NITROGEN FERTILIZATION OF *Pinus sylvestris* SEEDLINGS

by

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INTRODUCTION

Christmas tree production is a largely unrecognized but important sector of agriculture. Nationally, 30 to 40 million natural Christmas trees were sold in 1982 (Gwinner, 1983). Production increased 350% between 1972 and 1982. In addition, the planting to harvest ratios (number of trees planted to number of trees harvested in the same year) have increased from 2.1:1 in 1972 to 3.6:1 in 1982.

Much of the increased production has occurred in the Southern states, California, and New York (National Christmas Tree Association, 1982). The resultant reduction in southern markets for northern grown trees has prompted greater efforts to market more northern grown trees in the Midwest. This will undoubtedly create greater economic pressure on Midwest growers (Gwinner, 1983).

Kansas is a net importer of Christmas trees. In 1982, Kansas Christmas tree growers harvested only 25,000 trees while 320,000 trees were sold. Production estimates indicate that Kansas will produce about 156,000 trees, while consuming 336,000 trees in 1991 (Loucks, 1983).

In order to compete with imported trees, Kansas growers must improve transplant survival, and increase tree growth and quality (Turner, 1979; Noecker, 1984; Gwinner, 1984). These areas of improvement are affected by genetic potential, environment, and management practices (Noecker, 1984).

The grower can implement improvements by selecting genetically superior trees that were grown under favorable environmental conditions, manage the trees to minimize stress, shear to encourage bud formation, and provide an adequate supply of available nutrients (Richards and Leaf, 1971; Noecker, 1984). The nutritional requirements are probably the most over looked area of management in the production of Christmas tree.

CHAPTER I

LITERATURE REVIEW

Nitrogen Recommendations

Wilde (1938) and Stoeckeler and Arneman (1960) recommended that soils contain from 22.4 to 50.4 kg available N ha^{-1} for satisfactory growth of Pinus sp. and Picea sp. Powers (1980) refined these recommendations by observing that young Pinus ponderosa Dougl, (ponderosa pine), Pinus jeffreyi Grev. & Balf. (Jeffrey pine), Abies concolor (Gord.) Lindl. (white fir) and Abies procera Rehd. (noble fir) trees grown in soils containing less than 20 ppm of available nitrogen responded significantly to nitrogen fertilization.

Over half of the soil samples analyzed by the Soil Analysis Laboratory, Kansas State University during 1979-1980, contained less than 15 ppm available nitrogen (Whitney, 1981). These samples were primarily from soils in agronomic production. Christmas tree production has been recommended for nonfertile soils (Gallaher, 1971). It is reasonable to assume that soil nitrogen reserves will be deficient in most sites where Christmas trees are produced. Currently, there are no nitrogen fertilizer recommendations for Christmas trees in Kansas (Loucks, 1985), Missouri (Solomon, 1985) or Oklahoma (Craighead, 1985). Nitrogen fertilization, therefore, appears to be a prime area for study.

Nitrogen Fertilization

Nitrogen fertilization of soils deficient in available nitrogen affects many biological processes within the tree. Supplemental nitrogen increased net photosynthetic rate of _Pinus sylvestris_ L. (Scotch pines) and other conifers (Brix and Ebell, 1969; Kellomaki, et al., 1982) and auxin concentrations in new _P. sylvestris_ needles (Michniewicz and Stopinska, 1980). Needles formed after nitrogen fertilization, were more succulent, longer, and had a greater volume than controls (Helms, 1964; Brix and Ebell, 1969; Michniewicz and Stopinska, 1980). In addition, the number of needles per shoot and the number of lateral buds and branches formed increased after nitrogen fertilization (Timmer, Stone, and Embree, 1977; Michniewicz and Stopinska, 1980).

Stem diameter growth of _P. sylvestris_ increased during the year of fertilization and the six following years. Maximum increase occurred during the first or second year after fertilization, depending upon vegetative competition (Fagerstrom and Lohm, 1977; Haapanen, Hari, and Kellomaki, 1979). The apical shoot growth of _P. sylvestris_ seedlings did not increase during the season of fertilization, but increased during the first three years after application (Rutter, 1955; Rutter, 1957; Paavilainen, 1972; Timmer, Stone, and Embree, 1977; Kellomaki, Putttonen, Tamminen, and Westman, 1982).

Nitrogen Sources

Plant available nitrogen comes from various sources, both abiotic and biotic. Biotic processes which make nitrogen available include mineralization and nitrogen fixation. Mineralization consists of the conversion of organic nitrogen to an inorganic form (ammonia and nitrate) via ammonification and nitrification by microbial enzymes (Sauchelli, 1964). Mineralization was the major source of available nitrogen found in unfertilized forests and was able to supply sufficient nutrition for tree survival (Van Praag and Weissenn, 1973; Wollum and Davey, 1975).

Nitrogen fixation by free-living microorganisms produces an average of 1 to 5 kg N ha^{-1} yr^{-1} (Hardy, Burns, and Holstein, 1973). Bormann, Likens, and Melillo (1977) measured 0.27 kg N ha^{-1} yr^{-1} fixed in young _P. sylvestris_ forests in central Sweden. The quantity of nitrogen fixed was dependent upon the thickness of the surface organic layer, the soil nutrient status, and environmental conditions (Granball and Lindberg, 1980).

Major abiotic nitrogen sources include precipitation

(4 to 10 kg N ha^{-1} yr^{-1}) (Stewart, 1968) and inorganic fertilizer (Wollum and Daves, 1973). Atmospheric nitrogen may also be oxidized by lightning and precipitated with moisture (Bormann, Likens, and Melillo, 1977), weathering of inorganic minerals (Adams and Stevenson, 1964), and chemical fixation of atmospheric nitrogen (Dalton and Mortenson, 1972).

Nitrogen Supplementation

Nitrogen fertilization may be achieved with fast or slow release nitrogenous compounds. Rapid nitrogen release is accomplished with water soluble materials, such as NH_4NO_3, $(NH_4)_2SO_4$, KNO_3, and urea. Slow release is accomplished with slightly water soluble compounds (urea formaldehyde and isobutyl diurea) or by coating soluble nitrogenous material to reduce solubility or diffusion (sulfur coated urea and Osmocote).

Water soluble fertilizers hydrolyze readily to form ammonium and/or nitrate in the soil solution. The ammonium may be adsorbed onto clay particles or other exchange sites, volatilized, oxidized to nitrite and nitrate, or absorbed and utilized by microorganisms, competing vegetation, or the crop. Nitrate ions may be lost through leaching, demineralized to nitrogen oxide gases, reduced to ammonia, adsorbed onto anionic exchange particles, such as organic matter, or adsorbed by microorganisms, competing vegetation, or the crop (Bolin and Arrhenius, 1977).

High concentrations of soluble fertilizer salts will restrict growth and even kill pine seedlings. The height, stem diameter, shoot and root weights of Pinus elliottii Engelm. (slash pine) seedlings were retarded by 200 ppm nitrogen as NH_4NO_3 applied at transplanting; while 400 ppm killed them. Corresponding levels of urea formaldehyde had no detrimental effects and produced growth comparable to 100 ppm of ammonium nitrate (Smith, Underwood, and Hays, 1971).

Slow release nitrogen fertilizer is not readily soluble in the soil solution. The availability of urea formaledhyde nitrogen is limited by its solubility (Yee and Love, 1947; Hays and Haden, 1966), which controls the rate of chemical and microbial mineralization (Nommik, 1967). The nitrogen fraction of commercial urea formaldehyde (Nitroform, Nor-Am Chemical Company, Wilmington, Delaware) ground to pass through a 35 mesh screen contained 38.7% total nitrogen. The ureaform contained 25.8% water insoluble nitrogen and 12.9% water soluble nitrogen, including 8.6% urea nitrogen (Hays and Haden, 1966).

Affect of Nitrogen Fertilization on Plant Growth

Fertilizer Placement

Fertilizer placement affects nitrogen availability to plants. Water soluble nitrogen may be incorporated or surface applied and will dissolve and leach through the root zone (van der Driessche, 1984). Slow-release nitrogen fertilizers, however, should be incorporated since their availability is dependent upon soil moisture and microbial activity (Yee and Love, 1946; Nommik, 1967).

Time of Application

Late summer or early fall fertilization of _P. sylvestris_, _Pinus resinosa_ Ait. (red pine), _Picea mariana_ Mill. (black spruce), and _Picea glauca_ Moench. Voss (white spruce) produced less dry weight and the shoot:root ratio was reduced when compared to late spring and early summer treatment. These differences were apparent in both the year of application and following season. Foliar nitrogen concentration of October sampled needles was greatest in fall fertilized trees (Armson, Reese, and Carman, 1963; Puro, 1982).

McKee and Sommers (1971) found dormant early spring and late fall applications of water soluble fertilizer produced comparable growth in seedling _P. elliottii_. Late spring or early summer applications of water soluble nitrogen to *P. sylvestris*, *P. resinosa*, *P. mariana*, and *P. glauca*, resulted in more growth than late summer or early fall treatments (Armson, 1963; Armson, Reese, and Carman, 1963).

P. elliottii absorbed more nitrogen from ammonium nitrate than from the urea formaldehyde over a fifteen week study in a fine sandy soil (Bengtson and Voigt, 1962). This was due to the relatively slow dissolution rate of ammonium nitrate when leached with 5.1 cm or less water per week. However, if the soil was leached with 10.2 cm water per week, more nitrogen was absorbed from urea formaldehyde. Similar results were obtained by Hagin and Cohen (1976), using silty clay, sandy loam, and sandy soils. There were no significant height differences during a six year period between *P. elliottii* fertilized with comparable levels of water insoluble and water soluble fertilizers (Fisher and Pritchett, 1982).

Nitrogen Uptake and Utilization

Pinus sylvestris absorbed between 12 and 28 per cent of the applied ammonium nitrate nitrogen within a year of application (Nommik and Moller, 1981; Melin, et al., 1983). Nitrogen from both ammonium and nitrate was absorbed at about equal rates by *P. sylvestris* in acidic soils (Nommik, 1966; Bjorkman, Lundberg, and Nommik, 1967). The rate of nitrate uptake, however, was greater than ammonium uptake in similar studies conducted by Jensen and Petersson (1980); Melin, Nommik, Lohm, and Flower-Ellis (1983).

It is apparent that nitrogen fertilization can have a significant influence on the growth of conifers. It was the purpose of this study to determine if application of nitrogen through various sources at or after planting could influence the quality and growth of P. sylvestris in Kansas.

CHAPTER II

PREPLANT INCORPORATION OF NITROGEN FERTILIZER TO SPRING AND FALL PLANTED BAREROOT AND CONTAINERIZED *Pinus sylvestris* SEEDLINGS

INTRODUCTION

Establishment and initial growth of *Pinus sylvestris* seedlings is critical to their survival and long-term growth. The forestry and Christmas tree industries traditionally plant during the spring, however, increasing numbers of plantings are being made in the fall.

Christmas tree production in Kansas is generally a side line, thus other crops are given preference for labor and equipment usage. Since spring in Kansas is frequently wet, planting is often delayed. Late spring planting often results in insufficient root development before summer heat and drought stress (Ryker, 1976). A viable alternative to spring planting is fall planting. Satisfactory survival and growth rates for fall planted conifers have been reported. The seedlings, however, must be physiologically dormant at planting and remain so until spring to achieve success (Boyd, 1976; Ryker, 1976; Jenkinson, 1980).

Nitrogen deficiency is a common phenomenon in Kansas soils (Whitney, 1981). Application of nitrogen fertilizer at planting is a logical management practice because of reduced labor and equipment expenses. The nitrogen source may be readily (water soluble) or slowly available. Use of water soluble fertilizer may result in much of the nitrogen being lost due to surface run off or leaching. Surface application of ^{15}N labeled urea to young Pseudotsuga menziesii (Mirb.) Franco (Douglas Fir) resulted in major loss due to precipitation (Heilman, et al. 1982a&b). Preplant fertilizer incorporation can reduce surface run-off and volatilization. Incorporation of slowly soluble fertilizer is important since its availability is dependent upon soil water and microorganisms (Fuller and Clark 1947).

Nitrogen fertilizer utilization by plants is related to solubility and quantity. Water soluble nitrogen is generally more available to Pinus sp. However, nitrogen salts from an insoluble fertilizer were more utilizable than from soluble sources after heavy precipitation (Bengtson and Voigt, 1962; Fisher and Pritchett, 1982). Too little available nitrogen failed to stimulate Pinus sp. growth, while too much retarded growth (Ingestad, 1960&1979; Smith, Underwood, and Hays, 1971).

Containerized conifer seedlings are becoming more popular in the tree industry because the plants survive and grow better than bareroot seedlings. The root system of containerized seedlings is subjected to less stress and the planting season may be extended. Increased survival and growth were observed with containerized transplants of *Abies procera* Rehd. (Noble fir) and *Pseudotsuga menziesii* (Owston and Stein, 1972) and *Pinus sylvestris* (Henderson and Hensley, 1983, Kansas State University, unpublished data).

The purpose of this study was to evaluate the effect of nitrogen fertilization on spring and fall planted *Pinus sylvestris* seedlings.

MATERIALS AND METHODS

The research site was a nearly level field of Eudora silt loam, located in the Blue River Valley of Riley County, Kansas. The area was sampled in March 1984, and soil analysis performed by the Soil Analysis Laboratory, Kansas State University. Results are shown in Table II-1.

The field was twice tilled before application of fertilizer treatments on 23 April 1984. Treatments consisted of 0, 56, 112, or 224 kg N ha^{-1} as either ammonium nitrate (34-0-0) or urea formaldehyde (38-0-0, Blue Chip Ureaform) nitrogen. Treatments were applied in 53 cm wide by 11 m long bands and twice tilled. Treatments were arranged in a completely randomized design and replicated three times. Each experimental unit contained

Table II-1. Soil analysis of study site.

ELEMENT OR COMPONENT	MEAN	STANDARD DEVIATION
N (ppm)		
total available	32.80[Z]	3.52
NH_4^+	24.53	2.00
NO_3^-	8.27	2.33
pH	7.65	0.07
Organic Matter (%)	2.17	0.29
P (kg ha^{-1})	14.41	1.41
K (kg ha^{-1})	806.40	19.40

[Z] Mean of three separate samples

six trees. Both bareroot seedlings and containerized transplants were hand planted 1.8 m apart within rows 3.0 m apart within seven days after fertilizer application.

The bareroot seedlings, 2:0 Pinus sylvestris aquitana (French Blue), were grown by the Missouri Conservation Commission and containerized 1:1 Pinus sylvestris haquenensis were grown by the Kansas State University Forestry Extension Service. Both were purchased from the Kansas State University Forestry Extension Service.

Stem diameter, apical internode length, and the number of lateral buds at the terminal bud were recorded before planting. Stem diameter values represented an average of two measurements made one centimeter below the cotyledon. Trees selected for the study had a stem diameter between 3 and 5 cm. These same parameters were measured in November 1984, and except for stem diameter, again in July 1985.

The fall planting treatments were adjacent to the spring planting. The rows were laid out, fertilizer treatments applied, and trees planted as described for the spring planting. Fertilizer treatments were applied on 3 and 4 November 1984. Containerized transplants, 1:1 P. sylvestris haquenensis, were purchased from the same source as in spring, and were planted between 11 and 20 November 1984. Bareroot seedlings were 2:1 P. sylvestris auvarque, grown by Vans Pines Incorporated (West Olive, Michigan) for two growing seasons and one growing season at the Delp's Christmas Tree Farm and Nursery Company (St. John, Kansas). They were planted 26 to 28 November 1984. Initial height, number of lateral buds, and stem diameter were recorded within two weeks of planting. Stem diameter measurements were made 5 to 6 cm below the first node. Growth parameters were again measured in July 1985.

Survival of spring planted trees was determined in late June and November 1984, and July 1985 and the fall 1984 planting in July 1985. An arcsine transformation was performed on percent survival data before statistical analysis (Little, 1985).

Weeds within rows were controlled during 1984 with oxyfluorfen (Goal) at 1.12 kg ai ha^{-1} and EPTC (Eptam) at 1.12 kg ai ha^{-1} applied during mid-June 1984. Glyphosate (Round-up) (19.53 ml l^{-1}) was applied as a directed spray. Tree rows were also hand weeded periodically and vegetation between rows controlled by monthly tillage.

During 1985, existing weeds were again controlled with directed sprays of glyphosate in late April and mid-June and a mid-July directed spray of sethoxydim (Poast) at 24 ml l^{-1}. Simazine (Princep) at 2.24 kg ai ha^{-1} and oryzlin (Surflan) at 0.75 kg ai ha^{-1} were applied over the rows in mid-June. Rows were hand weeded periodically and between row areas tilled monthly.

Statistical analysis was performed on the average percent changes from initial measurements by experimental units (Smith, Underwood, and Hays, 1971). The significance of independent variable effects (nitrogen source, nitrogen quantity, nursery management system confounded with seed source, and planting date) on the dependent variables (survival, stem elongation and diameter, and number of lateral buds around the apical bud) were determined as a series of one way general linear model analysis and contrast statements for the 1984 growing season's data. Significant differences between treatment means were determined by Tukey's studentized range (HSD) test. Analyses were performed using the Statistical Analysis System programs with computers in the Kansas State University Department of Statistics and Computing Center.

RESULTS AND DISCUSSION

SURVIVAL

Spring Planted, Bareroot

Pinus sylvestris aquitana

Survival of spring planted, bareroot *P. sylvestris aquitana* was not affected by fertilization treatments (PR>F=0.50), nitrogen source (PR>F=0.75), or nitrogen quantity (PR>F=0.57) by the June evaluation (Table II-2). However, in November, significant survival differences were observed among the treatments (PR>F=0.01). Survival by trees that received 224 kg of nitrogen from urea formaldehyde was significantly greater than trees that received the same amount of nitrogen from ammonium nitrate or 112 kg of urea formaldehyde nitrogen. All other treatments were statistically similar. The trend continued through the second growing season (PR>F=0.02).

Survival of trees fertilized with ammonium nitrate was less than those treated with urea formaldehyde or controls but the differences were not significant during both evaluations (PR>F=0.06 and 0.06). Nitrogen quantity was not a major factor during either season (PR>F=0.68 and 0.55).

Table II-2. Percent survival based on arcsine transformation of data during 1984 and 1985 by spring 1984 planted bareroot P. sylvestris aquitana seedlings.

EFFECTS	SURVIVAL (%)		
	JUNE 1984	NOVEMBER 1984	JULY 1985
TREATMENT MEANS			
CONTROL	83.33	83.33ab[Z]	83.33ab
AMMONIUM NITRATE			
56 kg N ha^{-1}	77.78	72.22ab	50.00ab
112 kg N ha^{-1}	88.83	83.33ab	77.78ab
224 kg N ha^{-1}	83.33	44.44b	27.78b
UREA FORMALDEHYDE			
56 kg N ha^{-1}	77.78	77.78ab	77.78ab
112 kg N ha^{-1}	77.78	55.56b	50.00ab
224 kg N ha^{-1}	100.00	100.00a	88.89a
NITROGEN SOURCE			
CONTROL	83.33	83.33	83.33
AMMONIUM NITRATE	83.33	66.67	51.85
UREA FORMALDEHYDE	85.19	77.78	72.22
NITROGEN QUANTITY			
0 kg N ha^{-1}	83.33	83.33	83.33
56 kg N ha^{-1}	77.78	75.00	63.89
112 kg N ha^{-1}	83.33	69.44	63.89
224 kg N ha^{-1}	91.67	72.22	58.33

[Z] Mean separation within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by letters were not significantly different (F-test, PR>F=0.05).

Spring Planted, Containerized
Pinus sylvestris haquenensis

June 1984 survival of spring planted, containerized plants was not significantly influenced by preplant fertilization (PR>F=0.20) (Table II-3). No response patterns were apparent as controls survived less than all other treatments. Nitrogen sources and quantities were not significantly different (PR>F=0.22) and (PR>F=0.22) respectively.

Survival by the end of one growing season was not significantly affected by fertilization (PR>F=o.25), nitrogen source (PR>F=0.22), or quantity (PR>F=0.22), however the experimental error was large. The same survival trends continued through July 1985. Fertilizer treatment (PR>F=0.26), nitrogen source (PR>F=0.19) and quantity (PR>F=0.22) were not major factors.

Fall Planted, Bareroot
Pinus sylvestris auvarque

Survival, after one growing season, of fall planted, bareroot pines was not significantly influenced by fertilizer treatments (PR>F=0.12) or nitrogen source (PR>F=0.24) (Table II-4). Nitrogen quantity appeared to influence survival (PR>F=0.07), as trees treated with 224 kg of nitrogen survived less frequently than controls or trees treated with 56 kg of nitrogen.

Table II-3. Percent survival based on arcsine transformation of data during 1984 and 1985 by spring 1984 planted containerized P. sylvestris hagunensis seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for any growing period.

EFFECTS	SURVIVAL (%)		
	JUNE 1984	NOVEMBER 1984	JULY 1985
TREATMENT MEANS			
CONTROL	44.45	38.89	33.33
AMMONIUM NITRATE			
56 kg N ha^{-1}	83.33	83.33	77.78
112 kg N ha^{-1}	55.56	44.45	44.45
224 kg N ha^{-1}	83.33	72.22	72.22
UREA FORMALDEHYDE			
56 kg N ha^{-1}	50.60	44.44	38.89
112 kg N ha^{-1}	55.55	50.00	50.00
224 kg N ha^{-1}	66.67	66.67	66.67
NITROGEN SOURCE			
CONTROL	44.45	38.89	33.33
AMMONIUM NITRATE	74.07	66.67	64.82
UREA FORMALDEHYDE	57.61	53.70	51.85
NITROGEN QUANTITY			
0 kg N ha^{-1}	44.45	38.89	33.33
56 kg N ha^{-1}	66.97	63.88	58.33
112 kg N ha^{-1}	55.55	47.22	47.22
224 kg N ha^{-1}	75.00	69.44	69.44

Table II-4. Percent survival based on arcsine transformation of data during 1985 by fall 1984 planted bareroot *P. sylvestris auvarque* and containerized *P. sylvestris haqunensis* seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either plant source.

EFFECTS	SURVIVAL (%)	
	Bareroot *P. sylvestris auvarque*	Containerized *P. sylvestris haquenensis*
TREATMENT MEANS		
CONTROL	66.67	66.67
AMMONIUM NITRATE		
56 kg N ha^{-1}	61.11	61.11
112 kg N ha^{-1}	33.33	50.00
224 kg N ha^{-1}	33.33	33.33
UREA FORMALDEHYDE		
56 kg N ha^{-1}	77.78	55.56
112 kg N ha^{-1}	66.67	72.22
224 kg N ha^{-1}	38.89	61.11
NITROGEN SOURCE		
CONTROL	66.67	66.67
AMMONIUM NITRATE	42.59	48.15
UREA FORMALDEHYDE	61.11	62.96
NITROGEN QUANTITY		
0 kg N ha^{-1}	66.67	66.67
56 kg N ha^{-1}	69.44	58.33
112 kg N ha^{-1}	50.00	61.11
224 kg N ha^{-1}	36.11	47.22

Fall Planted, Containerized

Pinus sylvestris haquenensis

Survival as of July 1985, of fall planted, containerized pine seedlings was not influenced by preplant nitrogen fertilization, source, or quantity (PR>F=0.25, PR>F=0.19, and 0.38) respectively (Table II-4).

DISCUSSION

Survival of spring planted, bareroot *P. sylvestris aquitana* was apparently not affected by handling or fertilization since most trees survived through the spring of planting with no statistical differences between treatments. By the end of the first growing season, however, there were significant differences among treatment means. The highest rate of ammonium nitrate appeared to induce greater seedling death, while of urea formaldehyde did not. Smith, Underwood, and Hayes (1971) and Ingestad (1979) observed reduced survival from high fertilizer concentrations in the root zone. Physiological changes within the root may have occurred as a result of high soil solution osmolarity and/or aqueous ammonia toxicity (Bennett and Adams, 1970). These conditions may have resulted in suppressed root growth (Smith, Underwood, and Hayes, 1971), fewer long, fine roots, (Persson, 1980), and fewer mycorrhizae in the root zone (Ekwebelam and Reid, 1983).

No conclusions could be drawn on the survival of spring planted containerized P. sylvestris haquenensis since containerized seedlings normally survive better than bareroot seedlings (Owston and Stein, 1972). The causes of the poor survival are not known.

Survival of fall planted bareroot and containerized plants appeared to be reduced by high rates of ammonium nitrate, but not significantly, while high rates of urea formaldehyde apparently affected only the bareroot plants.

Containerized P. sylvestris haquenensis trees appeared more tolerant of higher rates of water soluble fertilizer than bareroot P. sylvestris aquitana or auvarque trees. Those that survived the first spring generally lived through the duration of the study. The differences in fertilizer tolerance may have been genetic and/or the high cation exchange capacity (CEC) of the peat:perlite (1:1) container growing media may have reduced fertilization effects in the root zone.

GROWTH-HEIGHT

Spring Planted, Bareroot

Pinus sylvestris aquitana

Stem elongation by spring planted, bareroot P. sylvestris aquitana, expressed as percent of initial height, was not influenced by preplant fertilizer

Table II-5. Height growth, expressed as percent of initial height, during 1984 and 1985 by spring 1984 planted bareroot P. sylvestris aquitana and containerized P. sylvestris haquenensis seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either plant source during either growing season.

EFFECTS	HEIGHT (%)			
	Bareroot *P. sylvestris aquitana*		Containerized *P. sylvestris haquenensis*	
	1984	1985	1984	1985
TREATMENT MEANS				
CONTROL	30.23	22.77	49.30	62.20
AMMONIUM NITRATE				
56 kg N ha^{-1}	22.62	26.93	48.66	58.86
112 kg N ha^{-1}	20.94	23.61	50.92	60.59
224 kg N ha^{-1}	22.75	20.78	51.50	40.09
UREA FORMALDEHYDE				
56 kg N ha^{-1}	23.08	20.67	43.95	39.91
112 kg N ha^{-1}	19.42	23.11	60.55	53.61
224 kg N ha^{-1}	26.75	19.04	48.49	45.87
NITROGEN SOURCE				
CONTROL	30.23	22.77	49.30	62.20
AMMONIUM NITRATE	22.11	23.78	50.36	54.51
UREA FORMALDEHYDE	23.08	20.94	51.00	46.46
NITROGEN QUANTITY				
0 kg N ha^{-1}	30.23	22.77	49.30	62.20
56 kg N ha^{-1}	22.85	23.80	46.31	49.39
112 kg N ha^{-1}	20.18	23.36	55.74	57.10
224 kg N ha^{-1}	24.75	19.91	49.99	44.98

treatment during the first or second growing seasons (PR>F=0.36 and 0.71) (Table II-5). The source and quantity of supplemental nitrogen did not significantly influence height growth during the first (PR>F=0.14 and 0.14) or second (PR>F=0.56 and PR>F=0.67) growing seasons, respectively.

Spring Planted, Containerized

Pinus sylvestris haguenensis

Stem elongation of spring planted, containerized plants was also not statistically influenced by individual treatments during the first growing season (PR>F=0.58), source (PR>F=0.98), or quantity (PR>F=0.53) (Table II-5).

Height growth two years after treatment was not significantly affected by fertilizer treatments, nitrogen source, or quantity (PR>F=0.36, 0.23, and 0.29 respectively).

Fall Planted, Bareroot

Pinus sylvestris auvarque

Shoot elongation of fall planted, bareroot seedlings was not influenced by nitrogen fertilization, (PR>F=0.67) (Table II-6). Neither nitrogen source nor quantity seemed to influence growth (PR>F=0.40 and PR>F=0.24) respectively.

Table II-6. Height growth, expressed as percent of initial height, during 1985 by fall 1984 planted bareroot *P. sylvestris auvarque* and containerized *P. sylvestris haquenensis* seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either plant source.

EFFECTS	HEIGHT (%) Bareroot *P. sylvestris auvarque* 1985	HEIGHT (%) Containerized *P. sylvestris haquenensis* 1985
TREATMENT MEANS		
CONTROL	13.73	28.35
AMMONIUM NITRATE		
56 kg N ha^{-1}	14.04	27.82
112 kg N ha^{-1}	17.21	31.22
224 kg N ha^{-1}	13.56	30.00
UREA FORMALDEHYDE		
56 kg N ha^{-1}	18.03	32.90
112 kg N ha^{-1}	17.54	22.90
224 kg N ha^{-1}	12.34	26.76
NITROGEN SOURCE		
CONTROL	13.73	28.35
AMMONIUM NITRATE	14.93	29.68
UREA FORMALDEHYDE	15.97	27.49
NITROGEN QUANTITY		
0 kg N ha^{-1}	13.73	28.35
56 kg N ha^{-1}	16.04	30.36
112 kg N ha^{-1}	17.37	27.02
224 kg N ha^{-1}	12.95	28.38

Fall Planted, Containerized

Pinus sylvestris haquenensis

Shoot elongation of fall planted, containerized plants was not affected by fertilization treatments (PR>F=0.39), source (PR>F=0.69), or quantity (PR>F=0.76) (Table II-6).

GROWTH-STEM DIAMETER

Spring Planted, Bareroot

Pinus sylvestris aquitana

Stem diameter growth, expressed as percent increase from the initial stem diameter, of spring planted, bareroot seedlings was not significantly affected by fertilization (PR>F=0.17) (Table II-7). However, both the nitrogen source and quantity appeared to affect stem diameter growth (PR>F=0.08 and 0.08).

Spring Planted, Containerized

Pinus sylvestris haquenensis

Stem diameter growth of spring planted, containerized plants was not influenced by fertilizer treatments, (PR>F=0.60), nitrogen source (PR>F=0.83), or nitrogen quantity (PR>F=0.36) (Table II-7).

DISCUSSION

Powers (1980) reported growth response to supplemental

Table II-7. Mean stem diameter increase, expressed as percent of initial diameter, during 1984 by spring 1984 planted bareroot _P. sylvestris aquitana_ and containerized _P. sylvestris haquenensis_ seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either plant source.

EFFECTS	HEIGHT (%)	
	Bareroot _P. sylvestris aquitana_ 1984	Containerized _P. sylvestris haquenensis_ 1984
	TREATMENT MEANS	
CONTROL	60.89	68.80
AMMONIUM NITRATE		
56 kg N ha^{-1}	48.16	61.00
112 kg N ha^{-1}	48.39	74.58
224 kg N ha^{-1}	46.50	55.31
UREA FORMALDEHYDE		
56 kg N ha^{-1}	53.80	67.26
112 kg N ha^{-1}	43.49	67.20
224 kg N ha^{-1}	35.87	60.36
	NITROGEN SOURCE	
CONTROL	60.84	68.80
AMMONIUM NITRATE	47.69	63.63
UREA FORMALDEHYDE	44.39	64.94
	NITROGEN QUANTITY	
0 kg N ha^{-1}	60.84	68.80
56 kg N ha^{-1}	50.98	64.13
112 kg N ha^{-1}	45.94	70.89
224 kg N ha^{-1}	41.18	57.23

nitrogen when the soil contained less than 20 ppm of available nitrogen, while trees grown in soil with higher available nitrogen were not stimulated by supplemental nitrogen. Ingestad (1979) obtained maximum growth (dry weight) with a ratio of 100:6:45 (N:P:K). In the current study, the site contained 32.8 ppm of available N, 6.4 ppm of available P, and 360 ppm of available K, resulting in a ratio of N:P:K of 100:19.5:1097, thereby indicating that the site was not deficient in any of the macronutrients. Fertilization did not significantly influence stem elongation or stem diameter growth during this study.

DEVELOPMENT

LATERAL BUD FORMATION

Spring Planted, Bareroot
Pinus sylvestris aquitana

The number of lateral buds formed around the apical bud, by spring planted bareroot seedlings during the first growing season, was not significantly affected by preplant fertilization (PR>F=0.10) (Table II-8). Although, trees that received 112 or 224 kg of ammonium nitrate nitrogen produced fewer lateral buds than all other treatments.

Significantly fewer lateral buds were formed on trees fertilized with ammonium nitrate than urea

Table II-8. Lateral buds formed, during 1984 and 1985 by spring 1984 planted bareroot *P. sylvestris aquitana* and containerized *P. sylvestris haquenensis* seedlings.

EFFECTS	NUMBER OF LATERAL BUDS			
	Bareroot *P. sylvestris aquitana*		Containerized *P. sylvestris haquenensis*	
	1984	1985	1984	1985
TREATMENT MEANS				
CONTROL	4.28	3.82	6.22	5.00
AMMONIUM NITRATE				
56 kg N ha^{-1}	4.04	4.89	4.60	5.63
112 kg N ha^{-1}	3.11	4.22	4.81	5.11
224 kg N ha^{-1}	3.56	3.67	4.67	5.04
UREA FORMALDEHYDE				
56 kg N ha^{-1}	4.00	3.81	6.13	5.20
112 kg N ha^{-1}	4.39	4.11	5.16	5.22
224 kg N ha^{-1}	4.53	4.42	5.86	5.83
NITROGEN SOURCE				
CONTROL	4.28[z]a	3.82	6.22	5.00
AMMONIUM NITRATE	3.84b	4.26	4.69	5.26
UREA FORMALDEHYDE	4.31a	4.11	5.72	5.42
NITROGEN QUANTITY				
0 kg N ha^{-1}	4.28	3.82	6.22	5.00
56 kg N ha^{-1}	4.08	4.35	5.37	5.42
112 kg N ha^{-1}	4.15	4.17	4.98	5.17
224 kg N ha^{-1}	4.04	4.01	5.26	5.44

z Means separated within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by a letter were not significantly different (F-test, PR>F=0.05).

formaldehyde treated plants or controls (PR>F=0.05). Nitrogen quantity was not statistically important (PR>F=0.78).

Lateral bud formation two seasons after treatment was not influenced by fertilization treatments (PR>F=0.51), source (PR>F=0.70), or quantity (PR>F=0.79).

Spring Planted, Containerized

Pinus sylvestris haguenensis

Lateral bud production by spring planted, containerized pines was not influenced by fertilization during the first (PR>F=0.51) or second (PR>F=0.97) growing seasons (Table II-8). Neither nitrogen source nor quantity affected bud formation during the first (PR>F=0.14 and PR>F=0.60) or second (PR>F=0.87 and 0.94) seasons, respectively.

Fall Planted, Bareroot

Pinus sylvestris auvargue

Lateral bud formation by bareroot seedlings, during the year following fall planting, was not significantly influenced by fertilizer treatment (PR>F=0.16), nitrogen source (PR>F=0.84), or quantity (PR>F=0.80) (Table II-9).

Table II-9. Lateral buds formed, during 1985 by fall 1984 planted bareroot _P. sylvestris auvarque_ and containerized _P. sylvestris haquenensis_ seedlings.

EFFECTS	NUMBER OF LATERAL BUDS Bareroot _P. sylvestris auvarque_ 1985	Containerized _P. sylvestris haquenensis_ 1985
	TREATMENT MEANS	
CONTROL	2.86	3.42[z]b
AMMONIUM NITRATE		
56 kg N ha^{-1}	2.43	3.93ab
112 kg N ha^{-1}	3.83	3.33b
224 kg N ha^{-1}	3.08	4.50a
UREA FORMALDEHYDE		
56 kg N ha^{-1}	3.63	3.50ab
112 kg N ha^{-1}	2.67	3.28b
224 kg N ha^{-1}	2.79	4.22ab
	NITROGEN SOURCE	
CONTROL	2.86	3.42
AMMONIUM NITRATE	3.12	3.92
UREA FORMALDEHYDE	3.03	3.67
	NITROGEN QUANTITY	
0 kg N ha^{-1}	2.86	3.42b
56 kg N ha^{-1}	3.03	3.72ab
112 kg N ha^{-1}	3.25	3.31b
224 kg N ha^{-1}	2.94	4.36a

z Means separated within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by a letter were not significantly different (F-test, PR>F=0.05).

Fall Planted, Containerized
Pinus sylvestris haquenensis

Lateral bud formation during the year following fall planting was significantly affected by fertilization (PR>F=0.01) (Table II-9). The high level (224 kg of nitrogen) of ammonium nitrate produced significantly more buds than the controls or trees that received 112 kg of either nitrogen source, however, there were no differences among other treatments.

The source of nitrogen was not a major factor in bud formation (PR>F=0.15). However, the highest rate of supplemental nitrogen caused significantly more buds to be formed than the control or 112 kg treatments (PR>F=0.01).

DISCUSSION

Even though, in some instances, lateral bud formation was significantly affected by nitrogen fertilization, there were no apparent patterns. It was unlikely that the differences were real. Similar results were reported by Kellomaki (Kellomaki, *et al.*, 1982).

SUMMARY

The high rate of ammonium nitrate tended to injure and kill fall planted containerized seedlings and bareroot seedlings regardless of planting time. All other treatments were ineffective. No conclusions could be drawn about the spring planted containerized plants since their survival was low.

Height and stem diameter growth of seedlings was not significantly affected by fertilization during the course of this experiment. No clear trends in lateral bud development existed for either planting stock or fertilizer treatment.

Chapter III

POSTPLANT APPLICATION OF NITROGEN FERTILIZER TO *Pinus sylvestris* SEEDLINGS AT DIFFERENT STAGES OF ESTABLISHMENT

INTRODUCTION

Production of *Pinus sylvestris* Christmas trees is a relatively slow process. Marketable trees are routinely produced within six to seven years in Michigan (Rudolph, 1968), but rarely in Kansas. Most Kansas grown Christmas trees require eight to ten years (W. Loucks, 1984).

The ability of *P. sylvestris* seedlings to utilize surface applied nitrogen fertilizer depends upon many factors. Among these are the solubility and mineralization of the material, quantity applied, retention within the root zone, and the stage of plant development at application. The purpose of this study was to investigate these factors under field production conditions.

MATERIALS AND METHODS

The study was conducted at Delp's Christmas Tree Farm and Nursery Company, St. John, (Stafford County) Kansas. The site was nearly level Naron, fine sandy loam with a small incursion of Carwile, fine sandy loam. Treatment areas were selected to primarily utilize Naron fine sandy loam soil.

Soil samples were taken from the surface 20 cm during May 1984, and analyzed by the Soil Analysis Laboratory, Kansas State University. These results are provided in Table III-1.

Bare root 2:0 Pinus sylvestris aquitana (French Blue) were mechanically planted in April 1982, March 1983, and March 1984 by the grower 1.2 m apart in rows 2.4 m apart. Those planted in 1982 and 1984 were purchased from Vans Pines Incorporated, West Olive, Michigan; while the 1983 plants were purchased from Armintrout's West Michigan Farms, Incorporated, Allegan, Michigan.

Applications of 0, 56, 112, and 224 kg N ha^{-1} either as ammonium nitrate (34-0-0) or urea formaldehyde (38-0-0) (Blue Chip) were made in 11 m by 0.5 m bands to each year's planting. All fertilizer treatments were replicated three times in a completely randomized design and made during mid-May 1984.

Weeds were controlled in the 1983 and 1984 plantings by cultivation and herbicides in late May 1984. The 1984 planting was treated with a band application of oxyfluorfen (Goal) at 0.56 kg ai ha^{-1} and simazine (Princep) at 1.68 kg ai ha^{-1}. A directed application of glyphosate (19.53 ml l^{-1}) was made in early July. The 1982 and 1983 plantings

Table III-1. Soil analysis of study site at Delp's Christmas Tree Farm, St. John, Kansas.

ELEMENT OR COMPONENT	MEAN	STANDARD DEVIATION
N (ppm)		
total available	12.00[Z]	3.00
pH	6.33	0.37
Organic Matter (%)	0.69	0.19
P (kg ha^{-1})	21.44	3.63
K (kg ha^{-1})	243.20	58.09
Ca (ppm)	792.90	87.12
Mg (ppm)	94.29	34.09
Fe (ppm)	15.43	3.82
Cu (ppm)	0.74	0.41
Mn (ppm)	6.71	1.05
Zn (ppm)	0.49	0.20

[Z] Mean of seven separate samples

were treated with hexazinone (Velpar), at 0.28 kg ai ha^{-1}, during late May 1984.

Vegetation control during 1985 consisted of early May cultivation of the 1984 planting and a late May band application of oxyfluorfen at 0.56 kg ai ha^{-1} and sethoxydim (Poast) at 0.38 kg ai ha^{-1}. Both previous plantings were not cultivated, but were treated with oxyfluorfen and sethoxydim.

Fields were irrigated monthly during July and August 1984. The precipitation and irrigation schedule is listed in Table III-2.

Apical internode length, number of lateral buds at the apical bud, and survival were recorded in May 1984, December 1984, and July 1985. Stem diameter was measured in May 1984 and December 1984, and were averages of two measurements 5 to 6 cm below the first node. An arcsine transformation was performed on percent survival data before statistical analysis (Little, 1985).

Statistical analysis was performed using a series of one way analysis of variance and contrast statements within the general linear model procedure of the Statistical Analysis System in Kansas State University's Department of Statistics and Computing Center. Significant differences between treatment means were determined by Tukey's studentized (HSD) range test.

Table III-2. Precipitation and irrigation during the 1984 growing season. Sources for data are Delp's Christmas Tree Farm and Nursery and the Kansas State University Weather Center with a recording station at Hudson, Kansas.

MONTH	PRECIPITATION (cm)	IRRIGATION (cm)	TOTAL (cm)
JUNE	3.8	-	3.8
JULY	0.6	8.9	9.5
AUGUST	2.5	8.9	11.4
SEPTEMBER	11.4	-	11.4
OCTOBER	9.8	-	9.8

RESULTS AND DISCUSSION

SURVIVAL

Nitrogen Fertilization During the Planting Year

Nitrogen fertilization during the year of planting apparently affected survival during both the first (PR>F=0.06) and second (PR>F=0.02) growing seasons (Table III-3). After the second growing season, trees that received 56 kg N ha^{-1} of urea formaldehyde had a greater percent survival than trees that received 224 kg N ha^{-1} of ammonium nitrate. The 224 kg of urea formaldehyde nitrogen application did not improve survival.

Nitrogen source was not a significant factor during either growing season (PR>F=0.38 and 0.23), but the quantity of nitrogen applied affected survival during both seasons (PR>F=0.03 and 0.01). There were no significant differences between quantity means during the first growing season, but differences were evident after the second. Trees treated with 56 kg of nitrogen had a significantly greater survival rate than either those treated with 224 kg of nitrogen or controls.

Table III-3. Percent survival based on arcaine transformation of data during 1984 and 1985 by 1984 planted P. sylvestris seedlings.

EFFECTS	SURVIVAL (%) 1984	SURVIVAL (%) 1985
TREATMENT MEANS		
CONTROL	90.55	73.89ab
AMMONIUM NITRATE		
56 kg N ha^{-1}	100.00	94.44ab
112 kg N ha^{-1}	83.89	72.22ab
224 kg N ha^{-1}	83.89	61.11b
UREA FORMALDEHYDE		
56 kg N ha^{-1}	100.00	100.00a
112 kg N ha^{-1}	88.89	83.33ab
224 kg N ha^{-1}	88.89	72.22ab
NITROGEN SOURCE		
CONTROL	90.55	73.89
AMMONIUM NITRATE	81.48	75.93
UREA FORMALDEHYDE	92.59	85.18
NITROGEN QUANTITY		
0 kg N ha^{-1}	90.55[z]a	73.89b
56 kg N ha^{-1}	100.00a	97.22a
112 kg N ha^{-1}	80.55a	77.78ab
224 kg N ha^{-1}	80.55a	65.56b

[z] Mean separation within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by letters were not significantly different (F-test, PR>F=0.05).

Nitrogen Fertilization One and Two Years After Planting

The survival of trees fertilized one year after planting was independent of treatment during either the first (PR>F=0.49), or the second (PR>F=0.46) growing season (Table III-4). Similarly, fertilization two years after planting had no effect on survival (Table III-5) within the first (PR>F=1.00) or second (PR>F=0.46) growing seasons following treatment.

DISCUSSION

The actual cause of poor survival of trees fertilized the year of planting is not known. One plausible explanation is that high levels of ammonium nitrate or urea formaldehyde might have resulted in a high soil solution osmolarity. Approximately one third of the nitrogen in the urea formaldehyde was in the form of free urea or water soluble urea formaldehyde polymers (Hays and Haden, 1966). Even though high ion concentration may have been present for a short duration, damage may have occurred to mycorrhizae as well as roots. The high osmolarity may have damaged and retarded root growth (Smith, Underwood, and Hayes, 1971; Ingestad, 1979), suppressed fine root formation (Persson, 1980), and/or reduced the mycorrhizal population (Ekwebelam and Reid, 1983). Aqueous

Table III-4. Percent survival based on arcsine transformation of data during 1984 and 1985 by 1983 planted P. sylvestris seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	SURVIVAL (%)	
	1984	1985
TREATMENT MEANS		
CONTROL	100.00	100.00
AMMONIUM NITRATE		
56 kg N ha^{-1}	94.44	83.89
112 kg N ha^{-1}	100.00	100.00
224 kg N ha^{-1}	100.00	100.00
UREA FORMALDEHYDE		
56 kg N ha^{-1}	100.00	86.67
112 kg N ha^{-1}	100.00	100.00
224 kg N ha^{-1}	100.00	83.33
NITROGEN SOURCE		
CONTROL	100.00	100.00
AMMONIUM NITRATE	98.15	95.30
UREA FORMALDEHYDE	100.00	90.00
NITROGEN QUANTITY		
0 kg N ha^{-1}	100.00	100.00
56 kg N ha^{-1}	97.22	87.78
112 kg N ha^{-1}	100.00	100.00
224 kg N ha^{-1}	100.00	94.67

Table III-5. Percent survival based on arcsine transformation of data during 1984 and 1985 by 1982 planted *P. sylvestris* seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	SURVIVAL (%) 1984	1985
TREATMENT MEANS		
CONTROL	100.00	100.00
AMMONIUM NITRATE		
56 kg N ha^{-1}	100.00	100.00
112 kg N ha^{-1}	100.00	94.44
224 kg N ha^{-1}	100.00	100.00
UREA FORMALDEHYDE		
56 kg N ha^{-1}	100.00	100.00
112 kg N ha^{-1}	100.00	100.00
224 kg N ha^{-1}	100.00	100.00
NITROGEN SOURCE		
CONTROL	100.00	100.00
AMMONIUM NITRATE	100.00	98.15
UREA FORMALDEHYDE	100.00	100.00
NITROGEN QUANTITY		
0 kg N ha^{-1}	100.00	100.00
56 kg N ha^{-1}	100.00	100.00
112 kg N ha^{-1}	100.00	97.22
224 kg N ha^{-1}	100.00	100.00

ammonia toxicity may have also occurred. Urea and water soluble urea formaldehydes undergo ammonification and release free ammonia. Most of the free ammonia dissolves in the soil water and dissociates to form $NH_4^+OH^-$. A small portion however is not dissociated, NH_3H_2O, and is highly toxic to plants (Bennett and Adams, 1970).

The root systems of newly planted seedlings were small, shallow, and not well established and therefore the more susceptible to a high ionic soil solution or aqueous ammonia. Older, more established trees did not experience a reduced survival. Root systems were established and wider spread and deeper, thus, were less subject to localized soil solution osmolarity.

HEIGHT GROWTH

Nitrogen Fertilization During the Planting Year

Stem elongation of newly planted trees, expressed as percent of initial stem length, was not affected by the fertilizer treatments during either the first (PR>F=0.29) or second (PR>F=0.13) growing season (Table III-6). Nitrogen source did not influence growth during either season (PR>F=0.62 or PR>F=0.86 respectively). The nitrogen quantity affected stem elongation during the year of planting (PR>F=0.10). However, the second year after treatment, nitrogen quantity was a significant

Table III-6. Height growth, expressed as percent of initial height, during 1984 and 1985 by 1984 planted *P. sylvestris* seedlings.

EFFECTS	HEIGHT (%)	
	1984	1985
TREATMENT MEANS		
CONTROL	46.46	89.70
AMMONIUM NITRATE		
56 kg N ha^{-1}	52.81	120.52
112 kg N ha^{-1}	57.48	67.82
224 kg N ha^{-1}	43.45	57.96
UREA FORMALDEHYDE		
56 kg N ha^{-1}	49.18	100.51
112 kg N ha^{-1}	60.13	95.98
224 kg N ha^{-1}	44.96	66.28
NITROGEN SOURCE		
CONTROL	46.46	89.70
AMMONIUM NITRATE	51.25	82.10
UREA FORMALDEHYDE	49.13	87.59
NITROGEN QUANTITY		
0 kg N ha^{-1}	46.46	89.70[Z]ab
56 kg N ha^{-1}	50.99	110.52a
112 kg N ha^{-1}	55.37	80.90ab
224 kg N ha^{-1}	44.20	62.11b

Z Mean separation within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by letters were not significantly different (F-test, PR>F=0.05).

factor (PR>F=0.05), as trees treated with 56 kg of nitrogen grew significantly more than those treated with 224 kg of nitrogen.

Nitrogen Fertilization One Year After Planting

Stem elongation of trees fertilized one year after planting was not significantly affected during the first growing season by fertilizer treatments (PR>F=0.20), source (PR>F-0.26), or quantity (PR>F=0.60) (Table III-7).

Treatment means appeared to be different after the second growing season (PR>F=0.06). Trees that received 224 kg of nitrogen, as urea formaldehyde, grew significantly taller than trees that received the same amount of ammonium nitrate (Tukey's, 5%). Nitrogen source appeared to affect stem elongation (PR>F=0.08). Trees fertilized with urea formaldehyde grew taller than controls, but they were not significantly different, because of variations within treatment. The quantity of nitrogen was not a significant factor (PR>F=0.52).

Nitrogen Fertilization Two Years After Planting

Fertilization of P. sylvestris seedlings two years after field planting did not influence stem elongation during either the first (PR>F=0.78) or second (PR>F=0.61) year after treatment (Table III-8). Nitrogen source

Table III-7. Height growth, expressed as percent of initial height, during 1984 and 1985 by 1983 planted *P. sylvestris* seedlings.

EFFECTS	HEIGHT (%)	
	1984	1985
TREATMENT MEANS		
CONTROL	43.79	68.25[z]ab
AMMONIUM NITRATE		
56 kg N ha^{-1}	63.11	87.55ab
112 kg N ha^{-1}	51.39	78.45ab
224 kg N ha^{-1}	39.50	62.54b
UREA FORMALDEHYDE		
56 kg N ha^{-1}	49.40	74.02ab
112 kg N ha^{-1}	58.60	92.31ab
224 kg N ha^{-1}	70.97	123.47a
NITROGEN SOURCE		
CONTROL	43.79	68.25
AMMONIUM NITRATE	51.33	76.19
UREA FORMALDEHYDE	59.66	95.79
NITROGEN QUANTITY		
0 kg N ha^{-1}	43.79	68.25
56 kg N ha^{-1}	56.25	80.79
112 kg N ha^{-1}	55.00	85.39
224 kg N ha^{-1}	55.23	92.98

z Means separated within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by a letter were not significantly different (F-test, PR>F=0.05).

and quantity did not affect stem growth during the first (PR>F=0.21 and 0.57) or second (PR>F=0.30 and 0.63) growing year.

DISCUSSION

Recently planted trees in nitrogen deficient soils (12 ppm) grew significantly better with 56 kg of added nitrogen compared to 224 kg (Table III-6). Differences may have been due to improved growth with small amounts of nitrogen, while greater amounts may have suppressed growth due to a high soil solution osmolarity or aqueous ammonia in the root zone. The high osmolarity or ammonia may have resulted from ammonium nitrate or urea formaldehyde, since one third of the urea formaldehyde formulation used in this study was water soluble. The resulting high osmolarity and/or ammonia may have retarded root growth and reduced the soil mycorrhizal population.

The site consisted of a sandy loam soil with a low organic matter concentration (Table III-1), it is reasonable to assume that the concentration of mineralized nitrogen was not buffered by adsorption onto soil particles. Precipitation was probably inadequate to leach fertilizer salts out of the newly planted tree's root zone; consequently, more of the root system was exposed to

Table III-8. Height growth, expressed as percent of initial height, during 1984 and 1985 by 1982 planted *P. sylvestris* seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	HEIGHT (%)	
	1984	1985
TREATMENT MEANS		
CONTROL	57.34	124.99
AMMONIUM NITRATE		
56 kg N ha^{-1}	62.76	120.19
112 kg N ha^{-1}	63.59	124.09
224 kg N ha^{-1}	64.35	132.90
UREA FORMALDEHYDE		
56 kg N ha^{-1}	69.33	114.17
112 kg N ha^{-1}	66.42	105.69
224 kg N ha^{-1}	63.97	125.34
NITROGEN SOURCE		
CONTROL	57.34	124.99
AMMONIUM NITRATE	62.38	128.12
UREA FORMALDEHYDE	67.44	114.72
NITROGEN QUANTITY		
0 kg N ha^{-1}	57.34	124.99
56 kg N ha^{-1}	66.04	117.18
112 kg N ha^{-1}	64.53	117.95
224 kg N ha^{-1}	64.16	129.12

high salt concentrations. The soil contained 9.6 ppm of available P and 109 ppm of available K, which were adequate to meet the tree's requirements (Ingestad, 1979).

Pinus sylvestris fertilized one year after planting (Table III-7) appeared less sensitive to high rates of urea formaldehyde and better able to utilize this nitrogen. Growth was not retarded the first year, and enhanced the second. This may have been due to the slow dissolution rate of a majority of the urea formaldehyde nitrogen (Hays and Haden, 1966) or enhanced growth. The trees were likely damaged by high concentrations of ammonium nitrate and were not able to recover.

Trees fertilized two years after planting were not affected by fertilization (Table III-8). Trees were apparently sufficiently established to obtain an adequate supply of nutrients so that fertilization was not economical.

STEM DIAMETER

Nitrogen Fertilization During the Year of Planting

Stem diameter growth, expressed as percent of initial stem diameter, of Pinus sylvestris was not affected (PR>F=0.24) by nitrogen fertilization during the planting year (Table III-9)). Nitrogen source and quantity did not statistically affect stem diameter growth (PR>F=0.16 and PR>F=0.17) during the first growing season.

Nitrogen Fertilization One or Two Years After Planting

Increases in stem diameter of trees fertilized one or two years after planting (Table III-9) were not significantly affected by treatment (PR>F=0.10 and 0.81). Nitrogen source did not influence growth of either planting (PR>F=0.73 and PR>F=0.33). Nitrogen quantity appeared to influence stem diameter growth of trees planted one year prior to treatment (PR>F=0.04), although the means were not significantly different (Tukey's, 5%), probably because of a large error variance. Trees treated with 56 kg of nitrogen grew more than controls, while those treated with 224 kg of nitrogen grew less than controls.
The quantity of supplemental nitrogen did not influence growth when applied two years after planting (PR>F=0.51).

DISCUSSION

Stem diameter growth of newly planted trees was not significantly affected by fertilization, but growth appeared to be suppressed by 112 and 224 kg of ammonium nitrate, and 224 kg of urea formaldehyde nitrogen. This was likely due to the same factors affecting survival and stem elongation (high fertilizer salt concentrations within the root zone, aqueous ammonia toxicity, and reduction of the mycorrhizal population).

Diameter increase by trees planted one year

Table III-9. Mean stem diameter increase, expressed as percent of initial diameter, during 1984 by 1982, 1983 and 1984 planted _P. sylvestris_ seedlings.

EFFECTS	INCREASE (%) DURING 1984		
	1984	1983	1982
TREATMENT MEANS			
CONTROL	88.94	31.16	25.07
AMMONIUM NITRATE			
56 kg N ha^{-1}	79.43	39.78	15.98
112 kg N ha^{-1}	47.21	29.17	21.02
224 kg N ha^{-1}	52.42	29.17	20.83
UREA FORMALDEHYDE			
56 kg N ha^{-1}	91.14	40.05	21.21
112 kg N ha^{-1}	81.76	27.93	17.74
224 kg N ha^{-1}	61.92	31.73	18.52
NITROGEN SOURCE			
CONTROL	88.94	31.16	25.07
AMMONIUM NITRATE	59.68	30.49	19.18
UREA FORMALDEHYDE	78.27	33.24	19.62
NITROGEN QUANTITY			
0 kg N ha^{-1}	88.94	31.16[z]a	25.07
56 kg N ha^{-1}	85.29	39.92a	18.60
112 kg N ha^{-1}	64.48	28.55a	19.92
224 kg N ha^{-1}	57.17	27.12a	19.68

[z] Means separated within columns utilizing Tukey's HSD procedure, 5% level. Means within each effect column followed by the same letter are not significantly different. Means not followed by letters were not significantly different (F-test, PR>F=0.05).

before treatment appeared stimulated by the low rate (56 kg) of nitrogen from either nitrogen source. Higher rates (112 or 224 kg) did not affect growth. Apparently, benefits of supplemental nitrogen were offset by damage to the root system. This could have been due to the root system being sufficiently developed to overcome localized elevated salt concentrations, aqueous ammonia, and/or mycorrhizal population disruptions.

Nitrogen fertilization two years after planting did not significantly affect growth, although most fertilized trees grew less than the controls.

LATERAL BUD DEVELOPMENT

The number of lateral buds developed at the apical bud was not significantly affected by any nitrogen fertilizer treatment during the year of fertilization or the following year by any of the three plantings in this study (Table III-10, 11, and 12). Similar results were observed by Kellomaki (Kellomaki, et al., 1982).

SUMMARY

Survival of *Pinus sylvestris* seedlings was adversely affected by fertilization during the year of planting but not when application was made one or two years after establishment. The higher survival rates resulted from

Table III-10. Mean lateral buds formed during 1984 and 1985 by 1984 planted P. *sylvestris* seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	NUMBER OF LATERAL BUDS	
	1984	1985
TREATMENT MEANS		
CONTROL	4.78	5.09
AMMONIUM NITRATE		
56 kg N ha^{-1}	5.39	5.86
112 kg N ha^{-1}	4.04	5.85
224 kg N ha^{-1}	4.33	4.63
UREA FORMALDEHYDE		
56 kg N ha^{-1}	5.44	5.39
112 kg N ha^{-1}	5.26	5.24
224 kg N ha^{-1}	3.94	4.16
NITROGEN SOURCE		
CONTROL	4.78	5.09
AMMONIUM NITRATE	4.60	5.45
UREA FORMALDEHYDE	4.90	4.93
NITROGEN QUANTITY		
0 kg N ha^{-1}	4.78	5.09
56 kg N ha^{-1}	5.45	5.62
112 kg N ha^{-1}	4.75	5.55
224 kg N ha^{-1}	4.16	4.39

Table III-11. Mean lateral buds formed during 1984 and 1985 by 1983 planted P. sylvestris seedlings. There were no significant differences among treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	NUMBER OF LATERAL BUDS	
	1984	1985
TREATMENT MEANS		
CONTROL	4.18	9.18
AMMONIUM NITRATE		
56 kg N ha^{-1}	5.26	8.02
112 kg N ha^{-1}	4.21	9.03
224 kg N ha^{-1}	4.42	8.16
UREA FORMALDEHYDE		
56 kg N ha^{-1}	5.31	11.22
112 kg N ha^{-1}	5.67	8.56
224 kg N ha^{-1}	3.92	9.86
NITROGEN SOURCE		
CONTROL	4.18	9.18
AMMONIUM NITRATE	4.23	8.40
UREA FORMALDEHYDE	4.97	9.88
NITROGEN QUANTITY		
0 kg N ha^{-1}	4.18	9.18
56 kg N ha^{-1}	5.28	9.62
112 kg N ha^{-1}	4.94	8.79
224 kg N ha^{-1}	4.17	9.01

Table III-12. Mean lateral buds formed during 1984 and 1985 by 1982 planted *P. sylvestris* seedlings. There were no significant differences among the treatment means, nitrogen sources, or nitrogen quantities (F-tests) for either year.

EFFECTS	NUMBER OF LATERAL BUDS	
	1984	1985
TREATMENT MEANS		
CONTROL	6.11	7.31
AMMONIUM NITRATE		
56 kg N ha^{-1}	6.88	5.98
112 kg N ha^{-1}	6.70	4.97
224 kg N ha^{-1}	8.06	5.78
UREA FORMALDEHYDE		
56 kg N ha^{-1}	8.03	6.03
112 kg N ha^{-1}	6.89	6.17
224 kg N ha^{-1}	6.29	5.87
NITROGEN SOURCE		
CONTROL	6.11	7.31
AMMONIUM NITRATE	7.21	5.57
UREA FORMALDEHYDE	7.07	6.02
NITROGEN QUANTITY		
0 kg N ha^{-1}	6.11	7.31
56 kg N ha^{-1}	7.45	6.00
112 kg N ha^{-1}	6.79	5.82
224 kg N ha^{-1}	7.17	5.57

the lowest application rate of both nitrogen fertilizers.

Small quantities of supplemental nitrogen stimulated stem elongation of newly transplanted seedlings, while large amounts retarded growth. Stem elongation of trees fertilized one year after planting was stimulated by the high rate (224 kg N) of urea formaldehyde, but not ammonium nitrate. Trees fertilized two years after planting showed no response.

Stem diameter increase of all three age groups appeared to be reduced by high rates of ammonium nitrate or urea formaldehyde when applied during the year of planting. Treatment one year after planting with the lowest rate of urea formaldehyde stimulated growth. Fertilization two years after planting appeared to reduce growth. Lateral bud development was not affected by nitrogen fertilization.

LITERATURE CITED

Adams, R.S., Jr. and F.J. Stevenson. 1964. Ammonium sorption and release from rock and minerals. Soil Sci. Soc. Amer. Proc. 28:345-351.

Armson, K.A., K.H. Reese, and R.A. Carman. 1963. Time of fertilizer application affects size of conifer seedlings. Tree Planters' Notes 59:9-12.

Armson, K.A. 1963. The effect of levels and time of fertilizer application on the growth of white spruce seedlings. Soil Sci. Soc. Amer. Proc. 27:596-597.

Bengtson, G.W. and G.K. Voigt. 1962. A greenhouse study of relations between nutrient movement and conversion in a sandy soil and the nutrition of slash pine seedlings. Soil Sci. Soc. Amer. Proc. 26:609-612.

Bennett, A.C. and F. Adams. 1970. Concentration of NH_3 required for incipient NH_3 toxicity to seedlings. Soil Sci. Soc. Amer. Proc. 34:259-263.

Bjorkman, E., G. Lundeberg, and H. Nommik. 1967. Distribution and balance of ^{15}N labelled fertilizer nitrogen applied to young pine trees (Pinus sylvestris L.). Studia Forestalia Suecica 48:1-23.

Bolin, B. and E. Arrhenius. 1977. Nitrogen-An essential life factor and a growing environmental hazard. Report from Nobel Symposium no. 38. Ambio 6:96-105.

Bormann, F.H., G.E. Likens, and J.M. Melillo. 1977. Nitrogen budget for an ageing northern hardwood forest ecosystem. Science 196:981-983.

Boyd, R. J. 1976. The biology of planting. 10-17. In: D. M. Baumgartner and R. J. Boyd (eds.). Tree Planting in the Inland Northwest. Washington State University, Coop. Exten. Serv., Pullman, Wash.

Brix, H. and L.F. Ebell. 1969. Effects of nitrogen fertilization on growth, leaf area, and photosynthesis rate in Douglas-fir. For. Sci. 15:189-195.

Craighead, M. 1985. personal communication.

Dalton, H. and L.E. Mortenson. 1972. Dinitrogen (N_2) fixation (with a biochemical emphasis). Bacteriol. Rev. 36:231-260.

Ekwebelam, S.A. and C.P.P. Reid. 1983. Effect of light, nitrogen fertilizer, and mycorrhizal fungi on growth and photosynthesis of lodgepole pine seedlings. Can. J. For. Res. 13:1099-1106.

Fagerstrom, T. and U. Lohm. 1977. Growth in scots pine (Pinus sylvestris L.): Mechanism of response to nitrogen. Oecologia (Berl.) 26:305-515.

Fisher, R.F. and W.L. Pritchett. 1982. Slash pine growth response to different nitrogen fertilizers. Soil Sci. Soc. Amer. J. 46:133-136.

Fuller, W.H. and K.G. Clark. 1947. Microbiological studies on urea-formaldehyde preparations. Soil Sci. Soc. Amer. Proc. 12:198-202.

Gallaher, H.G. 1971. Growing Christmas trees in Kansas. (Unnumbered):1-8.

Granhall, U. and T. Lindberg 1980. Nitrogen input through biological nitrogen fixation. 333-340. In: T. Persson (ed.). Structure and Function of Northern Coniferous Forests-An Ecosystem Study. Ecol. Bull. 32. Swedish National Science Research Council, Stockholm, Sweden.

Gwinner, G.M. April 1983. Should we cut back on planting?. Christmas Trees 8-13.

Gwinner, G. M. 1984. Shearing for uniform maturity and minimum density. 2-12. In: Shearing with a definite purpose. Annual Gathering of the Mid-America Christmas Trees, August 2-4, 1984, Cedar Rapids, Iowa, Mid-America Christmas Trees, Hermann, Missouri.

Haapanen, T., P. Hari, and S. Kellomaki. 1979. Effect of fertilization and thinning on radial growth of scots pine. Silva Fennica 13:184-189.

Hagin, J. and L. Cohen. 1976. Nitrogen fertilizer potential of an experimental urea formaldehyde. Agron. J. 68:518-520.

Hardy, R.W.F., R.C. Burns, and R.D. Holstein. 1973. Application of the acetylene-ethylene assay for measurement of nitrogen fixation. Soil Biol. Biochem. 5:47-81.

Hays, J.T. and W.W. Haden. 1966. Soluble fraction of ureaforms-nitrification, leaching, and burning properties. J. Agr. Food Chem. 14:339-341.

Heilman, P.E., T. Dao, H.H. Cheng, S.R. Webster, and S.S. Harper. 1982a. Comparison of fall and spring applications of ^{15}N-labeled urea to Douglas-fir. I. Growth response and nitrogen levels in foliage and soil. Soil Sci. Soc. Amer. J. 46:1293-1299.

Heilman, P.E., T.H. Dao, H.H. Cheng, S.R. Webster, and L. Christensen. 1982b. Comparison of fall and spring applications of ^{15}N-labeled urea to Douglas-fir: II. Fertilizer nitrogen recovery in trees and soil after 2 years. Soil Sci. Soc. Amer. J. 46:1300-1304.

Helms, J.A.. 1964. Apparent photosynthesis of Douglas-fir in relation to silvicultural treatment. For. Sci. 10:432-442.

Henderson, J. and D.L. Hensley. 1983. personal communication.

Ingestad, T. 1977. Nitrogen and plant growth; maximum efficiency of nitrogen fertilizers. Ambio 6:146-151.

Ingestad, T. 1960. Studies on the nutrition of forest tree seedlings. III. Mineral nutrition of pine. Physiol. Plant. 13:513-533.

Ingestad, T. 1979. Mineral nutrition requirements of Pinus sylvestris and Picea abies seedlings. Physiol. Plant. 45:373-380.

Jenkinson, J. L. 1980. Improving plantation establishment by optimizing growth capacity and planting time of western yellow pines. 1-22. In: U S Forest Serv. Pacific Southwest Forest and Range Experiment Station

Jensen, P. and S. Pettersson 1980. Nitrogen uptake in roots of scots pine. 229-237. In: T. Persson (ed.). Structure and function of northern coniferous forest-An ecosystem study. Ecol. Bull. 32. Swedish National Science Research Council, Stockholm, Sweden.

Kellomaki, P., P. Puttonen, H. Tamminen, and C.J. Westman. 1982. Effect of nitrogen fertilization on photosynthesis and growth in young scots pines-Preliminary results. Silva Fennica 16:363-371.

Little, T.M. 1985. Analysis of percent and rating scale data. Hortscience 20:642-644.

Loucks, W. 1983. Christmas tree glut-fact or fiction. Kansas State University, Forestry Exten. Serv. (Unnumbered series):1-9.

Loucks, W. 1984. personal communication.

Loucks, W. 1985. personal communication.

McKee, W.H., Jr. and R.A. Sommers. 1971. Slash pines respond equally to nitrogen applications in fall and spring. Res. Notes SO-128:1-4.

Melin, J., H. Nommik, U. Lohm, and J. Flower-Ellis. 1983. Fertilizer nitrogen budget in a Scots pine ecosystem attained by using root-isolated plots and ^{15}N tracer technique. Plant and Soil 74:249-263.

Michniewicz, M. and J. Stopinska. 1980. Comparison of the effect of nitrogen and potassium nutrition on growth and plant hormones content in Scots pine seedlings. Bulletin de L'Academie Polonaise des Sciences. Series de Sciences Biologiques. Cl.II 28:5:327-334.

National Christmas Tree Assoc., Inc. 1982. NCTA 1981 planting and harvesting survey. (Unnumbered series).

Noecker, N. 1984. Quality 7 foot trees in 6 years. Christmas Trees April 1984:18-19, 22, 37.

Nommik, H. 1966. The uptake and translocation of fertilizer ^{15}N in young trees of scots pine and Norway spruce. Studia Forestalia Suecica 35:1-18.

Nommik, H. 1967. Mineralization and availability of nitrogen in urea-formaldehyde compounds. Acta Agri. Scand. 17:33-38.

Nommik, H. and G. Moller. 1981. Nitrogen recovery in soil and needle biomass after fertilization of a scots pine stand, and growth responses observed. Studia Forestalia Suecica 159:1-35.

Owston, P.W. and W.I. Stein. 1972. First-year performance of Douglas-fir and noble fir outplanted in large containers. Research Note: Pacific Northwest Forest and Range Experiment Station 174:1-10.

Paavilainen, E. 1972. Reaction of scotch pine on various nitrogen fertilizers on drained peatlands. Comm. Inst. For. Fenn. 77:1-46.

Persson, H. 1980. Death and replacement of fine roots in a mature Scots pine stand. 251-260. In: T. Persson (ed.). Ecol. Bull. Structure and function of Northern Coniferous Forest-An Ecosystem Study. Ecol. Bull. 32. Swedish National Science Research Council, Stockholm, Sweden.

Powers, R.F. 1980. Mineralizable soil nitrogen index in nitrogen availability to forest trees. Soil Sci. Soc. Am. J. 44:1314-1320.

Puro, T. 1982. Effect of fertilization time on growth reaction of different tree species. Folia Foresta. 507:1-14.

Richards, N.A. and A.L. Leaf. 1971. Efficient Christmas tree fertilization. American Christmas Tree J. May 1971:11-14.

Rudolph, V.J. Nov. 1968. Economic analysis of growing four Christmas tree plantation species. American Christmas Tree J. 5-11.

Rutter, A.J. 1957. Studies in the growth of young seedlings of Pinus sylvestris L. 1. The annual cycle of assimilation and growth. Ann. Bot 21:399-426.

Rutter, A.J. 1955. The relation between dry weight increase and linear measures of growth in young conifers. Forestry 28:125-135.

Ryker, R. A. 1976. When to plant. 185-192. In: D. M. Baumgartner and R. J. Boyd (eds.). Tree Planting in the Inland Northwest. Washington State University, Coop. Exten. Serv., Pullman, Wash.

Sauchelli, V. 1964. Soil Nitrogen. 18-39. In: V. Sauchelli (ed.). Fertilizer Nitrogen: Its Chemistry and Technology Reinhold Publishing Corp., New York City, New York.

Smith, W.H., H.G. Underwood, and J.T. Hays. 1971. Ureaforms in the fertilization of young pines. J. Agr. Food Chem. 19:816-821.

Solomon, C. 1985. personal communication.

Stewart, W. D. P. 1968. Nitrogen input into aquatic ecosystems. 53-72. In: Algae, Man, and the Environment. Syracuse University Press, Syracuse, New York.

Stoeckeler, J.H. and H.F. Arneman. 1960. Fertilizers in Forestry. 34-38. In: A. G. Norman (ed.). Advances in Agronomy. Academic Press, New York.

Timmer, V.R., E.L. Stone, and D.G. Embree. 1977. Growth response of young balsam fir fertilized with nitrogen, phosphorous, potassium, and lime. Can. J. For. Sci. 7:441-446.

Turner, D.O. 1979. Effects of nitrogen and shearing treatments on growth and quality of Douglas-fir Christmas trees in western Washington. Col. of Ag. Res. Cen., Wash. State Univ. Bull. 875.

van der Driessche, R. 1984. Soil fertility in forest nurseries. 63-80. In: M. L. Duryea and T. D. Landis (eds.). Forest Nursery Manual: Production of bareroot seedlings. Martinus Nijhoff/Dr W. Jung Publishers, Boston.

van Praag, H.J. and F. Weissen. 1973. Elements of a functional definition of oligotroph humus based on the nitrogen nutrition of forest stands. J. Appl. Ecol. 10:569-583.

Whitney, D.A. 1981. Summary of soil test results in Kansas 1979-1980. (Unnumbered series):1-12.

Wilde, S.A. 1938. Soil-fertility standards for growing northern conifers in forest-nurseries. J. Agri. Res. 57:945-952.

Wollum, A. G. and C. B. Davey 1975. Nitrogen accumulation, transformation, and transport in forest soils. 67-108. In: B. Bernier and C. H. Winget (eds.). Forest Soils and Land Management. Proc. 4th North American Forest Soils Conf., Les Presses de l'Universite Laval, Quebec, Can.

Yee, J.Y. and K.S. Love. 1946. Nitrification of urea-formaldehyde reaction products. Soil Sci. Soc. Amer. Proc. 11:389-392.

APPENDIX I. Height growth (cm) during 1984 and 1985 by spring 1984 planted bareroot *P. sylvestris aquitana* and containerized *P. sylvestris haguenensis* seedlings.

EFFECTS	HEIGHT (cm)			
	Bareroot *P. sylvestris aquitana*		Containerized *P. sylvestris haguenensis*	
	1984	1985	1984	1985
TREATMENT MEANS				
CONTROL	6.84	5.08	9.56	12.44
AMMONIUM NITRATE				
56 kg N ha^{-1}	5.31	6.60	8.47	10.09
112 kg N ha^{-1}	5.08	5.94	10.19	12.21
224 kg N ha^{-1}	5.06	4.50	8.93	7.70
UREA FORMALDEHYDE				
56 kg N ha^{-1}	5.46	4.92	8.77	8.43
112 kg N ha^{-1}	4.50	5.50	9.16	8.05
224 kg N ha^{-1}	5.92	4.21	8.59	8.42
NITROGEN SOURCE				
CONTROL	6.84	5.08	9.56	12.44
AMMONIUM NITRATE	5.15	5.68	9.20	10.00
UREA FORMALDEHYDE	5.29	4.88	8.84	8.30
NITROGEN QUANTITY				
0 kg N ha^{-1}	6.84	5.08	9.56	12.44
56 kg N ha^{-1}	5.38	5.76	8.62	9.26
112 kg N ha^{-1}	4.79	5.72	9.67	10.13
224 kg N ha^{-1}	5.49	4.35	8.78	8.36

APPWNDIX II. Height growth during 1985 by fall 1984 planted bareroot _P. aylveatria auvarque_ and containerized _P. aylveatria haquenenaia_ aeedlinga.

EFFECTS	HEIGHT (cm) Bareroot _P. sylveatris auvarque_ 1985	HEIGHT (cm) Containerized _P. sylvestris haquenensis_ 1985
TREATMENT MEANS		
CONTROL	3.40	6.03
AMMONIUM NITRATE		
56 kg N ha^{-1}	3.14	7.08
112 kg N ha^{-1}	3.83	6.61
224 kg N ha^{-1}	3.71	7.00
UREA FORMALDEHYDE		
56 kg N ha^{-1}	4.54	6.67
112 kg N ha^{-1}	4.31	5.73
224 kg N ha^{-1}	2.86	6.57
NITROGEN SOURCE		
CONTROL	3.40	6.03
AMMONIUM NITRATE	3.57	6.90
UREA FORMALDEHYDE	3.90	6.32
NITROGEN QUANTITY		
0 kg N ha^{-1}	3.40	6.03
56 kg N ha^{-1}	3.86	6.87
112 kg N ha^{-1}	4.07	6.17
224 kg N ha^{-1}	3.285	6.78

APPENDIX III. Height growth (cm) during 1984 and 1985 by 1984 planted *P. sylvestris* seedlings.

EFFECTS	HEIGHT (cm) 1984	HEIGHT (cm) 1985
TREATMENT MEANS		
CONTROL	6.29	11.28
AMMONIUM NITRATE		
56 kg N ha^{-1}	7.00	15.64
112 kg N ha^{-1}	8.18	9.06
224 kg N ha^{-1}	6.21	8.13
UREA FORMALDEHYDE		
56 kg N ha^{-1}	6.92	13.72
112 kg N ha^{-1}	7.31	12.24
224 kg N ha^{-1}	6.21	9.10
NITROGEN SOURCE		
CONTROL	6.29	12.28
AMMONIUM NITRATE	7.14	10.94
UREA FORMALDEHYDE	6.81	11.69
NITROGEN QUANTITY		
0 kg N ha^{-1}	6.29	12.28
56 kg N ha^{-1}	6.96	14.68
112 kg N ha^{-1}	7.74	10.65
224 kg N ha^{-1}	6.22	8.62

APPENDIX IV. Height growth (cm) during 1984 and 1985 by 1983 planted P. sylvestris seedlings.

EFFECTS	HEIGHT (cm) 1984	1985
TREATMENT MEANS		
CONTROL	9.79	15.20
AMMONIUM NITRATE		
56 kg N ha^{-1}	12.17	17.22
112 kg N ha^{-1}	10.08	15.77
224 kg N ha^{-1}	9.01	14.34
UREA FORMALDEHYDE		
56 kg N ha^{-1}	10.76	16.18
112 kg N ha^{-1}	11.53	17.70
224 kg N ha^{-1}	11.37	18.33
NITROGEN SOURCE		
CONTROL	9.79	15.20
AMMONIUM NITRATE	10.42	15.77
UREA FORMALDEHYDE	11.22	17.40
NITROGEN QUANTITY		
0 kg N ha^{-1}	9.79	15.20
56 kg N ha^{-1}	11.47	15.70
112 kg N ha^{-1}	10.81	16.73a
224 kg N ha^{-1}	10.19	15.34

APPENDIX V. Height growth (cm) during 1984 and 1985 by 1982 planted *P. sylvestris* seedlings.

EFFECTS	HEIGHT (cm) 1984	1985
TREATMENT MEANS		
CONTROL	18.79	39.23
AMMONIUM NITRATE		
56 kg N ha^{-1}	19.05	35.07
112 kg N ha^{-1}	19.60	39.87
224 kg N ha^{-1}	22.11	45.77
UREA FORMALDEHYDE		
56 kg N ha^{-1}	21.76	34.67
112 kg N ha^{-1}	19.28	30.83
224 kg N ha^{-1}	17.62	32.88
NITROGEN SOURCE		
CONTROL	18.79	39.23
AMMONIUM NITRATE	20.25	40.24
UREA FORMALDEHYDE	19.55	32.79
NITROGEN QUANTITY		
0 kg N ha^{-1}	18.79	39.33
56 kg N ha^{-1}	20.41	34.87
112 kg N ha^{-1}	19.79	35.35
224 kg N ha^{-1}	19.86	39.33

NITROGEN FERTILIZATION OF *Pinus sylvestris* SEEDLINGS

by

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Two field studies were conducted to determine the effects of nitrogen fertilization on survival, stem growth, and lateral bud development of young *Pinus sylvestris* L. seedlings. The first study utilized preplant incorporation of ammonium nitrate or urea formaldehyde (0, 56, 112, or 224 kg N ha^{-1}) into Eudora silt loam soil which contained 32.8 ppm of available nitrogen. The following plantings were studied: spring planted, bareroot *P. sylvestris aquitana*, fall planted, bareroot *P. sylvestris auvarque*, and spring and fall planted containerized *P. sylvestris haguenensis* seedlings.

Ammonium nitrate at 224 kg N tended to injure and kill spring or fall planted bareroot seedlings, while containerized seedlings were not affected by fertilizer treatments. Height growth, stem diameter growth, and lateral bud development of all plantings were not influenced by fertilization.

A second study utilized postplant, surface applications of 0, 56, 112, or 224 kg of ammonium nitrate or urea formaldehyde nitrogen to 2:0 bareroot *P. sylvestris* seedlings planted two months, one year, and two years prior to spring treatment. The site consisted of Carwile sandy, loam soil containing 11.8 ppm of available nitrogen.

Fertilization affected survival of newly planted trees, but survival of trees planted one or two years

before treatment was not affected. Higher survival was observed among trees that received 56 kg of nitrogen, while 224 kg of ammonium nitrate nitrogen reduced survival.

Small quantities (56 kg) of supplemental nitrogen stimulated stem elongation of newly transplanted seedlings during the planting year, while 224 kg retarded growth. Stem elongation of trees fertilized one year after planting was stimulated by the 224 kg of urea formaldehyde nitrogen, but not ammonium nitrate. Trees fertilized two years after planting showed no response.

Stem diameter increase and lateral bud development of all three age groups studied was not significantly influenced by nitrogen fertilization.