7	0.36	0.04	0.15	0.55	2.79
14	0.05	--	42	30.9	0.38	0.04	0.15	0.56	2.66
15	0.10	--	--	30.8	0.43	0.04	0.17	0.65	2.57
16	0.10	14	--	29.4	0.38	0.04	0.13	0.56	3.27
17	0.10	42	--	30.6	0.39	0.05	0.15	0.59	2.90
18	0.10	--	14	30.6	0.42	0.03	0.16	0.61	3.21
19	0.10	--	14	29.6	0.36	0.04	0.15	0.55	2.59
20	0.10	--	42	29.7	0.37	0.04	0.14	0.55	2.55
21	0.10	--	42	29.4	0.39	0.05	0.18	0.61	2.26

[1]Treatments 5, 7, 12, 14, 19, and 21 contained N-Serve at a rate of 10% of the respective N level.

[2]See Tables 11 and 12 for statistical significance.

APPENDIX B

Appendix Table IV.--Effect of simazine and nitrogen treatments on the foliar nitrogen concentration and accumulation of slash pine seedlings grown in the growth chamber for 12 weeks; Experiment 2 (means of 4 replications).

Treatment[1]				Foliar Nitrogen[2]		% N Increase Over Control	
No.	Simazine	NO_3^-	NH_4^+	Conc.[3]	Accum.		
	ppm	--ppm	N--	%	mg/top	Conc.	Accum.
1	--	--	--	1.30	4.93	--	--
2	--	28	--	1.58	5.79	20.8	17.4
3	--	84	--	1.97**	5.05	51.5	2.6
4	--	--	28	1.55	7.30	19.2	48.1
5	--	--	84	1.90**	5.37	46.2	8.9
6	0.2	--	--	1.63	5.55	24.6	12.6
7	0.2	28	--	1.50	6.16	15.4	24.9
8	0.2	84	--	2.00**	5.94	53.8	20.5
9	0.2	--	28	1.70	5.77	30.8	16.8
10	0.2	--	84	2.02**	6.16	55.4	24.9
11	0.4	--	--	1.55	6.22	19.2	26.2
12	0.4	28	--	1.53	6.17	16.9	25.2
13	0.4	84	--	2.07**	5.30	59.2	7.5
14	0.4	--	28	2.13**	6.52	62.3	32.2
15	0.4	--	84	1.95**	7.27	50.0	47.5
16	0.8	--	--	1.87**	5.86	43.8	18.9
17	0.8	28	--	2.07**	7.24	58.5	46.9
18	0.8	84	--	2.22**	7.18	70.8	45.6
19	0.8	--	28	1.92**	5.79	47.7	17.4
20	0.8	--	84	2.15**	8.22*	65.4	66.7
Tukey's w (.05)					3.07		
(.01)					3.52		

[1]Treatments with NH4-N contained N-Serve at a rate of 10% of the respective N level.

[2]Determined on a dry weight basis. See Table 13 for statistical significance.

[3]Significance determined from transformed data (arcsin $\sqrt{\%}$), thus no Tukey's w shown.

* Significantly greater than control at 0.05 level.
** Significantly greater than control at 0.01 level.

Appendix Table V.--Effect of simazine and nitrogen treatments on the green weight of slash pine seedlings grown in the growth chamber for 12 weeks; Experiment 2 (means of 4 replications).

Treatment[1]				Green Weight[2]				
No.	Simazine	NO_3^-	NH_4^+	Foliage	Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		-----------------g---------------				
1	--	--	--	1.14	0.13	0.50	1.52	2.30
2	--	28	--	1.26	0.13	0.48	1.88	2.73
3	--	84	--	0.92	0.11	0.34	1.37	3.07
4	--	--	28	1.30	0.15	0.43	1.89	3.12
5	--	--	84	0.89	0.09	0.34	1.32	2.59
6	0.2	--	--	1.26	0.13	0.37	1.75	3.57
7	0.2	28	--	1.35	0.14	0.46	1.95	2.91
8	0.2	84	--	1.05	0.11	0.34	1.50	3.11
9	0.2	--	28	1.16	0.11	0.38	1.65	3.11
10	0.2	--	84	1.01	0.11	0.39	1.51	2.60
11	0.4	--	--	1.25	0.13	0.49	1.87	2.66
12	0.4	28	--	1.31	0.12	0.47	1.90	2.81
13	0.4	84	--	0.92	0.11	0.28	1.32	3.38
14	0.4	--	28	1.06	0.11	0.46	1.63	2.36
15	0.4	--	84	1.21	0.12	0.49	1.82	2.55
16	0.8	--	--	1.06	0.11	0.30	1.47	3.49
17	0.8	28	--	1.34	0.13	0.36	1.82	4.06
18	0.8	84	--	1.15	0.11	0.31	1.57	3.78
19	0.8	--	28	1.04	0.11	0.37	1.53	2.86
20	0.8	--	84	1.27	0.13	0.46	1.86	2.84

[1]Treatments with NH_4-N contained N-Serve at a rate of 10% of the respective N level.

[2]See Table 14 for statistical significance.

Appendix Table VI.--Effect of simazine and nitrogen treatments on the dry weight of slash pine seedlings grown in the growth chamber for 12 weeks; Experiment 2 (means of 4 replications).

Treatment[1]				Dry Weight[2]					
No.	Simazine	NO_3^-	NH_4^+	Foliage		Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		%	------------	------g------	------------		
1	--	--	--	32.5	0.37	0.04	0.19	0.60	2.02
2	--	28	--	29.6	0.37	0.05	0.16	0.57	2.40
3	--	84	--	27.9	0.25	0.04	0.11	0.40	2.56
4	--	--	28	30.9	0.40	0.05	0.15	0.61	2.64
5	--	--	84	32.6	0.29	0.03	0.11	0.44	2.54
6	0.2	--	--	27.9	0.35	0.04	0.12	0.51	3.02
7	0.2	28	--	29.9	0.40	0.05	0.16	0.61	2.43
8	0.2	84	--	28.6	0.30	0.04	0.12	0.46	2.60
9	0.2	--	28	29.2	0.34	0.04	0.12	0.50	2.71
10	0.2	--	84	30.6	0.31	0.04	0.14	0.49	2.21
11	0.4	--	--	31.7	0.40	0.04	0.16	0.60	2.54
12	0.4	28	--	30.7	0.40	0.04	0.16	0.60	2.50
13	0.4	84	--	28.3	0.26	0.04	0.09	0.40	2.84
14	0.4	--	28	28.9	0.31	0.04	0.16	0.51	1.93
15	0.4	--	84	30.8	0.38	0.05	0.17	0.59	2.20
16	0.8	--	--	29.6	0.31	0.03	0.10	0.45	3.11
17	0.8	28	--	26.8	0.36	0.04	0.12	0.52	3.30
18	0.8	84	--	27.8	0.32	0.03	0.11	0.46	3.15
19	0.8	--	28	28.9	0.30	0.04	0.13	0.47	2.39
20	0.8	--	84	29.9	0.38	0.05	0.15	0.58	2.59

[1]Treatments with NH_4-N contained N-Serve at a rate of 10% of the respective N level.

[2]See Tables 13 and 14 for statistical significance.

APPENDIX C

Appendix Table VII.--Effect of atrazine and nitrogen treatments on the foliar nitrogen concentration and accumulation of slash and loblolly pine seedlings grown in the growth chamber for 11 weeks; Experiment 3 (means of 4 replications).

Treatment[1]				Foliar Nitrogen[2]		% N Deviation from Control	
No.	Atrazine	NO_3^-	NH_4^+	Conc.[3]	Accum.		
	ppm	--ppm	N--	%	mg/top	Conc.	Accum.
				Slash Pine			
1	--	--	--	1.58	3.91	--	--
2	--	84	--	1.97*	4.54	25.5	16.1
3	--	--	84	2.07**	4.97	32.5	27.1
4	0.1	--	--	1.50	3.72	-4.4	-4.9
5	0.1	84	--	2.35**	3.98	49.0	1.8
6	0.1	--	84	2.00**	4.58	27.4	17.1
7	0.4	--	--	1.63	4.42	3.2	13.0
8	0.4	84	--	2.32**	4.21	46.5	7.9
9	0.4	--	84	2.12**	7.07**	35.0	80.6
				Loblolly Pine			
1	--	--	--	1.63	3.15	--	--
2	--	84	--	2.20**	2.86	36.6	-9.2
3	--	--	84	2.10**	2.62	30.4	-16.8
4	0.1	--	--	1.63	2.39	0.6	-24.1
5	0.1	84	--	2.05**	2.37	26.7	-24.8
6	0.1	--	84	2.20**	2.88	36.6	-9.2
7	0.4	--	--	1.82	2.42	13.0	-23.2
8	0.4	84	--	2.47**	3.63	53.4	14.9
9	0.4	--	84	2.20**	3.21	36.6	2.2
Tukey's w (.01)[4]					2.57		

[1] Treatments with NH_4-N contained N-Serve at a rate of 10% of the N level.

[2] Determined on a dry weight basis. See Table 15 for statistical significance.

[3] Significance determined from transformed data (arcsin $\sqrt{\%}$), thus no Tukey's w shown.

[4] For treatments within species.

* Significantly greater than control at 0.05 level.
** Significantly greater than control at 0.01 level.

Appendix Table VIII.--Effect of atrazine and nitrogen treatments on the green weight of slash and loblolly pine seedlings grown in the growth chamber for 11 weeks; Experiment 3 (means of 4 replications).

Treatment[1]				Green Weight[2]				
No.	Atrazine	NO_3^-	NH_4^+	Foliage	Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		---------------g---------------				
				Slash Pine				
1	--	--	--	0.78	0.11	0.27	1.17	2.96
2	--	84	--	0.88	0.12	0.28	1.27	3.20
3	--	--	84	0.79	0.10	0.24	1.14	3.34
4	0.1	--	--	0.81	0.10	0.25	1.15	3.22
5	0.1	84	--	0.62	0.07	0.15	0.84	4.57
6	0.1	--	84	0.75	0.09	0.24	1.08	3.31
7	0.4	--	--	0.88	0.10	0.29	1.27	3.09
8	0.4	84	--	0.64	0.10	0.17	0.90	3.83
9	0.4	--	84	1.07	0.11	0.27	1.45	4.13
				Loblolly Pine				
1	--	--	--	0.62	0.07	0.17	0.86	3.92
2	--	84	--	0.43	0.05	0.10	0.58	4.08
3	--	--	84	0.38	0.04	0.09	0.51	4.13
4	0.1	--	--	0.49	0.06	0.13	0.67	4.04
5	0.1	84	--	0.39	0.05	0.08	0.52	4.89
6	0.1	--	84	0.41	0.05	0.12	0.57	3.57
7	0.4	--	--	0.43	0.05	0.11	0.58	4.51
8	0.4	84	--	0.51	0.05	0.12	0.68	4.40
9	0.4	--	84	0.46	0.06	0.13	0.64	3.82

[1]Treatments with NH_4-N contained N-Serve at a rate of 10% of the N level.

[2]See Table 16 for statistical significance.

Appendix Table IX.--Effect of atrazine and nitrogen treatments on the dry weight of slash and loblolly pine seedlings grown in the growth chamber for 11 weeks; Experiment 3 (means of 4 replications).

Treatment[1]				Dry Weight[2]					
No.	Atrazine	NO_3^-	NH_4^+	Foliage		Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		%	-------------	------g------	------------		
				Slash Pine					
1	--	--	--	31.7	0.25	0.03	0.09	0.37	2.94
2	--	84	--	27.4	0.24	0.04	0.10	0.38	2.56
3	--	--	84	30.5	0.24	0.04	0.09	0.38	2.65
4	0.1	--	--	30.5	0.24	0.03	0.07	0.34	3.28
5	0.1	84	--	27.6	0.17	0.03	0.06	0.25	3.39
6	0.1	--	84	30.5	0.23	0.04	0.09	0.36	2.69
7	0.4	--	--	30.8	0.27	0.03	0.11	0.41	2.60
8	0.4	84	--	28.8	0.18	0.03	0.05	0.26	3.58
9	0.4	--	84	34.2	0.33	0.04	0.11	0.48	3.24
				Loblolly Pine					
1	--	--	--	31.4	0.20	0.02	0.07	0.29	2.95
2	--	84	--	29.9	0.13	0.02	0.04	0.19	3.09
3	--	--	84	34.1	0.13	0.02	0.05	0.19	2.81
4	0.1	--	--	30.4	0.15	0.02	0.05	0.22	3.16
5	0.1	84	--	30.8	0.12	0.02	0.03	0.17	3.94
6	0.1	--	84	31.7	0.13	0.02	0.05	0.20	2.58
7	0.4	--	--	31.1	0.13	0.02	0.04	0.20	3.41
8	0.4	84	--	28.7	0.15	0.02	0.05	0.21	2.92
9	0.4	--	84	31.1	0.15	0.02	0.05	0.22	2.78

[1]Treatments with NH_4-N contained N-Serve at a rate of 10% of the N level.

[2]See Tables 15 and 16 for statistical significance.

APPENDIX D

Appendix Table X.--Effect of simazine and nitrogen treatments on the foliar nitrogen concentration, accumulation, and nitrates of slash pine seedlings grown in the greenhouse for 16 weeks (means of 4 replications).

Treatment[1]				Foliar Nitrogen[2]			% N Deviation from Control	
No.	Simazine	NO_3^-	NH_4^+	Conc.[3]	Accum.	Nitrates		
	ppm	--ppm N-		%	mg/top	µg/g	Conc.	Accum.
1	--	--	--	1.26	13.15	13.86	--	--
2	--	28	--	1.73**	19.09	13.70	37.3	45.2
3	--	84	--	1.71**	16.17	12.29	35.7	23.0
4	--	--	28	1.43	15.43	13.33	13.5	17.3
5	--	--	84	1.85**	21.49**	11.08	46.8	63.4
6	0.5	--	--	1.61	13.67	12.65	27.8	4.0
7	0.5	28	--	1.89**	17.68	11.55	50.0	34.4
8	0.5	84	--	1.86**	18.37	11.97	47.6	39.7
9	0.5	--	28	1.78**	17.30	12.86	41.3	31.6
10	0.5	--	84	2.21**	23.66**	11.60	75.4	79.9
11	1.0	--	--	1.99**	14.04	13.54	57.9	6.8
12	1.0	28	--	2.13**	13.85	13.97	69.0	5.4
13	1.0	84	--	2.23**	14.07	11.60	77.0	7.0
14	1.0	--	28	2.08**	15.31	11.92	65.1	16.4
15	1.0	--	84	2.26**	18.76	14.33	79.4	42.7
16	2.0	--	--	2.41**	9.44	17.22	91.3	-28.2
17	2.0	28	--	2.38**	11.12	12.60	88.9	-15.4
18	2.0	84	--	2.63**	9.86	16.01	108.7	-25.0
19	2.0	--	28	2.58**	10.57	16.64	104.8	-19.6
20	2.0	--	84	2.74**	11.64	17.38	117.5	-11.5
Tukey's w (.05)					6.01	5.32		
(.01)					6.90	6.11		

[1]All treatments contained N-Serve at a rate of 10% of the 84 ppm N level.

[2]Determined on a dry weight basis. See Table 17 for statistical significance.

[3]Significance determined from transformed data (arcsin $\sqrt{\%}$), thus no Tukey's w shown.

** Significantly greater than control at 0.01 level.

Appendix Table XI.--Effect of simazine and nitrogen treatments on the green weight of slash pine seedlings grown in the greenhouse for 16 weeks (means of 4 replications).

Treatment[1]				Green Weight[2]				
No.	Simazine	NO_3^-	NH_4^+	Foliage	Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		----------------g----------------				
1	--	--	--	3.72	0.19	1.74	5.65	2.15
2	--	28	--	4.33	0.22	1.82	6.29	2.41
3	--	84	--	3.76	0.19	1.52	5.38	2.65
4	--	--	28	4.12	0.20	1.66	5.98	2.55
5	--	--	84	4.61	0.19	1.62	6.42	3.01
6	0.5	--	--	3.47	0.13	0.89**	4.50	3.99
7	0.5	28	--	3.85	0.17	1.05**	5.07	3.82
8	0.5	84	--	4.01	0.16	1.12**	5.29	3.76
9	0.5	--	28	3.98	0.15	0.96**	5.10	4.14
10	0.5	--	84	4.48	0.18	1.43	6.09	3.22
11	1.0	--	--	2.91	0.10**	0.54**	3.55**	5.54**
12	1.0	28	--	2.79	0.11**	0.52**	3.43**	5.61**
13	1.0	84	--	2.69	0.10**	0.54**	3.33**	5.13**
14	1.0	--	28	3.03	0.12**	0.61**	3.73**	5.16**
15	1.0	--	84	3.34	0.15	0.66**	4.22	5.56**
16	2.0	--	--	1.56**	0.07**	0.24**	1.87**	6.78**
17	2.0	28	--	1.95**	0.07**	0.28**	2.28**	7.18**
18	2.0	84	--	1.48**	0.06**	0.18**	1.71**	8.45**
19	2.0	--	28	1.74**	0.07**	0.22**	2.03**	8.01**
20	2.0	--	84	1.76**	0.07**	0.23**	2.06**	7.77**
Tukey's w (.05)				1.08	0.06	0.53	1.44	2.11
(.01)				1.23	0.07	0.61	1.65	2.43

[1]All treatments contained N-Serve at a rate of 10% of the 84 ppm N level.

[2]See Table 18 for statistical significance.

** Significantly different from control at 0.01 level.

Appendix Table XII.--Effect of simazine and nitrogen treatments on the dry weight of slash pine seedlings grown in the greenhouse for 16 weeks (means of 4 replications).

No.	Treatment[1] Simazine	NO_3^-	NH_4^+	Dry Weight[2] Foliage		Stem	Root	Total	Foliage/Root
	ppm	--ppm N--		%	----------	----g----	----------	----------	
1	--	--	--	27.8	1.04	0.06	0.42	1.51	2.48
2	--	28	--	25.4	1.10	0.06	0.42	1.59	2.66
3	--	84	--	25.1	0.93	0.06	0.36	1.35	2.63
4	--	--	28	26.5	1.10	0.06	0.42	1.57	2.62
5	--	--	84	25.3	1.16	0.05	0.42	1.64	2.80
6	0.5	--	--	24.5*	0.85	0.04	0.27**	1.16*	3.17
7	0.5	28	--	24.2*	0.93	0.05	0.28**	1.27	3.26
8	0.5	84	--	24.4*	0.98	0.05	0.29*	1.33	3.35
9	0.5	--	28	24.4*	0.97	0.05	0.28**	1.30	3.41
10	0.5	--	84	24.0**	1.08	0.05	0.34	1.47	3.22
11	1.0	--	--	24.4*	0.71**	0.03**	0.19**	0.94**	3.66
12	1.0	28	--	23.2**	0.65**	0.03**	0.17**	0.85**	3.94
13	1.0	84	--	23.5**	0.63**	0.03**	0.18**	0.84**	3.55
14	1.0	--	28	24.4*	0.74**	0.04	0.21**	0.99**	3.60
15	1.0	--	84	24.9	0.83	0.04	0.22**	1.10**	3.88
16	2.0	--	--	25.2	0.39**	0.02**	0.09**	0.51**	4.35**
17	2.0	28	--	24.0**	0.47**	0.02**	0.10**	0.59**	4.77**
18	2.0	84	--	25.3	0.38**	0.02**	0.07**	0.47**	5.23**
19	2.0	--	28	23.7**	0.41**	0.02**	0.08**	0.51**	5.08**
20	2.0	--	84	24.2*	0.43**	0.03**	0.09**	0.54**	4.62**
Tukey's w (.05)					0.24	0.02	0.11	0.33	1.52
(.01)					0.28	0.02	0.13	0.38	1.74

[1]All treatments contained N-Serve at a rate of 10% of the 84 ppm N level.

[2]Significance for foliage % dry weight determined from transformed data (arcsin $\sqrt{\%}$), thus no Tukey's w shown. See Tables 17 and 18 for statistical significance.

* Significantly different from control at 0.05 level.

** Significantly different from control at 0.01 level.

Appendix Table XIII.--Effect of simazine and nitrogen treatments on the height and stem diameter of slash pine seedlings grown in the greenhouse for 16 weeks (means of 4 replications).

Treatment[1]					
No.	Simazine	NO_3^-	NH_4^+	Height[2]	Diameter[3]
	ppm	---ppm	N---	---------cm	---------
1	--	--	--	18.24	0.29
2	--	28	--	18.88	0.31
3	--	84	--	16.58	0.30
4	--	--	28	18.81	0.30
5		--	84	18.77	0.31
6	0.5	--	--	20.20	0.26
7	0.5	28	--	18.90	0.27
8	0.5	84	--	18.41	0.28
9	0.5	--	28	18.70	0.28
10	0.5	--	84	19.38	0.29
11	1.0	--	--	18.55	0.23**
12	1.0	28	--	18.95	0.23**
13	1.0	84	--	17.81	0.23**
14	1.0	--	28	19.19	0.25
15	1.0	--	84	19.55	0.26
16	2.0	--	--	15.63	0.18**
17	2.0	28	--	16.66	0.20**
18	2.0	84	--	15.91	0.17**
19	2.0	--	28	16.59	0.18**
20	2.0	--	84	16.26	0.18**
Tukey's w	(.05)			3.11	0.046
	(.01)			3.56	0.052

[1]All treatments contained N-Serve at a rate of 10% of the 84 ppm N level.

[2]Measured from soil surface.

[3]Measured 2 cm above root collar.

See Table 17 for statistical significance.
** Significantly less than control at 0.1 level.

Appendix Table XIV.--Changes in the foliar concentrations of N, K, P, Ca, and Mg in field planted SCOTCH PINE from ammonium nitrate and weed control treatments (means of 5 replications).

Treatment					Foliar Concentration[1]					
No.	Simazine	Atrazine	NH_4NO_3	Mulch	N	N('68)	K	P	Ca	Mg
	-------kg/ha-------		kgN/ha		--------------------%--------------------					
1	--	--	--	-	1.66	2.01	0.30	0.17	0.36	0.12
2	--	--	--	+	1.83	1.91	0.40	0.18	0.36	0.11
3	--	--	112	-	1.95	1.80	0.42	0.13	0.48	0.11
4	--	--	112	+	1.89	2.06	0.41	0.14	0.32	0.10
5	--	--	336	-	2.05	2.66	0.55	0.12	0.58	0.12
6	--	--	336	+	2.23	1.90	0.56	0.11	0.39	0.09
7	4.50	--	--	-	1.97	1.91	0.48	0.16	0.54	0.11
8	4.50	--	112	-	1.99	1.97	0.38	0.16	0.58	0.14
9	4.50	--	336	-	1.82	2.35	0.65	0.12	0.38	0.09
10	9.00	--	--	-	2.02	1.78	0.50	0.15	0.52	0.14
11	9.00	--	112	-	1.75	2.03	0.36	0.12	0.58	0.13
12	9.00	--	336	-	1.97	2.27	0.44	0.09	0.53	0.13
13	--	2.25	--	-	1.85	1.92	0.35	0.15	0.53	0.12
14	--	2.25	112	-	1.70	1.80	0.49	0.13	0.40	0.11
15	--	2.25	336	-	1.88	2.41	0.70	0.11	0.41	0.09
16	--	4.50	--	-	1.79	1.76	0.40	0.16	0.46	0.08
17	--	4.50	112	-	1.85	1.87	0.20	0.17	0.56	0.12
18	--	4.50	336	-	1.87	2.15	0.40	0.14	0.42	0.10

[1] 1967 growing season foliage, except second N concentration value. See Appendix Table XX for statistical significance.

APPENDIX E

Appendix Table XV.--Changes in the foliar concentrations of Na, Mn, Fe, Cu, B, Zn, and Al in field planted SCOTCH PINE from ammonium nitrate and weed control treatments (means of 5 replications).

Treatment					Foliar Concentration[1]						
No.	Simazine	Atrazine	NH_4NO_3	Mulch	Na	Mn	Fe	Cu	B	Zn	Al
	-------kg/ha-------		kgN/ha		---------------------ppm-------------------						
1	--	--	--	-	111	198	190	3.2	32.8	10.4	296
2	--	--	--	+	222	239	157	5.0	28.7	15.8	351
3	--	--	112	-	133	216	184	4.4	25.7	15.2	242
4	--	--	112	+	233	180	121	5.5	14.2	10.2	290
5	--	--	336	-	134	255	230	2.6	18.9	13.6	294
6	--	--	336	+	339	232	185	1.7	19.2	8.8	238
7	4.50	--	--	-	244	236	265	3.8	26.9	17.8	314
8	4.50	--	112	-	200	232	273	5.3	29.4	18.8	366
9	4.50	--	336	-	198	184	249	1.9	19.4	8.6	303
10	9.00	--	--	-	207	220	294	3.5	28.2	14.6	339
11	9.00	--	112	-	357	291	268	3.9	22.0	16.2	447
12	9.00	--	336	-	295	200	274	2.2	16.8	10.0	380
13	--	2.25	--	-	228	178	274	5.3	23.1	11.8	300
14	--	2.25	112	-	446	153	291	5.7	22.6	10.0	440
15	--	2.25	336	-	444	179	287	5.8	17.0	10.2	312
16	--	4.50	--	-	289	198	265	3.7	28.3	13.2	352
17	--	4.50	112	-	372	280	373	11.3	28.3	17.0	382
18	--	4.50	336	-	411	177	275	4.6	21.7	8.2	337

[1]See Appendix Table XX for statistical significance.

Appendix Table XVI.--Changes in the foliar concentrations of N, K, P, Ca, and Mg in field planted WHITE SPRUCE from ammonium nitrate and weed control treatments (means of 5 replications).

	Treatment				Foliar Concentration[1]					
No.	Simazine	Atrazine	NH_4NO_3	Mulch	N	N('68)	K	P	Ca	Mg
	------kg/ha--------		kgN/ha		--------------------%--------------------					
1	--	--	--	-	2.19	2.02	0.40	0.25	1.11	0.18
2	--	--	--	+	2.23	2.21	0.39	0.30	1.05	0.15
3	--	--	112	-	2.15	2.13	0.31	0.17	1.38	0.24
4	--	--	112	+	2.16	2.20	0.37	0.20	1.23	0.18
5	--	--	336	-	2.61	2.51	0.32	0.15	1.13	0.17
6	--	--	336	+	2.80	2.35	0.36	0.19	1.04	0.14
7	4.50	--	--	-	2.06	2.19	0.41	0.19	1.19	0.19
8	4.50	--	112	-	2.22	2.29	0.38	0.17	2.68	0.17
9	4.50	--	336	-	2.20	2.61	0.41	0.15	1.27	0.20
10	9.00	--	--	-	1.97	2.19	0.46	0.20	1.06	0.14
11	9.00	--	112	-	2.41	2.43	0.39	0.18	1.21	0.22
12	9.00	--	336	-	2.36	2.62	0.33	0.14	1.11	0.18
13	--	2.25	--	-	2.41	2.37	0.37	0.21	1.32	0.22
14	--	2.25	112	-	2.51	2.40	0.31	0.18	1.16	0.22
15	--	2.25	336	-	2.66	2.74	0.32	0.17	1.33	0.20
16	--	4.50	--	-	2.31	2.25	0.38	0.22	1.13	0.18
17	--	4.50	112	-	2.12	2.19	0.34	0.19	1.31	0.22
18	--	4.50	336	-	2.41	2.51	0.28	0.16	1.17	0.17

[1]1967 growing season foliage, except second N concentration value. See Appendix Table XX for statistical significance.

Appendix Table XVII.--Changes in the foliar concentrations of Na, Mn, Fe, Cu, B, Zn, and Al in field planted WHITE SPRUCE from ammonium nitrate and weed control treatments (means of 5 replications).

Treatment					Foliar Concentration[1]						
No.	Simazine	Atrazine	NH_4NO_3	Mulch	Na	Mn	Fe	Cu	B	Zn	Al
	------kg/ha--------		kgN/ha		----------ppm----------						
1	--	--	--	-	193	412	288	6.6	21.7	30.8	331
2	--	--	--	+	194	507	229	5.6	11.4	36.6	263
3	--	--	112	-	50	365	304	3.0	12.5	26.2	283
4	--	--	112	+	84	324	285	4.2	9.5	20.8	210
5	--	--	336	-	145	470	326	2.6	10.9	20.8	327
6	--	--	336	+	162	597	283	2.7	27.8	21.2	306
7	4.50	--	--	-	170	375	359	8.5	14.8	29.0	386
8	4.50	--	112	-	158	436	364	3.8	12.7	23.6	362
9	4.50	--	336	-	120	440	375	2.2	11.1	20.6	387
10	9.00	--	--	-	198	429	300	6.9	15.4	26.8	606
11	9.00	--	112	-	202	407	355	5.2	11.8	23.6	383
12	9.00	--	336	-	120	434	301	3.5	7.6	19.4	314
13	--	2.25	--	-	239	427	391	5.3	15.8	24.6	304
14	--	2.25	112	-	171	394	483	5.3	11.2	21.8	410
15	--	2.25	336	-	225	509	373	6.2	11.8	22.0	350
16	--	4.50	--	-	206	338	414	5.2	12.7	21.0	388
17	--	4.50	112	-	253	439	416	5.5	11.2	22.8	453
18	--	4.50	336	-	232	545	356	5.2	9.9	19.4	362

[1]See Appendix Table XX for statistical significance.

Appendix Table XVIII.--Changes in the foliar concentrations of N, K, P, Ca, and Mg in field planted BALSAM FIR from ammonium nitrate and weed control treatments (means of 5 replications).

Treatment					Foliar Concentration[1]					
No.	Simazine	Atrazine	NH_4NO_3	Mulch	N	N('68)	K	P	Ca	Mg
	------kg/ha--------		kgN/ha		------------------%------------------					
1	--	--	--	-	2.51	2.36	0.44	0.30	0.95	0.16
2	--	--	--	+	2.64	2.47	0.44	0.40	0.84	0.13
3	--	--	112	-	2.70	2.46	0.48	0.22	1.30	0.18
4	--	--	112	+	2.83	2.49	0.58	0.23	0.85	0.11
5	--	--	336	-	2.81	2.43	0.45	0.18	1.36	0.19
6	--	--	336	+	3.25	2.33	0.51	0.21	1.18	0.17
7	4.50	--	--	-	2.67	2.53	0.42	0.24	1.13	0.21
8	4.50	--	112	-	2.56	2.48	0.50	0.22	1.21	0.18
9	4.50	--	336	-	2.90	2.49	0.36	0.22	1.29	0.18
10	9.00	--	--	-	2.60	2.35	0.56	0.23	1.02	0.17
11	9.00	--	112	-	2.57	2.55	0.44	0.22	1.37	0.21
12	9.00	--	336	-	2.65	2.50	0.41	0.23	1.15	0.17
13	--	2.25	--	-	2.65	2.52	0.46	0.26	1.08	0.16
14	--	2.25	112	-	2.51	2.46	0.44	0.21	1.29	0.24
15	--	2.25	336	-	2.62	2.49	0.49	0.18	1.10	0.18
16	--	4.50	--	-	2.50	2.45	0.57	0.23	0.99	0.18
17	--	4.50	112	-	2.59	2.53	0.49	0.22	1.22	0.18
18	--	4.50	336	-	2.77	2.49	0.48	0.23	1.16	0.17

[1] 1967 growing season foliage, except second N concentration value. See Appendix Table XX for statistical significance.

Appendix Table XIX.--Changes in the foliar concentrations of Na, Mn, Fe, Cu, B, Zn, and Al in field planted BALSAM FIR from ammonium nitrate and weed control treatments (means of 5 replications).

Treatment					Foliar Concentration[1]						
No.	Simazine	Atrazine	NH_4NO_3	Mulch	Na	Mn	Fe	Cu	B	Zn	Al
	-------kg/ha-------		kgN/ha		------------------ppm------------------						
1	--	--	--	-	233	355	285	6.3	31.6	34.6	417
2	--	--	--	+	98	320	196	6.0	31.7	34.2	439
3	--	--	112	-	64	360	305	5.9	27.1	27.6	317
4	--	--	112	+	145	261	198	5.5	18.8	22.2	249
5	--	--	336	-	58	682	332	3.2	18.8	24.4	393
6	--	--	336	+	126	677	228	3.3	15.1	21.2	278
7	4.50	--	--	-	121	256	348	5.5	31.7	23.8	406
8	4.50	--	112	-	196	318	330	7.7	22.8	28.0	404
9	4.50	--	336	-	162	408	405	4.6	25.0	26.6	476
10	9.00	--	--	-	74	253	297	5.5	29.8	31.8	337
11	9.00	--	112	-	172	433	327	8.4	24.0	32.2	394
12	9.00	--	336	-	233	454	381	7.1	22.7	24.2	473
13	--	2.25	--	-	357	318	318	7.7	32.7	25.8	370
14	--	2.25	112	-	283	278	341	6.7	22.9	22.0	408
15	--	2.25	336	-	256	548	372	4.9	17.3	19.2	460
16	--	4.50	--	-	306	265	352	7.2	29.7	23.2	381
17	--	4.50	112	-	241	299	332	6.0	23.9	23.0	393
18	--	4.50	336	-	308	511	446	6.7	24.0	23.0	486

[1]See Appendix Table XX for statistical significance.

Appendix Table XX.--Significance of experimental factors on the foliar mineral nutrition of field planted Scotch pine, white spruce, and balsam fir.[1]

Source	df	Foliar Concentration[2]												
		N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
Rep	4													
Treatment	17	**	**	NS	**	NS	*	**	**	**	*	**	**	**
Nitrogen (N)	2	**	**	NS	**	NS	NS	NS	**	NS	*	**	**	*
Scotch Pine														
Control vs N	1	**	NS		**				NS		NS	**	NS	NS
112 vs 336 kgN/ha	1	NS	**		NS				NS		*	NS	NS	NS
White Spruce														
Control vs N	1	*	*		*				NS		**	NS	**	NS
112 vs 336 kgN/ha	1	**	**		NS				**		NS	*	NS	NS
Balsam Fir														
Control vs N	1	**	NS		**				**		NS	**	**	**
112 vs 336 kgN/ha	1	NS	NS		*				**		NS	NS	NS	NS
Mulch	1	*	NS	NS	**	NS	*	**	NS	**	NS	NS	NS	NS
N x Mulch	2	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS
Nitrogen (N)	2	NS	**	NS	**	NS	*	NS	NS	NS	*	**	**	NS
Scotch Pine														
Control vs N	1		**		**		NS				NS	*	NS	
112 vs 336 kgN/ha	1		**		**		NS				*	**	*	
White Spruce														
Control vs N	1		**		*		NS				**	NS	*	
112 vs 336 kgN/ha	1		*		*		*				NS	NS	NS	
Balsam Fir														
Control vs N	1		NS		NS		NS				NS	*	NS	
112 vs 336 kgN/ha	1		NS		NS		NS				NS	NS	NS	

Appendix Table XX (Continued)

Source	df	N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
		Foliar Concentration[2]												
Simazine	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Simazine	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nitrogen (N)	2	NS	**	NS	**	NS	NS	**	**	NS	NS	**	NS	NS
Scotch Pine														
Control vs N	1		*		NS			NS	NS			NS		
112 vs 336 kgN/ha	1		**		NS			NS	NS			NS		
White Spruce														
Control vs N	1		NS		**			NS	NS			NS		
112 vs 336 kgN/ha	1		**		NS			*	*			NS		
Balsam Fir														
Control vs N	1		NS		*			NS	*			NS		
112 vs 336 kgN/ha	1		NS		NS			**	**			NS		
Atrazine	1	NS	**	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
N x Atrazine	2	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (a)	68													
Species	2	**	**	**	**	**	**	**	**	**	**	**	**	**
SP vs WS & BF	1	**	**	NS	**	**	**	**	**	**	**	**	**	**
WS vs BF	1	**	NS	**	**	NS	NS	NS	**	*	**	**	NS	**
Treat x Species	34	*	**	**	**	NS	NS	**	**	**	**	*	NS	**
N x Species	4	NS	**	NS	*	NS	NS	**	**	NS	NS	**	NS	NS
Mulch x Species	2	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Mulch x Species	4	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

Appendix Table XX (Continued)

Source	df	N	N('68)	K	P	Na	Ca	Mg	Mn	Fe	Cu	B	Zn	Al
		Foliar Concentration[2]												
N x Species	4	*	NS	*	NS	NS	NS	NS	*	NS	**	NS	NS	**
Simazine x Species	2	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Simazine x Species	4	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	**
N x Species	4	NS	**	NS	NS	*	NS	NS	**	**	**	NS	NS	*
Atrazine x Species	2	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Atrazine x Species	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
Error (b)	144													
CV (%)														
Error (a)		5.9	5.1	24.0	9.0	106.5	17.3	11.6	42.1	21.8	71.2	35.4	34.2	32.8
Error (b)		5.7	4.5	21.6	8.6	63.8	18.0	11.4	31.6	20.2	46.5	35.0	33.0	22.3

[1]Error term for testing orthogonal contrasts was derived by: $S_p^2 = (s-1)E(b) + E(a)/s$. The approximate F value for determining significance was derived by the following weighted average: $F = (s-1)E(b)F(b) + E(a)F(a)/(s-1)E(b) + E(a)$; where, s = No. of species, E(a) and E(b) = Error (a) and Error (b) MS, respectively, and F(a) and F(b) = Tabular F at 68 and 144 df, respectively.

[2]1967 growing season foliage, except second N concentration value. Significance for N, K, P, Ca, and Mg was determined from transformed data (arcsin $\sqrt{\%}$).