

SEASON FOR APPLICATION OF UREA FERTILIZER TO PACIFIC NORTHWEST FORESTS

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ABSTRACT

Urea is most effective if it is quickly incorporated into the soil. With forests, this requires adequate rainfall soon after application. Consequently the best time for application of urea in the Pacific Northwest is in late fall and winter. Because of contrasting rainfall patterns and soils, more specific guidelines for various regions within the Pacific Northwest are proposed. In addition, Pacific Northwest studies on season of urea application and effects of rainfall are reviewed.

INTRODUCTION

In the early forest fertilization experiments conducted by University of Washington, applications were usually made from April to June with some treatments as late as July and August (Gessel et al. 1969). Ammonium sulfate and ammonium nitrate were the most common forms of N in these trials and high response to treatment was usual. Urea was also used in a few of those early trials and was generally equally effective. In those days, demonstration of response and its evaluation were of primary interest with effect of season, soil moisture status, weather following treatment, and other factors including comparison of N materials of less concern. Even today, almost 30 yr after the initial fertilizer experiments by Gessel, we have results from only a few, replicated, Pacific Northwest (PNW) trials in which season of application was evaluated, but most research with urea indicates that it must be moved into the soil with rainfall or other means for it to be most effective.

Research by Cole and Gessel (1965) showed that even on very coarse, gravelly soils, leaching losses from urea applied to Douglas-fir were minimal. Increased volatilization of ammonia with increase in soil temperature has been confirmed in PNW forest soils under laboratory conditions by DeBell and co-workers (in a 1979 draft report submitted to the Office of Research and Development, U.S. Environmental Protective Agency). For these reasons and to assure best chance for adequate rainfall to occur shortly after urea application, late fall and winter are recommended times for application of urea to the forests of the Pacific Northwest.

Information is given here on the relation of season and weather following application to effectiveness of urea. Area-specific guidelines are proposed for application of urea in recognition of the wide variation in soils and climatic conditions within the Pacific Northwest.

EFFECT OF SEASON ON DOUGLAS-FIR RESPONSE

Information from only three replicated trials wherein season of application was investigated is available for our evaluation. The first was conducted by Steinbrenner on Weyerhaeuser Company forests beginning in the fall of 1967. The purpose of this unpublished trial was to explore feasibility of fall applications of urea since, until then, virtually all trials with urea involved spring applications. Trees on the six trial sites varied in age from 10 to 18 yr at breast height and site index (50 yr) varied from 90 to 140 ft. Fertilizer for fall treatment was applied in October and for spring treatment in March.

An indication of the general rainfall patterns following treatment can be obtained from rainfall data from Centralia, Wash. Rainfall for October, November, and December 1967 at Centralia was 2.2, 0.5, and 0.6 times normal, respectively. Time of application at individual sites is not designated, but the quantity of rain following treatment may have differed among areas depending upon the data in October when the application was made. For March, April, and May, rainfall at Centralia was 1.2, 1.2, and 1.3 times normal.

Again, differences in rainfall after fertilizer application may have been present but, in general, rainfall appears to have been favorable for both the fall and spring applications. More consideration should be given in future experiments to determination of rainfall following application at sites near the fertilizer trials.

Results after 4 yr showed relatively minor response on two sites, about equal response to October and March treatments on two sites, and superior response to the October treatment on two sites. On the average, a significant increase in volume growth was obtained on the fertilized plots but, although the

fall-fertilized plots produced greater volume growth response, the difference between spring and fall treatments was not significant. Comparison of volume growth percentages (mean periodic annual increment divided by mean initial volume) on treated versus control plots indicated an average growth response on fall-treated plots of 20% and on spring-treated plots of 13%.

The second replicated experiment was established near Victoria, B.C., in 1968 by Lee (1974). Fertilizer was applied on 14 September 1968 and 15 April 1969. Four fertilizer rates were employed with and without thinning in a randomized block experiment with two replications. The stand was predominantly 25-yr-old Douglas-fir with an average site index (100 yr) of 110 ft. Rainfall after both treatment dates was favorable with 1.4 in. in 4 days after the September treatment and 1.9 in. in the 4 days following the April application.

Results after the first year showed the September treatment gave 42% better basal area response than the April treatment, a difference significant at the 1% level. At the end of 4 yr, there was still a significant difference between treatment dates (at the 5% level), but the September application averaged only 10% more basal area response than the April treatment. The basal area response to 200 lb N/acre in this trial over the 4-yr period averaged about 33% for both thinned and unthinned plots. Thus, although the 10% difference between September and April was statistically significant, from a practical viewpoint 10% of a 33% response is a minor difference. In this experiment, where rainfall after both treatments was favorable, a good response was obtained to both mid-September and mid-April applications of urea.

Another experiment (results unpublished) was initiated in 1972 by R. Miller, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Olympia, Washington. Application of fertilizer in April was compared with application in August. The experiment was in Douglas-fir approximately 60 yr old. Site index (100 yr) varied between 102 and 168 ft on the seven replications or areas in the study. Thus a wide range in site index was present. Some of the replications were in thinned stands. Within 5 days of the April application 2 in. of rain was recorded. In contrast, no rain fell for 10 days following the August application and then about 0.75 in. of precipitation occurred within 3 days.

Growth response after 5 yr was evaluated by comparison of growth rates on plots before treatment with growth rates obtained following treatment. Of the seven areas or replications, one showed insignificant response to fertilizer, two showed response to the April application to be higher, and on two areas the April application was better. Results on one of the areas were inconclusive since the data were incomplete. For the entire experiment, volume growth response averaged 11% and 8% for the April and August applications, respectively.

RESULTS OF OPERATIONAL APPLICATIONS

Some unsatisfactory results have been observed from several operational applications of urea that were not soon followed by sufficient rainfall. Under such circumstances, burning of foliage by volatilized ammonia and insignificant growth response of the trees have occurred. Examples are known from both early fall and spring applications.

In an operational fertilization in mid-September 1972, the Washington State Department of Natural Resources applied urea to Douglas-fir forests on the Tahuya Peninsula of Washington (Anderson, pers. commun.). Although appreciable rainfall had occurred in August of that year, September was a dry month and weather following treatment was both dry and warm. Within a few days after the application, foliage on both salal and the trees began to exhibit evidence of burning, presumably from volatilized ammonia. Following this observation, the fertilizer operation was discontinued until onset of wet weather. Unfortunately, no growth response data were available from this area.

Two examples of poor results from operational applications made during the spring are available. The first is from Whidbey Island where the application was made in April. Whidbey Island lies within the rain shadow of the Olympic Mountains and very little rain fell on the fertilized areas after fertilizer was applied. Growth response was evaluated 3 yr later using increment cores from trees on the three treated areas. This investigation showed response to fertilizer on only one of the tree areas (Heilman, unpubl. data).

The first operational applications of urea by Crown Zellerbach were made in spring 1965 at Mollala, Oreg., near a previously established replicated trial where growth response over 7 yr was as high as 70% for individual Douglas-fir trees (Strand, unpubl. data). That fertilizer trial was initiated in 1963, a normal rainfall year, with abundant rainfall occurring following the March application. In contrast, rainfall in 1965 was much below average with below normal rainfall beginning in February. Operational applications of 200 lb N/acre as urea were made from mid-April through mid-May on 1500 acres of Douglas-fir stands. Four sets of paired plots (control and fertilized) at three locations failed to show any growth response trends.

Similar results were obtained from a replicated trial established in April of the same year (1965) in a nearby location. Following treatment, salal on the lower site quality installation exhibited foliage burning. No growth response was detected from the 200 lb N/acre treatment, whereas at 400 lb N/acre a modest response was obtained. Salal was not present at the other, somewhat higher site quality location, but only modest growth response was observed there also.

The reasons for the low response to the mid-April through mid-May 1965 applications are not readily apparent from the rainfall data for those particular months, since 3.0 and 2.3 in.,

respectively, were recorded for those months. Very likely the warm, dry weather of that spring resulted in a soil moisture and temperature condition that is ordinarily not attained until late May or early June. Also, uptake and utilization of the N by the trees may have been affected by the very low rainfall occurring in June (0.7 in.) and July (0.5 in.).

FIELD STUDY OF SOIL N LEVELS AND UPTAKE

In 1977 a study was established on 7- and 9-yr-old planted Douglas-fir on Weyerhaeuser Company lands (Heilman, Cheng, and Webster, unpubl. data). One purpose of the study was to compare the effects of fall and spring applications of urea on soil N levels and rates and magnitudes of N uptake by the trees. Urea tagged with the isotope ^{15}N was used to permit tracing of the applied fertilizer. Urea was applied at the rate of 200 lb N/acre to trees on two sites, one on an Palix series (Pluvius site) and one on the Bunker series soil (Lucas Creek site). The fall application was made on 28 November and was followed immediately by a period of very heavy rainfall. Spring application was made on 24 April and was followed at Lucas by over 0.5 in. of rain within 3 days after treatment and then another 2–3 in. between the 16th and 21st days after fertilization. Thus rainfall after the fall application was very favorable for moving urea into the soil, whereas after the April application it was less favorable.

Results of soil analysis at the Lucas site are presented in Figure 1. The difference between the fall and spring applications in concentration of available N with depth can be seen clearly in this figure. Concentrations at the surface (0–3 in. depth) are lower whereas at a greater depth (3–6 in.) they are higher after the fall treatment, as compared with the spring application.

Maximum levels of available N appear to be reached between 9 and 21 days after fertilizer is applied. These levels

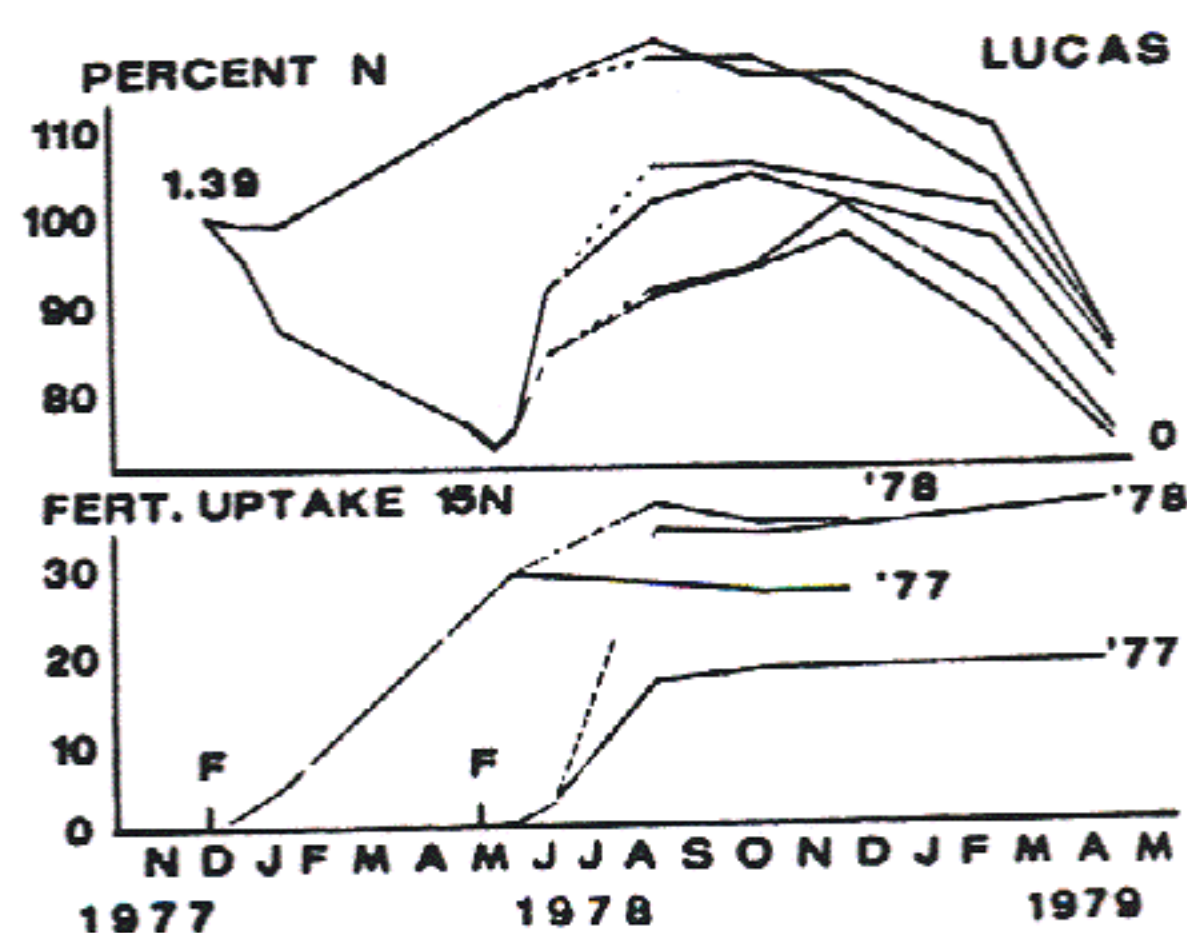
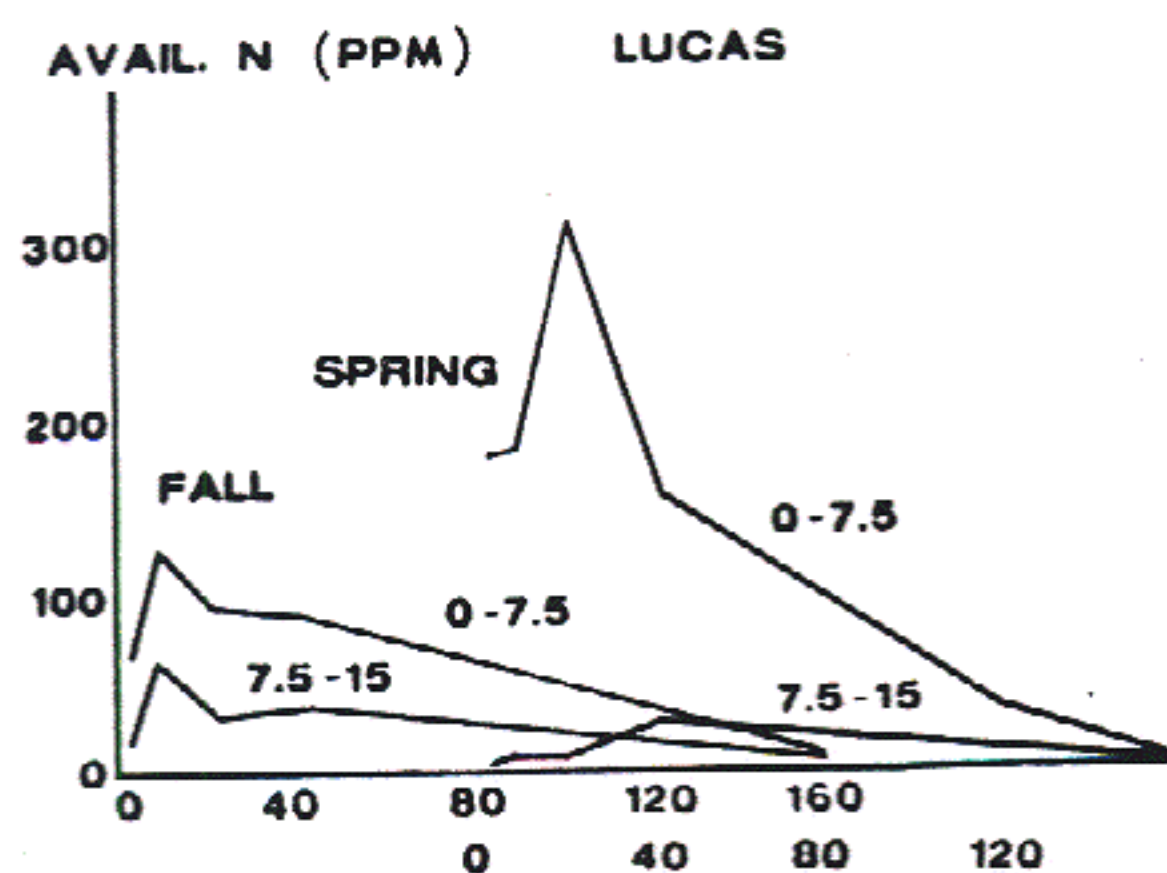
declined fairly rapidly until by the end of 6 mo the levels of available N were only slightly higher than those of the controls. Considerable "priming effect" was apparent since about 30% of the total available N at 21 and 42 days was derived from the soil organic matter. This percentage increased until by 6 mo most of the available N present on the fertilized soil appeared to be derived from soil organic matter. Thus it is apparent that increased mineralization of organic matter and increased release of available N from that organic matter are a significant response to urea fertilizer.

Although little nitrification was initially observed at the Lucas site, considerable nitrate was formed at the Pluvius site beginning as early as 3 days after application of urea. Nitrate did not make up a significant portion of the total available N until about 6 wk after the application, however, when almost 50% of the total available N in the soil was in the form of nitrate. Although high nitrification was not observed earlier in a different study with another Astoria soil (Heilman 1974), coastal soils in that study generally showed high capacity to nitrify urea under incubation.

Comparison of effects of fall and spring applications on N contents of foliage are shown in Figure 2. Relative concentrations were calculated in order to permit these comparisons. For this purpose, mean concentrations in 1977 foliage collected at the end of November 1977 for the control and fall treatments were arbitrarily assigned a relative concentration of 100%.

Figure 2. *Top.* Relative concentrations of N in foliage for control (lower pair of curves), fall fertilization (upper pair of curves), and spring fertilization (middle pair of curves). The partly dashed lines designate 1978 foliage values sampled beginning in August 1978 and the solid lines are 1977 foliage values. Control values and fall fertilization values are relative to the November value for control of 1.39% N. Spring fertilization values are relative to control values starting in April 1978. *Bottom.* Pattern of uptake of urea for fall and spring treatments. Values in 1978 foliage designated by the partly dashed lines and in the 1977 foliage by the solid lines. Uptake is presented as a percentage of total N in the foliage samples attributed to the ^{15}N -labeled urea.

Figure 1. Pattern of available N levels in soils with time (days) at two soil depths after fall and spring applications (average of four replications for each depth and time).



Nitrogen concentration in foliage from control trees declined markedly after November 1977, reaching a low point in early May 1978 and then increasing again until November 1978 to levels almost as high as the previous November. After November 1978 N values again declined through the winter of 1979. The levels in 1978 foliage are shown beginning with the August 1978 sampling. Similar concentrations and seasonal patterns were observed for both ages of foliage.

Higher levels of N were obtained from the fall application. The greatest difference in foliar N concentration between the fall and spring treatments occurred during the winter months preceding the spring application. Even after the spring treatment, however, N concentration in foliage of fall-treated trees was higher than in the spring-treated trees. Nevertheless, by April 1979 little difference in foliage N levels existed between fall and spring treatments, although levels for both fertilizer treatments were higher than the control levels. A longer period of monitoring the foliage levels of N is required and final evaluation of the effect of season must await the determination of the effects of season of treatment on tree growth. Nevertheless this experiment does illustrate significant early differences between spring and fall treatments in both soil and foliar levels of N.

LABORATORY STUDIES

Ammonia losses from surface applied urea were investigated in laboratory studies by Watkins et al. (1972) and DeBell and co-workers (1979). Ammonia losses from urea with no subsequent rain were twice as high from moist forest floors over moist soils as from moist but bare soils (Watkins et al. 1972). DeBell and co-workers showed that losses of ammonia increased as soil temperature increased, but even at 7°C when rainfall was delayed for 4 days, 21% N was lost as ammonia from one soil after 11 wk of simulated rain at the rate of 0.12 in. every 2 days. In comparison, the same soil lost 14% of the applied N as ammonia when rainfall was delayed 4 days but was followed by 11 wk of simulated rain at the rate of 0.5 in. every 2 days. At 21°C the ammonia loss increased to 42% of the applied N at the lower rate of rainfall.

While volatilization losses of ammonia are appreciable, part of the ammonia is probably absorbed by foliage and other plant tissues and thus can be utilized directly by the trees or indirectly as an addition to the N pool on the site. Consequently, volatilization of ammonia alone does not appear to account for the reduced growth response observed when dry weather follows urea application. Additional factors may be involved in reducing response to urea when rainfall is inadequate. Applied N is less available to roots when it is concentrated in the forest floor or at the soil surface. Also, because of poor distribution of urea in the soil, the priming effect referred to earlier may be greatly reduced. A high concentration of ammonia in the upper

soil may be damaging to roots and mycorrhizae of trees such as western hemlock, with high root concentrations in upper soil layers (Lavender, this volume).

Not only is volatilization of ammonia higher from a forest floor than from bare soil (Watkins et al. 1972) but urea can be immobilized in forest floor layers. According to research by Salenius and Mahendrappa (1979), immobilization of urea in forest floor material is increased with increasing soil temperatures. Thus utilization of urea by trees is perhaps further reduced by warm dry weather after application on soils with substantial forest floor accumulation.

Absence of rainfall after application of urea was shown by Marshall and DeBell (pers. commun. 1979) to increase unaccounted losses of N. These unaccounted losses, presumably primarily as dinitrogen and nitrous oxide were about 20% of the applied N without rain versus 14% with 0.5 in. of simulated rain occurring 4 days after application. Similar loss of like magnitude from urea application has been noted by Overin (1972) and others (Hauck, pers. commun. 1979).

Under certain circumstances, excess moisture following application of urea is also of concern. Until urea is hydrolyzed, it can be moved readily with runoff water. Consequently, because of the potential for runoff during rapid thaw, it is unwise to apply urea to snow deeper than about 1 ft, especially over frozen ground. Similar losses might also occur on soil with inherently restricted permeability during high rainfall or snowmelt periods. Also, excess moisture resulting in waterlogged soils is likely to lead to denitrification losses from those soils where significant nitrification of urea occurs.

GUIDELINES FOR SEASON OF UREA APPLICATION

In view of the apparent wide differences in soils from the Pacific Northwest with respect to nitrification capacity and also because of the importance of low soil temperature and adequate rainfall following urea application, new guidelines for best season of urea application are proposed for Washington State (Table 1). Corresponding modifications for Oregon and British Columbia should be considered. The geographical groupings are based upon both soil and rainfall differences. Evaluation of rainfall was done on the basis of the probability by month of occurrence of rainfall with an intensity of 0.5 in. or more in 24 hr. This provides an index of both rainfall frequency and intensity—the factors of rainfall that are most important for determining the movement of urea into the soil. The rate of 0.5 in. in 24 hr was selected based upon the work by Marshall and DeBell (pers. commun. 1979), who showed that this quantity of rain applied on the fourth day after fertilizer application reduced ammonia volatilization by about one-half, from 15.8% to 7.4% of the applied N. Total gaseous losses of N including ammonia were reduced from 35.3% with no rain to 21.5% with 0.5 in. of rain.

Table 1. Mean number of days with 0.5 in. precipitation or more.^a

Area of Washington	Month									
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Coastal	3	8	9	11	11	8	7	5	3	2
Puget Lowlands	1	3	4	6	5	3	3	2	1	1
West Cascades	2	4	6	7	7	4	4	3	2	2
Rain Shadow	1	1	2	2	2	1	1			
East Cascades	1	3	4	5	6	3	3	1	1	

^aRecommended times for urea application are designated by brackets.

Other factors considered in the proposed guidelines were capacity of the soils for nitrification (and subsequent denitrification) and occurrence of frozen soil and snow-cover periods. Guidelines for specific areas are discussed below, and are based upon average rainfall years. Modifications should be considered for abnormally dry or wet seasons. Delays in application are appropriate during dry and warm autumns. Based on the experience by Crown Zellerbach in the spring of 1965, cancellations may be advisable for abnormally dry and warm springs. Conversely, wet and cool fall or spring seasons can increase the time suitable for urea application.

COASTAL AREA

Because of apparently relatively high capacity for nitrification of urea in coastal soils and the high rainfall that occurs in this area, particularly in December and January, we feel that a delay in the application of urea is advisable to assure that minimal nitrate is produced. Also because of the high probability for considerable rainfall in April and May in this area and the generally cool soil temperatures, the period of application can probably be extended in most years until at least mid-April or later.

PUGET SOUND LOWLANDS

These soils do not generally exhibit strong capacity for nitrification of urea fertilizer and therefore the probability of rainfall is the primary concern. The end of October through the first of March appears to be a desirable average period for urea application in this area.

WEST CASCADES

This region is characterized by relatively heavy rainfall and low nitrification capability. A wide period is therefore suggested for urea application, ranging from mid-October to the first of April.

RAIN SHADOW AREA OF NORTHERN PUGET SOUND

This is a low rainfall area characterized also by low-intensity rains. Relatively few days occur in this area with over 0.5 in. of rainfall. Poor results from operational fertilization cited previously on Whidbey Island may be related in part to the low rainfall in this area.

Soils in this area often have a surface accumulation of forest floor material and thus heavy rainfall following application may be more important than for other areas. Even though a limited period of the 2 mo of November and December is proposed for applying urea in this area, the low rainfall dictates that care should be taken to apply urea when rainy periods are expected.

EAST OF CASCADES

East of the mountains the factors of soil temperature and snow cover must be considered. Thus, in order to avoid application of urea to either frozen ground or snow deeper than about 1 ft, the months of October and November are suggested for urea applications.

Because of the inconvenience and difficulty in limiting applications to 2 mo as proposed for both the Rain Shadow and East Cascade areas, renewed attention needs to be given to use on those areas of other forms of N fertilizer such as ammonium sulfate or ammonium nitrate. Early research information indicated those forms to be as effective as urea for Douglas-fir. Some workers have obtained better growth response from these fertilizers than from urea (Dangerfield, this volume). The materials can be used over a wider season than urea and thus may provide opportunity for more flexible and perhaps more successful applications of N to the forests of the Rain Shadow area and on the east side of the Cascade Mountains.

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