forest management note

Note No. 40 **Northern Forestry Centre** **Edmonton, Alberta**

REVIEW OF LITERATURE ON FERTILIZATION AND CONIFER SEED PRODUCTION

There is an annual requirement for approximately 4.0 billion conifer seeds in Canada, and by 1987 over 7.3 billion seeds will be required annually to fulfill regeneration needs (Morgenstern 1979). There is already a significant shortfall in the amount of suitably regenerated forest land. Between 1975 and 1980 the average annual area of forest harvested was 760 000 ha, 22% of which was regenerated artificially (17% by planting and 5% by direct seeding). Natural regeneration was estimated to occupy 30% of the total area, and the proportion of unstocked cutover was 48% (Brace and Golec 1982). Although 85% of directly seeded forest occurs in Alberta and Ontario, direct seeding is expected to increase nationwide as long as sufficient seed is available. It is estimated that by 1987, artificial regeneration will increase by 74%; 55% of all seed will come from seed production areas, 42% from general collections within seed zones, and 3% from seed orchards. A valuable seed export business (0.6 billion seeds annually) has also developed in British Columbia and Yukon Territory. Whether for domestic use or for export, seed production in Canada will be very important in the future.

This Note reviews literature on the role and effectiveness of fertilizers in conifer seed production, discusses the effect of physiological and environmental factors, and lists possible research needs. Scientific terms used in the text are defined in Appendix 1.

ROLE OF FERTILIZERS

Seed production is influenced by physiological (internal) and environmental (external) factors. Physiological factors relate to the activity of hormones (auxins and gibberellins) and to the synthesis and translocation of biochemical constituents within the plant. Environmental factors include temperature, precipitation, light intensity and photoperiod, spacing, root pruning, stem girdling, and fertilization. Fertilization is the most easily manipulated factor on an operational scale. Improved flower and seed production have been obtained in many conifers by applying fertilizers alone (Table 1) or in combination with other treatments such as thinning and irrigation. In past studies, most treatment sites were seed production areas; relatively few were seed orchards. Nitrogen (N) was the only nutrient applied in many studies, but mixed fertilizers were used in others. Only in a few cases were the designs of the experiments suited to identify conclusively other elements, such as phosphorus (P) and potassium (K), as being essential to seed production. Potassium, in particular, increased seed weight in jack pine (*Pinus banksiana* Lamb.) and prolonged the beneficial effect of N on cone production in black spruce (*Picea mariana* (Mill.) B.S.P.). It was concluded that N primarily increases crown size.

EFFECTIVENESS OF FERTILIZERS

The effectiveness of fertilizers depends on various factors, including the time, rate, and frequency of application and the form of N that is applied, which differs with the N assimilation characteristics of each tree species. Because of the variety of factors involved, the results of fertilizer experiments in seed production are often confounded. Nitrogen fertilization increases arginine concentration in reproductive buds, and it was thought that this biochemical constituent was a necessary precursor to flowering and seed production. Although

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Table 1. Summary of studies on use of fertilizers to increase cone and seed production

Species[a]	Stand description	Location	Soil description	Treatment
Balsam fir	Age: 60 yr Ht: 13 m Dbh: 11 cm	Gaspé Park, Quebec	—[b]	46-0-0 0-45-0 0-0-62
Black spruce	Age: 69 yr	Northern Ontario	—	46-0-0
Douglas-fir	Age: 20 yr Ht: 15 m	Southwest Washington	Shallow, silty clay loam with 50% gravel; adequate nutrients except P.	34-0-0 0-20-0
Douglas-fir	Ages: 13 & 20 yr	Vancouver Island, British Columbia	Well-drained, sandy loam, hardpan at 56-71 cm; chlorosis observed, N deficiency suspected.	21-0-0 15.5-0-0
Douglas-fir	Age: 20 yr	Vancouver Island, British Columbia	Well-drained, sandy loam, hardpan at 56-71 cm; chlorosis observed, N deficiency suspected.	34-0-0
Douglas-fir	Age: 13 yr	Vancouver Island, British Columbia	—	21-0-0 34-0-0 11-48-0 0-20-0
Jack pine	Age: 54 yr Ht: 13 m Dbh: 10 cm	Amos, Quebec	—	46-0-0 0-45-0 0-0-62
Jack pine	Age: 28 yr	Northwestern Ontario	Aeolian sand, slightly acid, high pH, low N.	46-0-0 0-0-50
Red pine	Age: 45-75 yr Ht: 17 m Dbh: 10-38 cm	Southeastern Manitoba	Excessively drained sand; moisture regime dry.	34-0-0
Red pine	Age: 23 yr Ht: 9.1 m Dbh: 15.0 cm Spacing: 5.2 m	Southeastern Manitoba	Excessively drained sand.	34-0-0 16-20-0 0-0-62
White spruce	Age: 10 yr	Chalk River, Ontario	—	34-0-0

[a] Scientific names are given in the text, except for balsam fir (*Abies balsamea* (L.) Mill.) and red pine (*Pinus resinosa* Ait.).
[b] Information on soil properties was not given by the authors.

Rate of application	Results	Reference
N at 112–224 kg/ha, P at 112 kg/ha, and K at 112 kg/ha, in May.	After 5 years, fertilized trees produced 52% more cones and 40% more seed; fertilizer had marked effect in naturally poor seed year.	Sheedy 1978
Fertilizer at 124–248 kg/ha.	Largest cone crop, heaviest cones, and heaviest seed produced using 248 kg/ha.	Ontario Ministry of Natural Resources 1974
N at 0–224 kg/ha and P at 0–98 kg/ha in September 1955, May 1956, and May 1957.	Best combination: 224 kg/ha of N + 98 kg/ha of P; flowering and cone production increased, and seed increased 10-fold.	Steinbrenner et al. 1960
N at 448 kg/ha on April 14, May 21, and June 11; N also at 224–1792 kg/ha.	Cone production enhanced 5-fold when NO_3-N applied at vegetative bud break; at 792 kg/ha of N, cones increased 10-fold.	Ebell 1972
N at 0–1792 kg/ha.	Best results when 448 kg/ha of N applied at vegetative bud break; application should be biennial rather than annual.	Ebell 1972
Fertilizer at 448 kg/ha. Fertilizer at 560 kg/ha.	Cone production increased 5-fold; NH_4-N useful in fall, NO_3-N + P useful in spring.	Stoate et al. 1961
N at 112–224 kg/ha, P at 112 kg/ha, and K at 112 kg/ha, in May.	Fertilized trees produced longer and heavier cones; seed was heavier and had a higher germination rate.	Sheedy 1978
Fertilizer at 224–448 kg/ha.	Significant increase in number and weight of cones.	Leech 1969
Fertilizer at 336 kg/ha in May.	Number of cones increased by 41%.	Cayford and Jarvis 1967
Fertilizer at 535 kg/ha, fertilizer at 597 kg/ha, and fertilizer at 238 kg/ha in April 1980 and March 1981.	Number of cones increased 130%; weight of seed increased 160%.	Dyck 1985
Fertilizer at 200 g/tree, in May	Cone production increased.	Holst 1959

nitrate-N increased arginine in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ammonium-N was associated with high arginine concentration in loblolly pine (*Pinus taeda*). Both forms of N increased arginine in Monterey pine (*Pinus radiata*), but cone production did not increase significantly. Because conifer species differ in the form of N that they assimilate most readily, it would be more effective to use the form of N required specifically by each species.

The effect of fertilizers is greatest when treatment is made during the period of initiation and differentiation of reproductive buds. This period is specific for each species in a given climate. Although most conifers ripen their seed in one growing season following the year of bud initiation and differentiation, pine seeds require 2 years to ripen following the year of formation of bud primordia. It is therefore likely that a more sustained application of fertilizers would be required through the life cycle of a seed crop in pine than for species that require only 1 year for seed development and ripening. Fall application of fertilizer is also useful. It was found that nitrate-N applied in the spring enhanced flowering in Douglas-fir, and ammonium-N applied in the fall maintained tree vigor and reduced the incidence of abortion and latency in bud development.

Natural periodicity also influences fertilizer effectiveness. Periodicity in cone production is due partly to the physiological limitations imposed on morphogenesis in the year following a heavy cone crop. Flower-bud formation in any year reduces the potential formation of vegetative buds that year, which in turn reduces the potential number of flowering buds the following year. A heavy seed crop in one year is followed invariably by several years of light or nonexistent crops. The length of these poor crop periods may vary with climate and species. The average period between good seed crops in white spruce (*Picea glauca* (Moench) Voss) was reported to be 6 years in British Columbia and 10–15 years in Alaska. Application of fertilizer to increase flowering in a naturally poor cone year (i.e., immediately following a good crop) would probably achieve primarily vegetative growth. The gap between good seed-years should be reduced considerably if seed production is treated as a long-term operation in which healthy and vigorous trees are given sufficient space and adequate nutrition while awaiting favorable weather conditions. Periodicity is also believed to be due to the competition between the reproductive and vegetative organs for food reserves and water; this competition influences the abscission of female flowers during seed development. The decrease in width of annual rings during years of heavy cone crops attests to this competition.

Fertilizer effectiveness is also influenced by weather. The effect of weather on cone production has been studied by deriving correlations between good cone crops and various parameters such as temperature, accumulated heat units, and precipitation for the period preceding and during the onset of flowering and seed maturity. In Norway spruce (*Picea abies* (L.) Karst.), for example, high temperatures and low precipitation in late June and early July of the year of flower initiation improved the following year's cone crop if the crop previous to flower initiation was poor. Flowering in longleaf pine (*Pinus palustris*) and slash pine (*Pinus elliottii*) was correlated with the March-to-July rainfall of the previous year and the size of the flower crop 2 years earlier. Low precipitation following application of fertilizer favored cone development in Douglas-fir. Physiologically, however, flower formation would be suppressed by a soil moisture deficit. The initiation and differentiation of male and female flowers are possibly affected differently by soil moisture availability. Although male flowering in slash pine was stimulated by irrigation, female flowering was stimulated by fertilization.

COMPARISON OF FERTILIZATION STUDIES

It is not possible to compare the data from most of the experiments designed to test the effect of fertilization on seed production. Quantities and relative proportions of the various major elements required to stimulate flowering and seed production differ according to species, age, tree size, stand density, and site conditions. Most of the published data lack adequate information on chemical characteristics of the soil prior to fertilization, thus precluding any assessment of soil response to the fertilizer. It is therefore not possible to decide what soil nutrient levels are optimum for flowering and seed production. Furthermore, without foliar analysis prior to fertilization, the sufficiency of nutrients other than those applied cannot be determined. Fertilizer has been applied on a per-tree basis, but without knowledge of the area of coverage, dosage cannot be converted to an area basis.

Fertilizers have been applied at different times of the year, yet the applications may not have been made at the most critical period for the species concerned, i.e., the period during which differentiation of reproductive buds occurs. Timing is critical because of the differing requirements of each species. Douglas-fir, for example, should be fertilized in April and May, but western hemlock (*Tsuga heterophylla*) responds best to fertilization in June and July. Timing of flowering will also be affected by geographic origin; northern origins tend to flower earlier, after fewer heat units have been accumulated.

Other differences in cone production experiments include the form of N applied, interaction of temperature and precipitation, available soil moisture, age of trees, stand exposure, and competition imposed by ground vegetation such as shrubs and grasses. Ground vegetation grew profusely following fertilization and had to be controlled by methods such as chemical spraying. The stimulating effect of thinning on cone production is well known, and the incorporation of thinning into fertilizer experiments has rendered data from different experiments incomparable, primarily because of different stand densities. Optimum density at a particular site would also be expected to vary among tree species.

CONCLUSIONS AND RECOMMENDATIONS

Fertilization is a practical means of increasing seed production and reducing the gap between good seedyears. Its success depends on 1) choosing the form of nitrogen that can best be assimilated by the tree species, and 2) the time of application, which is most opportune during differentiation of reproductive buds. Natural cone crop periodicity and weather in the year preceding and during bud differentiation are influential, indicating that fertilization for seed production requires a site-specific approach. Although current data do not lend themselves to comparison, fertilization for seed in combination with thinning should be continued to maintain adequate tree spacing, crown size, vigor, and nutrition until desirable weather prevails.

To develop seed production areas and seed orchards on a sound biological basis, the following recommendations should be considered:

1. For seed production areas and seed orchards, the timing of all phases of the reproductive life cycle of each species at each location should be determined. Northern populations will initiate and differentiate bud primordia later than southern ones because of genetic or climatic differences. Trees should be sufficiently thinned to produce an adequate crown size.

2. Experiments should be conducted to determine and subsequently enhance the nutritional well-being of the site. Through fertilization and soil and foliage analysis, nutritional deficiencies can be corrected. By determining the growth response associated with each level of applied nutrients, optimum nutritional status can be determined.

3. Trials should be conducted to determine the preferred form of N for each species. Urea, ammonium sulfate, ammonium nitrate, and calcium nitrate should be compared over a 5-year period in different locations and on different soil types. Given similar performances, the higher-analysis fertilizers can be applied more economically. Note that long-term use of ammonium sulfate may lower pH markedly in coarser soils.

4. Physical and chemical properties of the soil at each experimental site should be determined. There is an inverse relationship between the level of response following fertilization and the nutrient adequacy of the site for seed production.

5. No fertilization is necessary in the year immediately following a cone crop. In subsequent years the optimum frequency of fertilization must be determined. Also, the efficacy of spring- versus fall-applied P and K should be compared. Spring-applied N is considered best, because losses from leaching and denitrification are minimized.

6. Ground vegetation should be controlled, and damage from insects and disease should be minimized.

7. Meteorological instrumentation should be installed at strategic locations to enable collection and analysis of climatic data to determine the relationship between cone production and weather prior to and during cone formation and maturation.

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APPENDIX 1

DEFINITIONS

Abscission	The natural separation of flowers, fruit, and leaves from plants.
Assimilation	Absorption and utilization as nourishment by the plant system.
Differentiation	Point in cell development at which tissues and organs have recognizable functions.
Initiation	The beginning of formation of an organ, as with cell division.
Latency	Dormancy; formation of seed but without further development.
Life cycle	Phases or stages through which a seed crop passes from formation to maturity.
Morphogenesis	Formation and differentiation of tissues and organs.
Periodicity	Cyclical fluctuation in flowering and seed production.
Primordia (Singular: primordium)	Parts of a plant organ that are formed earliest; the most fundamental parts of an organ.
Reproductive	Relating to or capable of reproduction, e.g., flowering, seed formation.
Vegetative	Relating to or engaged in nutritive and growth functions, e.g., leaves.

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