COMPARATIVE EFFECTS OF AMMONIUM NITRATE AND UREA FERTILIZERS ON TREE GROWTH AND SOIL PROCESSES

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ABSTRACT

Growth response of Douglas-fir to ammonium nitrate and urea, applied at rates of 200 and 400 pounds per acre (224 and 448 kilograms of nitrogen per hectare), was studied over a 7-year period at Shawnigan Lake, B.C. Diameter growth was 21 and 9 percent better, respectively, for the two rates with ammonium nitrate than with urea in unthinned plots and 7 percent better for plots that had been thinned and received 400 pounds per acre (448 kilograms nitrogen per hectare). Foliar nitrogen concentrations also increased most with ammonium nitrate fertilization during the first 2 years, indicating that nitrogen from this source was initially more readily available to the trees. This is explained in part by the greater mobility of nitrate supplied by ammonium nitrate and by nitrogen immobilization in buildup of bacterial populations with urea.

INTRODUCTION

Early studies in forest fertilization in the Pacific Northwest in the 1950's and 1960's used various formulations of N, i.e., ammonium, nitrate, and urea, in addition to other nutrient elements. No extensive comparison of N source effect on tree growth appears to have been made and no superiority of one over another was established (Crossin et al. 1966, Gessel 1968). Urea has been used exclusively in the extensive operational applications that began in 1965 (Miller and Fight 1979), because good growth response was obtained with that N source and its high N concentration provided a cost advantage in application. Most Pacific Northwest research trials initiated in the late 1960's and 1970's have therefore concentrated on the use of urea.

Considering recent experience in Sweden where extensive field trials have demonstrated the superiority of ammonium nitrate to urea fertilizer, there is a need to reevaluate the relative merits for these forms under different site conditions and for different species in the Pacific Northwest.

This report summarizes the results from Sweden and from studies under way at the Canadian Forestry Service installation at Shawnigan Lake, B.C. Changes produced in the soil system and in tree nutrient status by these forms is compared in an attempt to explain differences in tree growth.

RESULTS FROM SWEDEN

Growth responses to ammonium nitrate and urea have been compared in 42 tests, using 138 plots for each source. Tests were carried out in Norway spruce and Scots pine stands throughout Sweden. Various fertilizer rates were applied and responses were related to current increments of control stands (Malm and Möller 1975).

Superiority of ammonium nitrate over urea for Scots pine was most marked at low rates of application (107–321 lb N/acre [120–360 kg/ha]) for which the 5-yr gross volume averaged 45% better (63 ft^3/acre [4.4 m^3/ha]) with ammonium nitrate. The difference in growth increased with increase in current annual increment. The ammonium nitrate source was also better for Norway spruce, but only by an average of 12% for all locations suggesting a species or a site difference associated with source effect. The operational practices have for this reason changed from an almost exclusive use of urea in the 1960's to only 10% in 1976, with the rest applied as ammonium nitrate (Holmen 1977).

As an explanation for the source effect on growth, soil studies have indicated that much of the ammonium produced from urea is tied up in the humus layer and does not reach the root zone, whereas the more readily leached nitrate from ammonium nitrate moves into this zone (Nömmik 1977). That N availability is an important factor has also been demonstrated in a study that showed a considerably higher foliar N concentration of Scots pine with ammonium nitrate than with urea after the first and second growing seasons (Nömmik 1977).

SHAWNIGAN LAKE PROJECT

Site and stand conditions and experimental design have been described in detail by Crown and Brett (1975). Briefly, the installation was established (1970) in a 24-yr-old Douglas-fir plantation in the wetter subzone of the coastal Douglas-fir biogeoclimatic zone (Krajina 1969) near Shawnigan Lake on Vancouver Island. The soils are shallow (18–24 in. [45–60 cm]), well drained, coarse-textured glacial till and are classified as Orthic Dystric Brunisol. The organic mantle is usually less than 0.1 in. (2 cm) thick and soil pH ranges from 4.5 to 5.0. The site index is 66 ft (21 m; 50 yr).

The basic design of the installation consists of three levels of N fertilization (F) with urea (0, 200, and 400 lb N/acre [0, to other plots again in 1972, using 1/5-acre (0.08-ha) plots surrounded by 33-ft-(10-m-) wide buffer zones. In addition to the basic design, several subsidiary treatments were included in 1972 and 1973. Ammonium nitrate was applied at 200 and 400 lb N/acre (224 and 448 kg/ha) on unthinned plots in 1072 and at 400 lb N/acre (448 kg/ha) on heavily thinned plots in 1973, in addition to similar treatments with urea in those years.

Tree and stand growth has been reported for all plots in the basic design for the first 3-yr period (Crown et al. 1977) and a 6-yr report is in preparation. In our report, breast height diameter growth is compared for ammonium nitratetreatėd plots from the subsidiary trial with plots in which urea was used as an N source. Data are based on 12 trees from two plots for each treatment. The trees were selected at the time of treatment for uniformity of growth, were classified as codominant and were of average breast height diameter for the stand. Their seasonal

Plots were also monitored for foliar N levels and soil characteristics. Soil measurements included pH, temperature, soil solution chemistry, and soil biological activity. The soil solution was collected using soil tension lysimeters adapted from the design of Cole et al. (1961). Lysimeters were installed below the organic layer (0.6 in. [1.5 cm]) and at depths of 4 and 12 in. (10 and 30 cm) below the surface, in plots to show the effects of thinning, rate of urea fertilization, and fertilizer source at 400 lb N/acre (448 kg/ha). Ammonium and nitrate ion were determined by specific ion electrode immediately after bringing water samples back to the laboratory. Measurements of soil microbiological activity included microflora population counts, dehydrogenase concentrations, and respiration rates.

TREE GROWTH

The breast height diameter growth in unthinned plots treated with ammonium nitrate and urea, expressed as a percentage of growth in unfertilized plots for application rates of 200 and 400 lb N/acre (224 and 448 kg/ha) is given in Figure 1. With the low N application rate, growth with AN was better than with urea for the first 6 yr of the 7-yr period, and averaged 21% better for the whole period (significant at $P = 0.01$). With the high fertilizer dose, ammonium nitrate was the best source for the first 3 yr of the 7 yr and averaged 9% better overall (significant at $P = 0.05$). In the heavily thinned plots fertilized in 1973, ammonium nitrate was best in 3 yr of the 6 yr (years 1, 3, and 4; significant at $P = 0.01$). There was no source effect in the other years and the overall average increase with ammonium nitrate compared with urea was 7%. Similar to our finding, Swedish results also indicated that the superiority of

After the first 2 yr there were no significant differences in foliar N levels between the sources, and by the end of the fourth growing season the N levels were equal to that of control trees. The data are for current year's foliage from thinned plots, but similar N source effects were found in unthinned plots. Based on calculations of foliage dry weight (9098 lb/acre [10 200 kg/ha]) and considering a lower N concentration in older than in current foliage (Brix 1971), the foliage N content was estimated to be 91, 125, and 167 lb N/acre (102, 140, and 187 kg/ha) in the fall following fertilization in March, in the unthinned stands without fertilization, with urea and ammonium nitrate, respectively. Thus, increase in N uptake by foliage with ammonium nitrate was about twice that with urea fertilization after the first growing season, which represents 10% more of the applied N (400 lb N/acre [448 kg/ha]).

SOIL CHARACTERISTICS

Urea and ammonium nitrate fertilizers differ in several

Figure 1. Breast height diameter growth following ammonium nitrate and urea fertilizer applications of 200 and 400 lb N/acre (224 and 448 kg/ha) in March 1972.

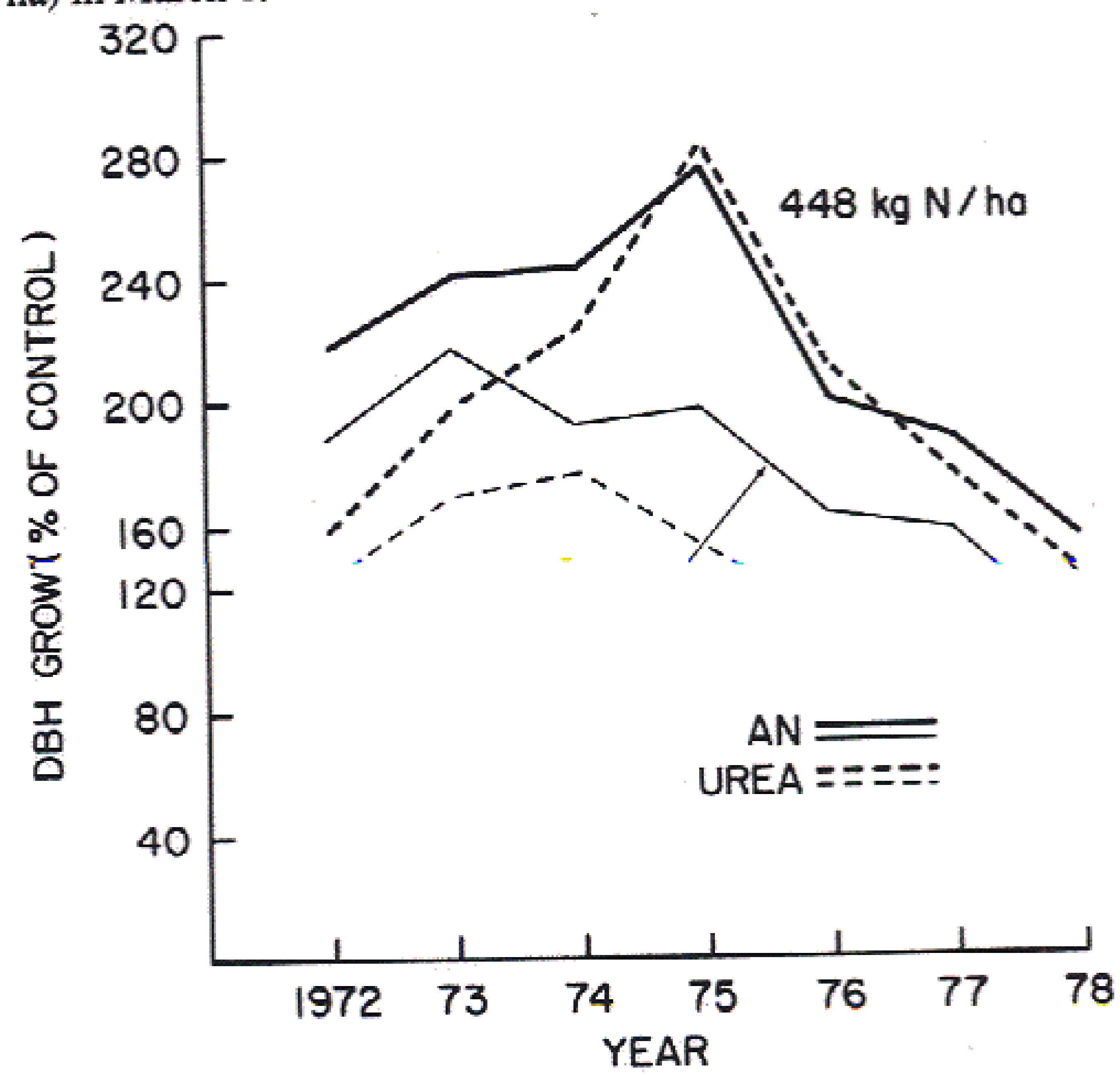
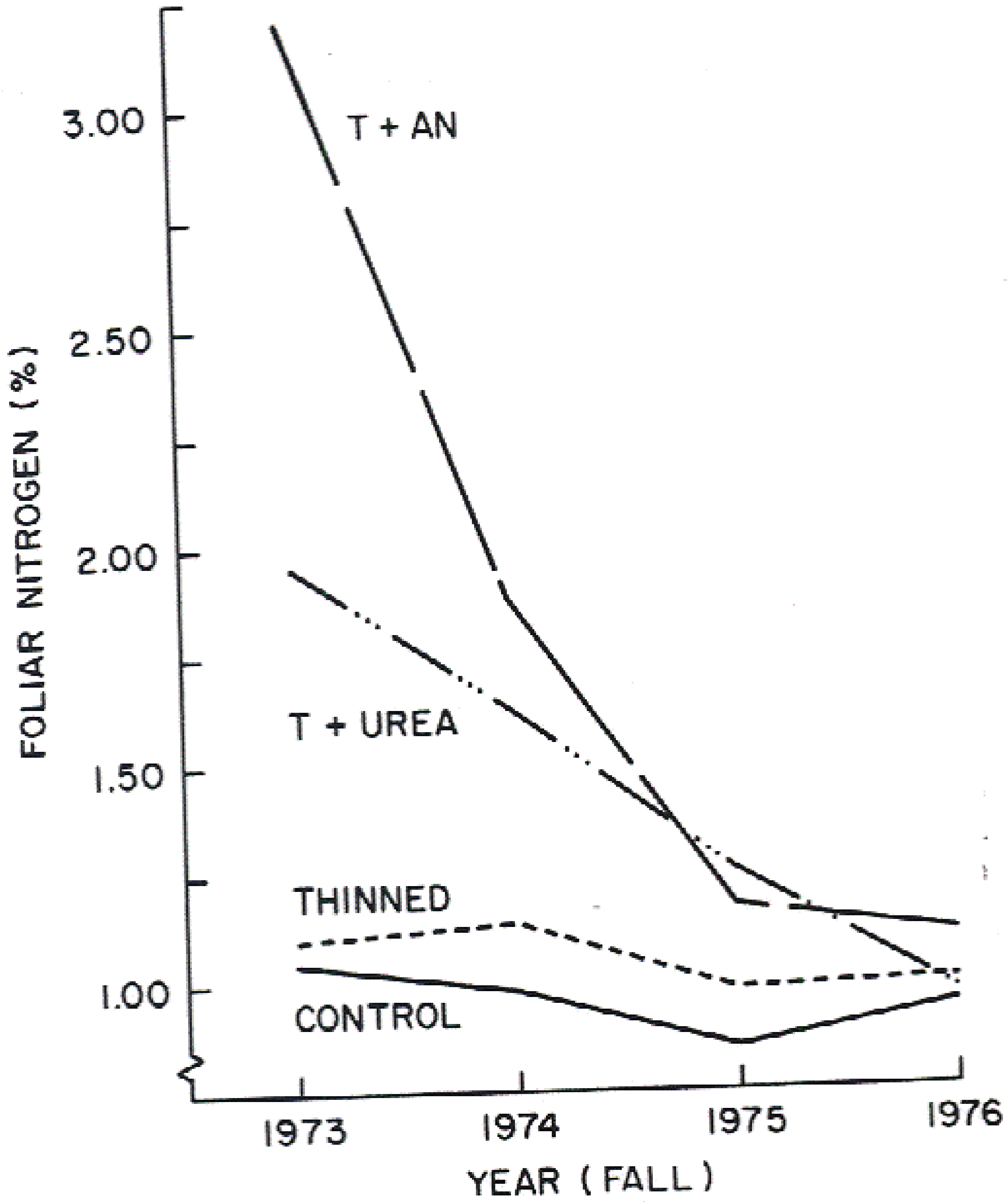


Figure 2. Foliage N concentrations (percentage of foliage dry weight) in relation to thinning (*T*) and N fertilization with ammonium nitrate or urea at 400 lb N/acre (448 kg/ha) in March 1973.



respects, which affect the availability of their N source to the trees. This results from differences in pH effect, chemical transformations, movement in the soil, effect on microbial populations, and losses by volatilization and leaching. The fate of the fertilizer is highly influenced by rainfall soon after application and it was normal for the time of year in 1972 but below average in 1973 (Figure 3).

SOIL SOLUTION CHEMISTRY

Soil Solution pH

With a fertilization rate of 400 lb N/acre (448 kg/ha), urea fertilization increased the soil solution pH about 1.5 units as a result of urea hydrolysis, whereas ammonium nitrate decreased pH by about 0.5 unit during the first month after application (Figure 4). In the fall, after the dry summer, the pH of the soil solution from all fertilized plots was less than the control. In the urea-treated plots, this results from nitrification of some of the ammonium to the acidic nitrate form.

Nitrate Nitrogen

The fertilizer sources lead to changes in availability and movement of various cations and anions in the soil solution, but we shall confine our discussion to N sources.[1]

1. Data in Figures 4–7 were provided by P. C. Pang and K. McCullough, Pacific Forest Research Centre, from a manuscript in preparation.

Figure 3. Cumulative rainfall following fertilization (March 21) in 1972 and 1973.

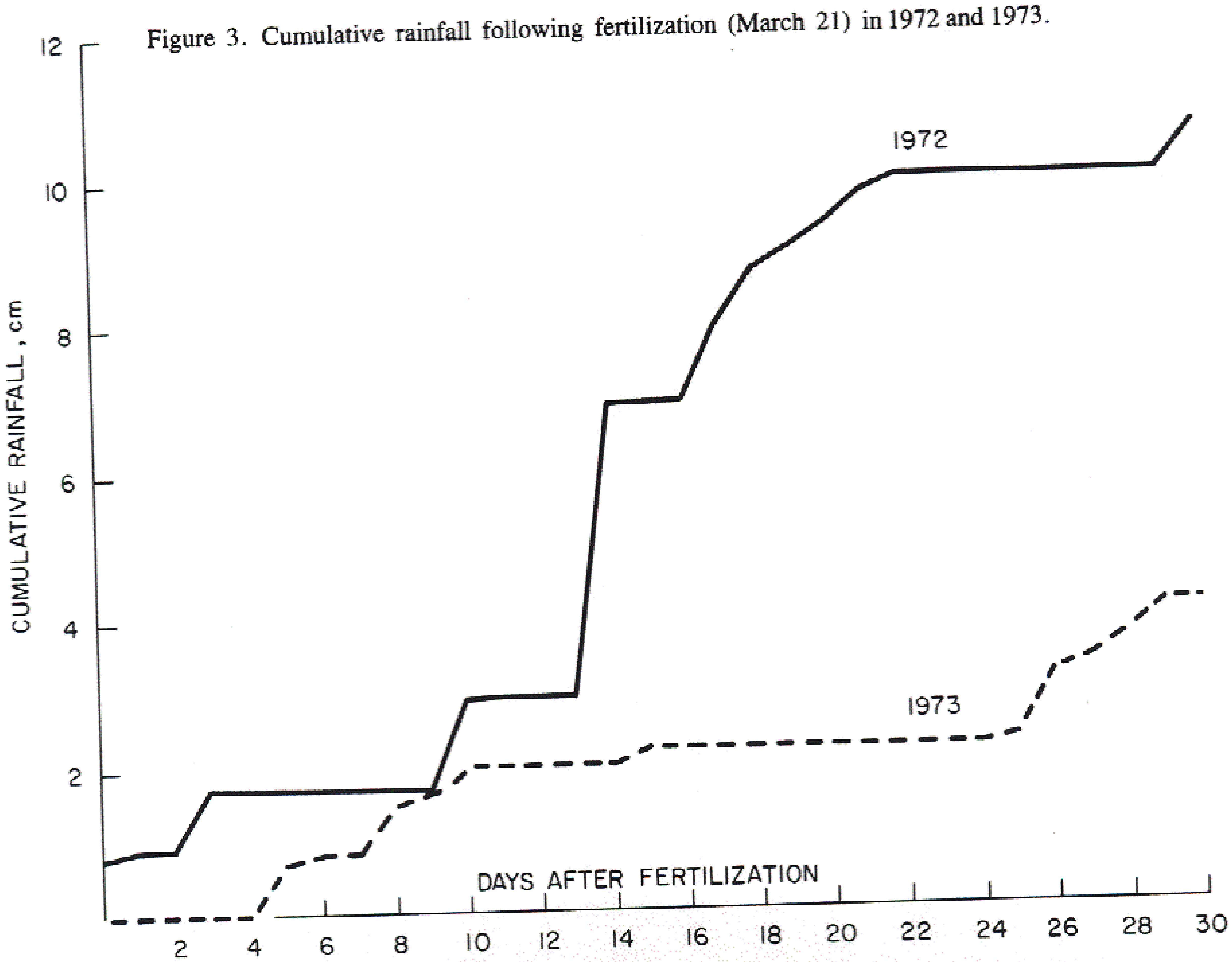
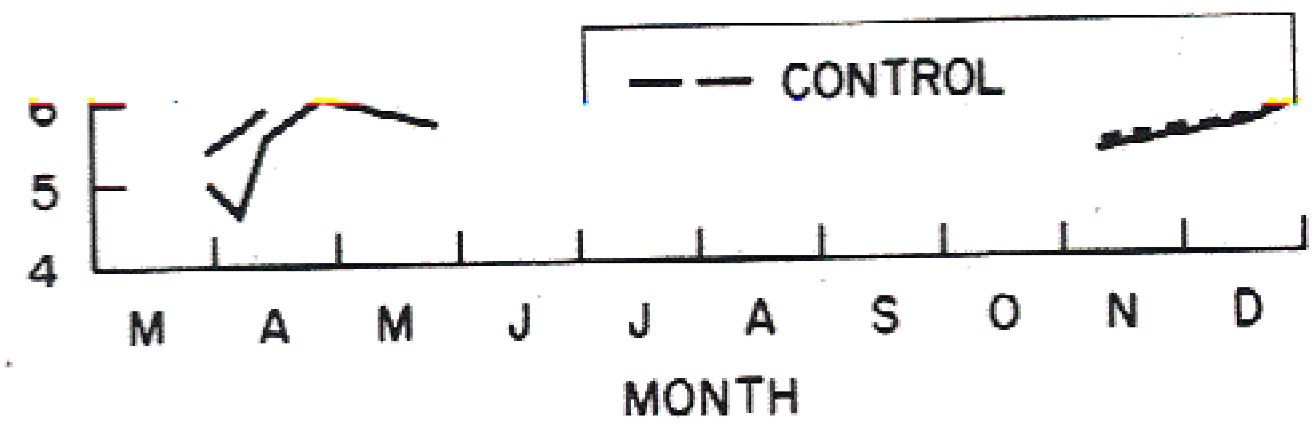


Figure 4. pH of soil solutions collected at 0.6 in. (1.5 cm) depth the first growing season following ammonium nitrate and urea fertilization (March 1972) at 400 lb N/acre (448 kg/ha).



Data in Figure 5 suggest that when ammonium nitrate is applied, nitrate moves rapidly downward to lower horizons. Following the initial increase in nitrate concentration in the surface horizon, resulting from fertilization, the concentration there decreases rapidly in early April. This corresponded to a concentration increase at the 12-in. (30-cm) depth from close to zero to more than 0.064 oz/gal (400 mg/litre). By late May, the concentration had also decreased at the 12-in. (30-cm) depth to 0.025 oz/gal (160 mg/litre). In late fall, the nitrate concentration was low at all depths, and by late January it approached zero.

dry summer months, but by early November the nitrifying microbial populations had converted ammonia to nitrate (Figure 6). High quantities of nitrate had accumulated only in the surface horizon, and by February the concentration approached zero at all depths. The presence of nitrate in the soil solution from the upper horizon in the fall corresponded with the drop in soil solution pH below the control values as noted above.

Figure 5. Nitrate concentrations in soil solutions collected at three depths, the first growing season following ammonium nitrate fertilization (March 1972) at 400 lb N/acre (448 kg/ha).

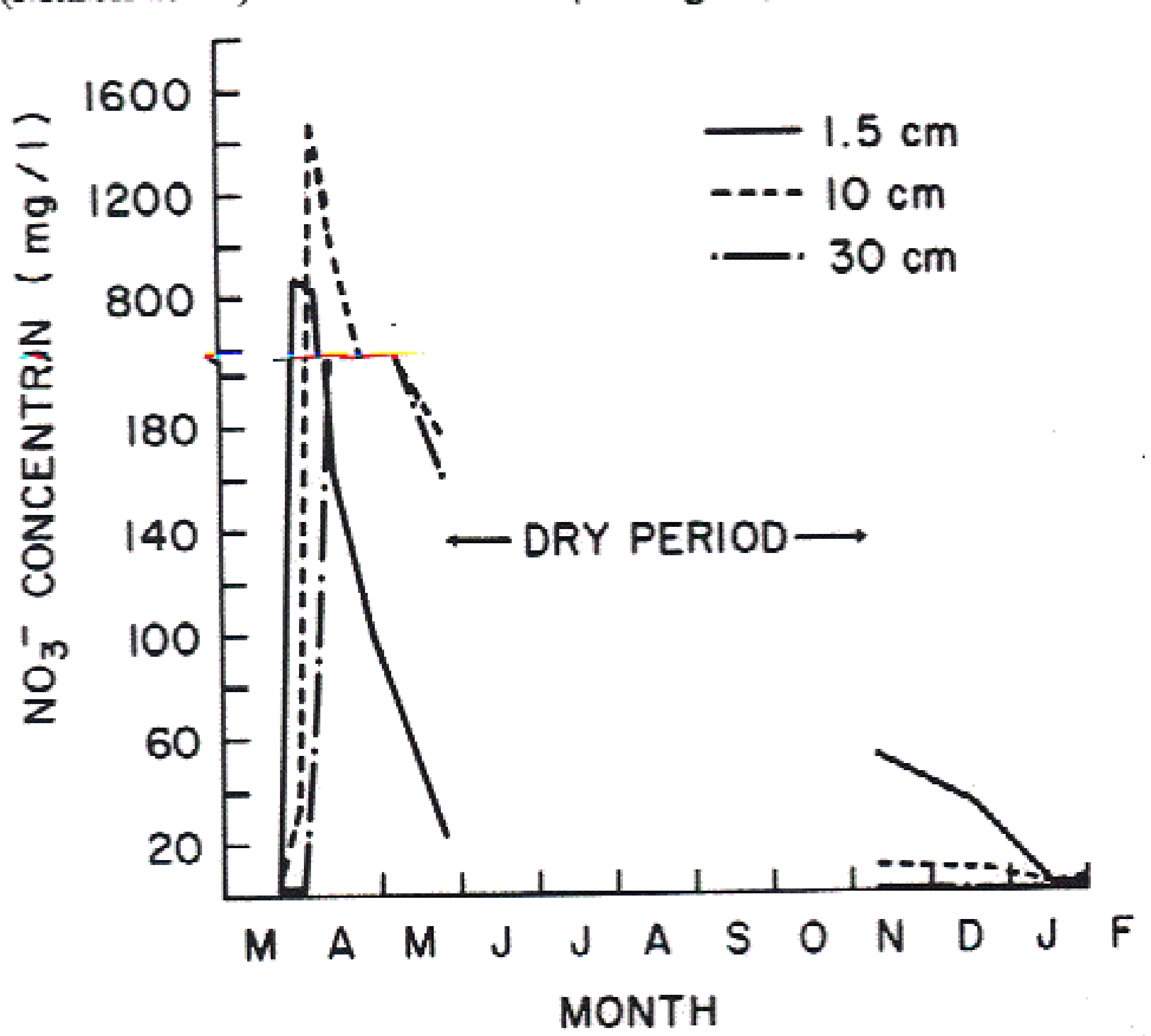
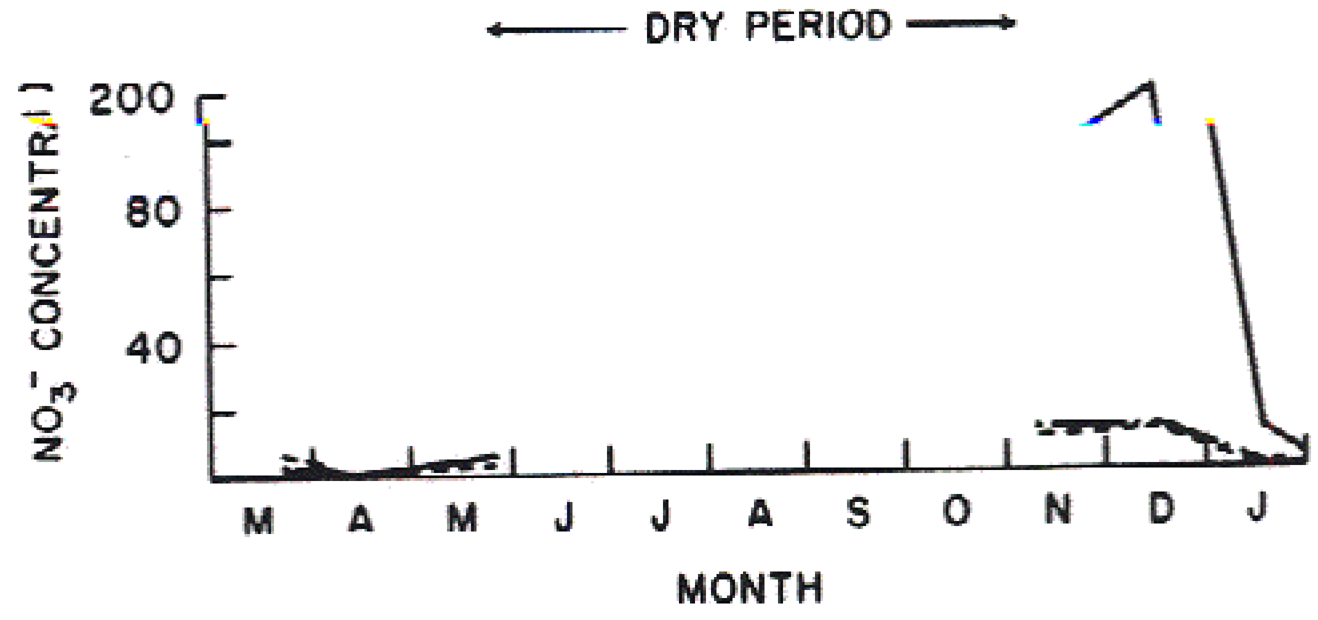


Figure 6. Nitrate concentrations in soil solutions collected at three depths, the first growing season following urea fertilization (March 1972) at 400 lb N/acre (448 kg/ha).



Ammonium Nitrogen

With both forms of fertilizer, little or no ammonium cation was detected below the 4-in. (10-cm) depth. Any movement that does occur is from the organic horizon in the early spring following fertilizer application (Figure 7). The concentrations of ammonium nitrate in the organic horizon are similar for the corded with urea in the second month, presumably as a result of a complete urea hydrolysis. The levels were close to zero at all depths by late November.

SOIL MICROBIOLOGY

The differences produced in soil characteristics by the two N fertilizers have significance to soil biology and are, in turn, affected thereby. The impact of fertilizer source on soil respiration is shown in Table 1. With ammonium nitrate there is an increase in activity, although less drastic than that observed with urea application. Urea, likewise, has more effect on other measures of microbial population characteristics that were

Figure 7. Ammonium concentrations in soil solutions collected at 0.6 in. (1.5 cm) depth, the first growing season following ammonium nitrate and urea fertilization (March 1972) at 400 lb N/acre (448

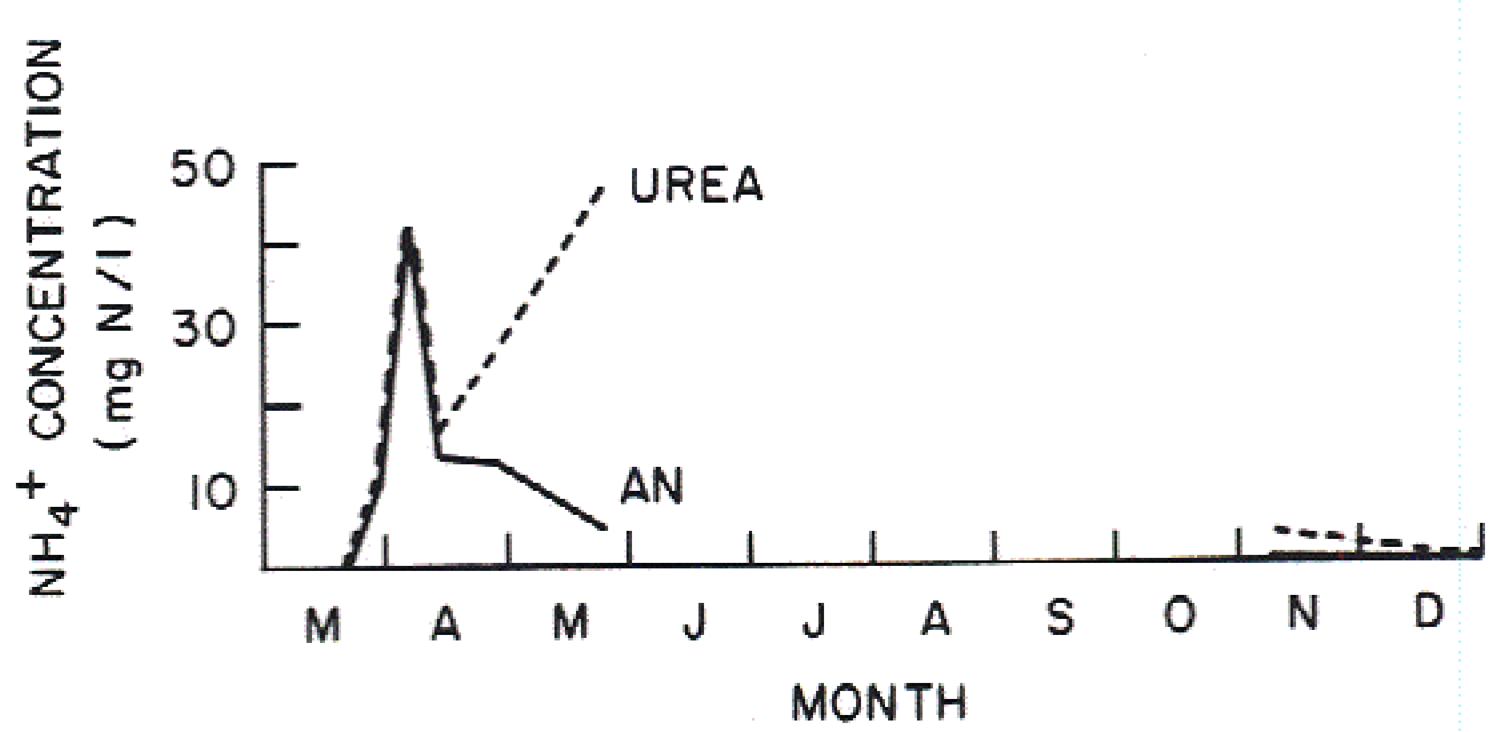


Table 1. Respiration rates (mg $CO_2 \cdot m^{-2} \cdot hr^{-1}$) for surface organic horizon cores collected the first growing season following fertilization with 448 kg/ha in March.

Month of sampling	Control	Urea	Ammonium nitrate
May	120	169	132
July	40	170	68
October	78	124	127

monitored: dehydrogenase levels, population numbers, and their composition (J. Dangerfield, unpubl. data).

With urea fertilization there is a shift in composition of the bacterial populations. One indication of this is the proportionately greater increase in the number of organisms isolated on media at pH 7.0 than on media at pH 5.0 with urea (Figure 8). The increase in population numbers declined over a 30-mo period. Further indication of changes in microbial composition is the recorded initial reduction in numbers of fungi isolated at pH 4.5 and the stimulation of the nitrifying population the first summer following urea application. These differences are not evident with ammonium nitrate. Figure 9 shows that the bacterial population, as exemplified by the proteolytic bacteria, is stimulated to a much greater extent by urea, whereas the fungal population, as exemplified by the cellulolytic fungi, generally tends to respond in a similar manner to the two fertilizer sources (Figure 10).

DISCUSSION

Fertilization with ammonium nitrate resulted in better tree growth than with urea with equal rates of N application in both thinned and unthinned stands. This was related to higher foliar N concentrations for the first 2 yr. Apparently N from the ammonium nitrate source was, initially, more readily available to the trees. Several explanations for this can be interpreted from the changes in soil characteristics and in soil biology.

The lysimeter data indicate a rapid movement of nitrate anion from the ammonium nitrate source down the soil profile, and thus a greater possibility of N uptake by the trees throughout the rooting, which extended to a depth of 18–24 in. (45–60 cm), than with the urea source. The high nitrate anion content appears to have been largely utilized during the first growing season, though it is possible that some had leached below the rooting zone during the rainy fall season or was lost by denitrification or immobilized by soil microflora and fauna. Release of ammonium cation from either fertilizer source did not take place to a degree that led to a significant accumulation, and part of it was nitrified during the summer or fall.

Following a fall fertilization with urea, Otchere-Boateng and Ballard (1978) recorded maximum ammonium cation concentrations shortly after fertilization with values in the first 4

Figure 8. Total numbers of bacteria isolated on media buffered at pH 5.0 and 7.0 at three dates after fertilization with ammonium nitrate and urea at 400 lb N/acre (448 kg/ha).

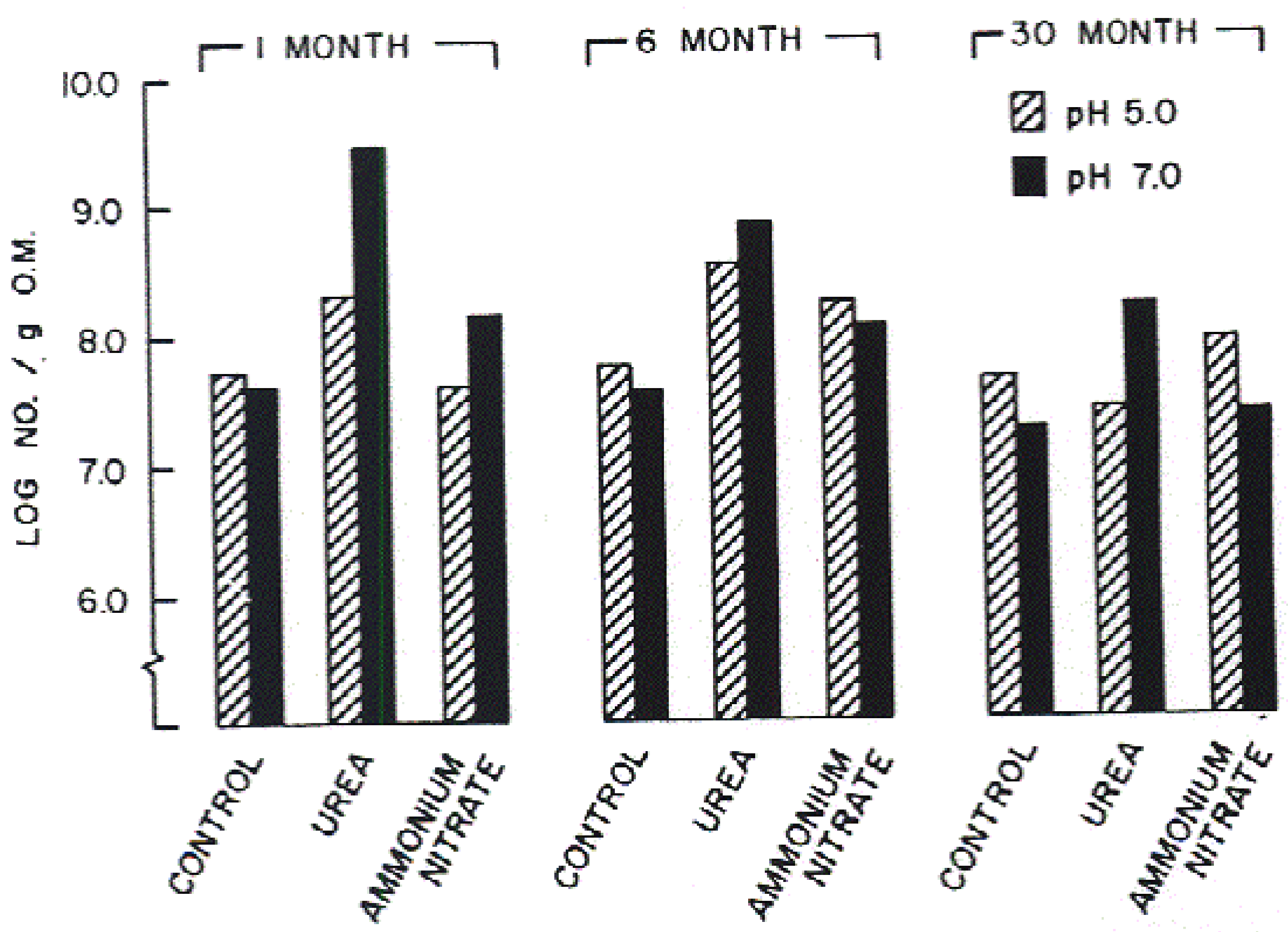


Figure 9. Total numbers of proteolytic bacteria isolated the first growing season after fertilization (March) with ammonium nitrate and urea at 400 lb N/acre (448 kg/ha).

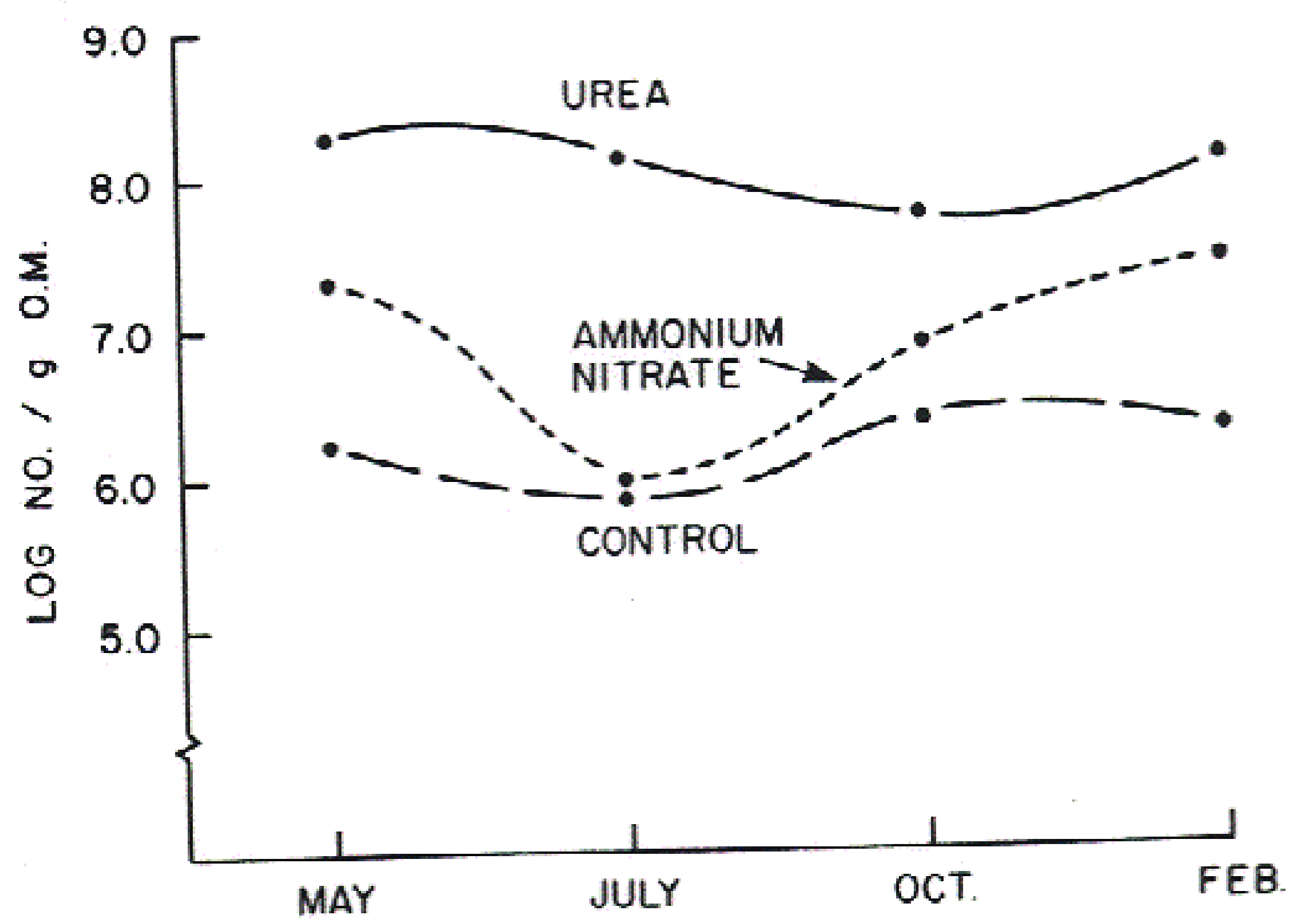
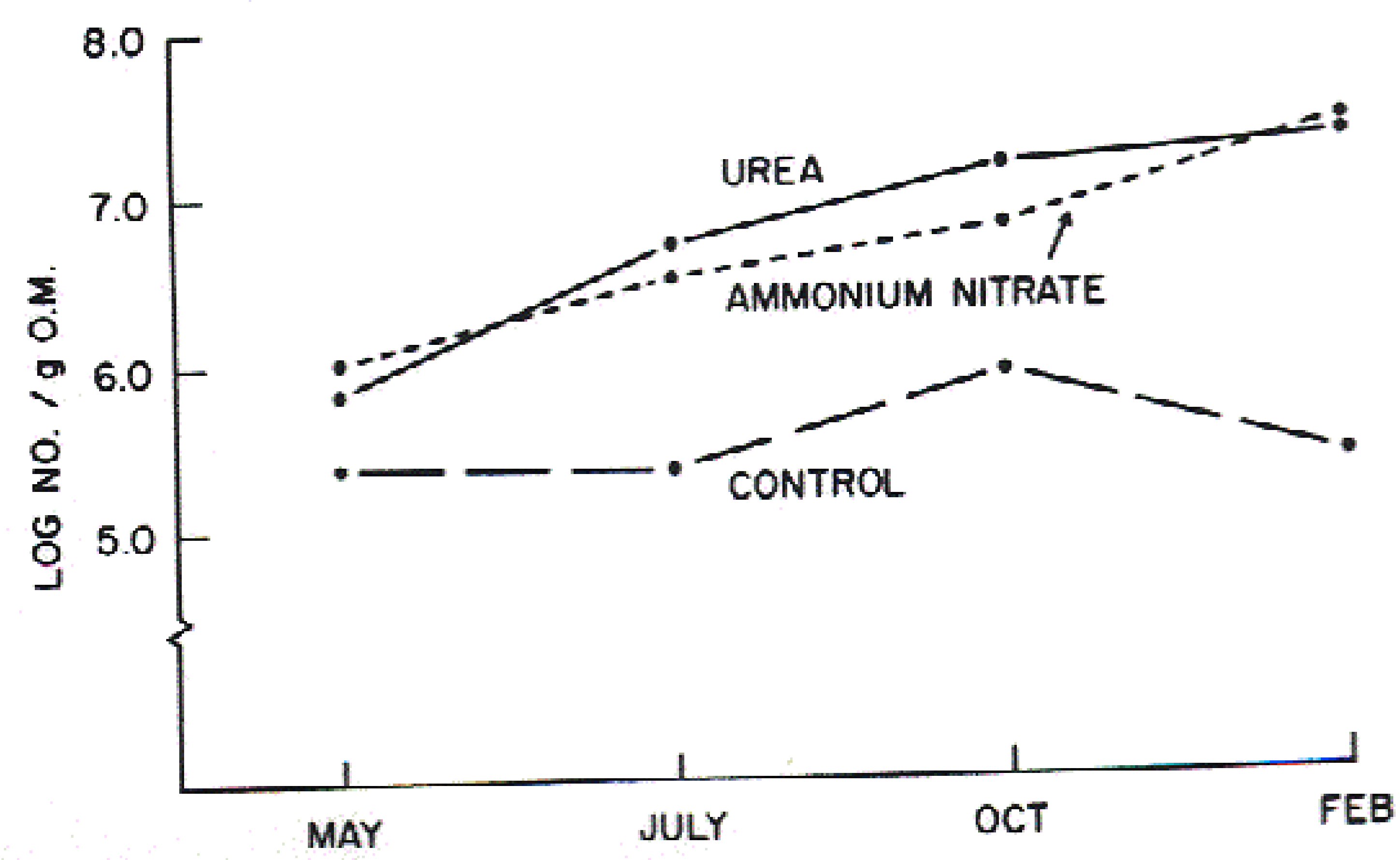


Figure 10. Total numbers of cellulolytic fungi isolated the first growing season after fertilization (March) with ammonium nitrate and urea at 400 lb N/acre (448 kg/ha).



mo ranging from 0.001 to 0.002 oz N/gal (7 to 18 mg/litre) for shallow lysimeters (2–6 in. [5–15 cm]). Generally they did not detect any ammonium cation at greater depths. Nitrate concentrations were low with a maximum of 0.003 oz N/gal (20 mg/litre), 3 mo after fertilization for the shallow lysimeters.

The considerably higher buildup of bacteria populations with urea than with ammonium nitrate could have led to a greater N immobilization with the former source. The buildup is initiated by production of the alkaline pH following urea hydrolysis, which results in a mild alkaline hydrolysis of organic material (Ogner 1972). This organic material contains a high proportion of carbohydrate available for microbial growth. The combined effects of high pH and substrate availability explain the dramatic increase in bacterial numbers following urea fertilization and the shift in composition to a more acid-intolerant bacterial flora. This increase requires substantial quantities of N, which, in the short term, are immobilized for other use. An estimation based on increases in bacterial population numbers (Dangerfield, unpubl. data), a factor of 15-fold for converting plate counts to total counts (Babiuk and Paul 1970), an average bacterial cell volume of 0.2263 μm^3/cell (Babiuk and Paul 1970), a dry weight-to-biovolume ratio of 0.8 g/cm^3 (van Veen and Paul 1979) suggests that 2 mo after fertilization, the bacterial populations have tied up 22 lb/acre (25 kg/ha) more N with urea than with ammonium nitrate fertilization.

Though it was not studied, it is likely that the high soil pH produced following urea fertilization would lead to some losses by ammonia volatilization during the first month (Fenn and Kissel 1973, Matocha 1976). This might especially have been the case in 1973 when the rainfall was low during the first few weeks after fertilization. Later on, however, losses of N would be more likely with ammonium nitrate fertilization through leaching of nitrate anion below the rooting zone and by denitrification of nitrate anion in water-saturated soil, but this was not ascertained.

Apart from causing differences in soil N availability, the two fertilizer sources supply different proportions of ammonium cation and nitrate anion. Initially almost all the N from urea is available as ammonium cation following a rapid urea hydrolysis, whereas ammonium nitrate provides a more balanced supply of the two ions. The form of N supplied may affect the uptake of N as well as of other elements, tree metabolism, and growth (Durzan and Steward 1967, Ebell and McMullan 1970, Kirkby and Hughes 1970, van den Driessche 1978). Though many conifers grow best with ammonium cation as the sole source, some, such as white spruce, use nitrate to advantage (Durzan and Steward 1967); others, such as Douglas-fir, appear to favor a balance of the two forms over a fairly wide range of soil pH (van den Driessche 1978).

Obviously, more field trials comparing N sources are needed and warranted on different site conditions in the Pacific Northwest and with different seasons of application before we can fully evaluate their relative merits. This and other studies indicate, however, that use of ammonium nitrate would be undesirable under conditions where heavy leaching losses can be expected and on heavy wet soils where a high potential for denitrification of nitrate anion exists (Hauck 1968). Movement of nitrate anion was very rapid in our situation, though the rainfall following fertilization in late March was moderate.

Severe nitrate anion losses would therefore be expected with a fall application followed by heavy rainfall, especially considering low nutrient uptake by the vegetation in the winter. Urea would normally not be subjected to leaching losses since its hydrolysis to the less mobile ammonium cation is usually rapid and nitrification thereof to nitrate anion is slow. Periods of dry weather following urea application, such as expected in certain seasons, would be critical for ammonia volatilization losses.

LITERATURE CITED

Babiuk, L. A., and E. A. Paul.
1970. The use of fluorescein isothiocyanate in the determination of the bacterial biomass of grassland soil. Can. J. Microbiol. 16:57–62.

Brix, H.
1971. Effects of nitrogen fertilization on photosynthesis and respiration in Douglas-fir. For. Science 17:407–414.

Cole, D. W., S. P. Gessel, and E. E. Held.
1961. Tension lysimeter studies of ion and moisture movement in glacial till and coral atoll soils. Soil Sci. Soc. Am. Proc. 25:321–325.

Crown, M., and C. P. Brett.
1975. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: An established report. Can. For. Serv. Rep. BC-X-110. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

Crown, M., R. V. Quenet, and C. Layton.
1977. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: 2. 3-year growth response. Can. For. Serv. Rep. BC-X-152. Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

Crossin, E. C., J. A. Marlow, and G. L. Ainscough.
1966. A progress report on forest nutrition studies on Vancouver Island For. Chron. 42:265–284.

Durzan, D. J., and F. C. Steward.
1967. The nitrogen metabolism of *Picea glauca* (Moench) Voss and *Pinus banksiana* Lamb. as influenced by mineral nutrition. Can. J. Bot. 45:695–710.

Ebell, L. F., and E. E. McMullan.
1970. Nitrogenous substances associated with differential cone production responses of Douglas-fir to ammonium and nitrate fertilization. Can. J. Bot. 48:2169–2177.

Fenn, L. B., and D. E. Kissel.
1973. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: I. General theory. Soil Sci. Soc. Am. Proc. 37:855–859.

Gessel, S. P.
1968. Progress and needs in tree nutrition research in the Northwest. *IN* Forest fertilization—Theory and practice. G. W. Bengtson, ed. p. 216–225. Tennessee Valley Authority, Muscle Shoals, Ala.

Hauck, R. D.
1968. Nitrogen source requirements in different soil-plant systems. *IN* Forest fertilization—Theory and practice. G. W. Bengtson, ed. p. 47–57. Tennessee Valley Authority, Muscle Shoals, Ala.
Holmen, H.
1977. Skogsgödsling i Sverige 1976. K. Skogs-och Lantbruksakad. Tidskr. 1977:6.
Kirkby, E. A., and A. D. Hughes.
1970. Some aspects of ammonium and nitrate nutrition in plant metabolism. *IN* Nitrogen nutrition of the plant. E. A. Kirkby, ed. p. 69–77. (Univ. Leeds Agricultural Chemistry Symposium.) The Waverley Press, Leeds.
Krajina, V. J.
1969. Ecology of forest trees in British Columbia. Ecol. West. North Am. 2:1–146. (Dept. Botany, Univ. B.C., Vancouver.)
Malm, D., and G. Möller.
1975. Skillnader i volymtillväxtökning efter gödsling med urea resp ammoniumnitrat. p. 46–63. Föreningen Skogsträdsförädling. Institutet för Skogsföfbättring. 1974 årsbok.
Matocha, J. E.
1976. Ammonia volatilization and nitrogen utilization from sulfur-coated urea and conventional nitrogen fertilizers. Soil Sci. Soc. Am. J. 40:597–601.
Miller, R. E., and R. D. Fight.
1979. Fertilizing Douglas-fir forests. USDA For. Serv. Gen. Tech. Rep. PNW-83. 29 p. USDA Forest Service, Portland, Oreg.
Nömmik, H.
1977. Delproblem med behov av intensifierade forskningsinsatser. K. Skogs- och Lantbruksakad. Tidskr. Suppl. 11. Stockholm.
Ogner, G.
1972. Leaching of organic matter from a forest soil after fertilization with urea. Medd. Nor. Skogforsöksves. 30:425–440.
Otchere-Boateng, J., and T. M. Ballard.
1978. Urea fertilizer effects on dissolved nutrient concentrations in some forest soils. Soil Sci. Soc. Am. J. 42:503–508.
van den Driessche, R.
1978. Response of Douglas-fir seedlings to nitrate and ammonium nitrogen sources at different levels of pH and iron supply. Plant Soil 49:607–623.
van Veen, J. A., and E. A. Paul.
1979. Conversion of biovolume measurements of soil organisms, grown under various moisture tensions, to biomass and their nutrient content. Appl. Environ. Microbiol. 37:686–692.