FERTILIZING SEMIMATURE JACK PINE

(*PINUS BANKSIANA* LAMB.)

IN NORTHWESTERN ONTARIO:

FOURTH-YEAR RESULTS

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ABSTRACT

In 1969, near Dryden in northwestern Ontario, Canada, nine fertilization experiments embracing a total of 301 measurement plots and 22,400 identified trees, were established in pure 55-year-old jack pine (*Pinus banksiana* Lamb.) forest of fire origin, on till and sandy outwash sites. Treatments evaluated were: combinations of N, P and K fertilizers (urea, triple superphosphate, and muriate of potash at various levels), N, P and Mg (supplied as magnesium oxide), N-sources (urea, urea-formaldehyde, ammonium nitrate and ammonium sulphate), time of application, split application, placement, and fertilization with thinning-from-below. These experiments were remeasured 4 years after establishment. Mean DBH, basal area, total and merchantable volume, and their increments were determined.

In general, the results suggested that N (and P in addition to N only when N demand was satisfied) were the elements limiting growth of jack pine on such sites. The best treatment of the series was a combination of N and P, supplied as urea and triple superphosphate, producing a gain over controls of approximately 13 m^3/ha in 4 years. The greater responses, both in percentage and absolute terms, were on the poorer sites; the poorest gains were on the best site. Nitrogen source appeared not significant, and placement had no effect. There was no conclusive evidence that season of application significantly affected response. Similarly, splitting a urea application over 2 or 3 years gave no advantage over a single dose. Thinning significantly increased mean DBH but not per hectare volume increment. Fertilizers at equivalent levels evoked similar responses in absolute terms regardless of thinning intensity.

RÉSUMÉ

En 1969, non loin de Dryden, dans le nord-ouest de l'Ontario, Canada, on a procédé à une série de neuf expériences de fertilisation comprenant au total 301 parcelles de mesurage et 22,400 arbres identifiés, en peuplement pur de pins gris (*Pinus banksiana* Lamb.) âgés de 55 ans, issu d'une forêt brûlée, dans des stations à till et de plaine alluviale proglaciaire sableuse. On a évalué les traitements suivants: les mélanges de fertilisants N, P et K (urée, triple superphosphate et chlorure de potassium à divers niveaux), de N, P, et Mg (fourni sous forme d'oxyde de magnésium), les sources de N (urée, formaldéhyde uréique, nitrate d'ammonium et sulphate d'ammonium), le temps d'application, l'application divisée, la mise en place (des fertilisants) et la fertilisation avec éclaircie par le bas. On a remesuré le tout quatre ans après le début des expériences. On a déterminé le d.h.p. moyen, la surface terrière, le volume total et le volume marchand, ainsi que leurs augmentations.

De façon générale, les résultats ont démontré que N (de même que P ajouté à N seulement lorsque les exigences en N étaient satisfaisantes) est l'élément qui a limité la croissance du pin gris en de telles stations. Le meilleur traitement appliqué à cette série combinait N et P, présentés sous forme d'urée et de triple superphosphate, produisant un gain d'approximativement 13 m^3/ha en 4 ans sur les témoins. Les meilleures réactions, en termes de pourcentages et en chiffres absolus, provenaient des stations les plus pauvres; les plus modestes gains ont été fournis par la meilleure station. La source azote s'est avérée peu significative et la mise en place n'a produit aucun effet. Il n'y eut aucune évidence concluante indiquant que la saison où on a procédé aux applications ait influé significativement sur le rendement. De même, l'échelonnage des applications d'urée sur une période de 2 ou 3 ans n'a pas été plus avantageux que l'application en une seule dose. Les éclaircies ont substantiellement augmenté le d.h.p. moyen, sans toutefois hausser la valeur en volume par hectare. Les fertilisants de niveaux équivalents ont suscité des réactions similaires en termes absolus, indépendamment de l'importance des éclaircies.

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INTRODUCTION

In January, 1974 a workshop on forest fertilization, bringing together forest scientists and managers from all over Ontario and from various other parts of Canada and the northern United States, was held in Sault Ste. Marie, Ontario. Among the papers delivered at this workshop, and subsequently published in the workshop proceedings (Anon. 1974), were several (Winston 1974, Hegyi 1974b, Tucker 1974, Morrison and Foster 1974) based on fourth-year remeasurements of fertilizer experiments established in 1969 near Dryden, Ontario by researchers of the Canadian Forestry Service.

The above papers, while presenting the essence of the results, were streamlined for the benefit of forest managers. The objective of the present paper is to present a more complete scientific account, with information on climate, fuller descriptions of site, soils, stands and associated ground cover, and experimental methodology.

THE DEVELOPMENT OF INTEREST IN FOREST FERTILIZATION IN EASTERN CANADA

In addition to carbon (C), hydrogen (H), and oxygen (O), derived from carbon dioxide (CO_2) and water (H_2O), forest trees, like all higher plants, require 13 soil-derived inorganic elements, including six in relatively large amounts, termed macroelements: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) and seven in only small amounts, termed micro- or trace elements: iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), and chlorine (Cl). In few soils do these elements occur in sufficient supply for optimum tree growth. When growth falls below an acceptable rate and response can be induced by application of fertilizers containing one or more of these elements, the soil is considered to be deficient in that element. Fertilization aims at ameliorating soils by applications of nutrient-containing materials, either organic or inorganic, usually to increase growth or otherwise affect site for some forestry purpose.

The use of fertilizers in forest tree nurseries in eastern Canada is a well established practice (Armson and Carman 1961, Armson and Sadreika 1974), whereas fertilization of established stands is still largely experimental. The earliest serious forest fertilization experiments in eastern Canada were the Conservation Commission manure applications some 50 years ago to plantations of the (then) Laurentide Pulp and Paper Company near Grand'Mère, Québec (Cunningham 1953, MacArthur 1957, Paine 1960, Swan 1962). Thereafter forest fertilization research in eastern Canada entered a period of slow development, during which it was concerned chiefly with greenhouse and laboratory studies, although some studies were carried out involving plantations (Gagnon 1965, Leech 1965, 1967, 1969).

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The 1960s, however, were marked by growing interest in fertilization in various parts of the world, and by the middle part of the decade there was a considerable body of review literature on the world scene and, in Canada, literature describing the upcoming role of mineral fertilization in forestry practice (Lafond 1962, Swan 1965, Armson 1966). Of 85 fertilization studies in Canada listed as under way at the time of review by Armson (1967), only seven were concerned with application of fertilizer to established natural stands at or near commercial age in eastern Canada. Of these seven experiments, four involved black spruce (*Picea mariana* [Mill.] B.S.P.) and three, jack pine (*Pinus banksiana* Lamb.).

So intense became the interest in this aspect of forest fertilization that, in the last 3 years of the 1960s, these seven eastern Canadian field trials were joined by at least 40 more, established by the Canadian Forestry Service, the Pulp and Paper Research Institute of Canada in conjunction with various paper companies, and various provincial governments as part of the Interprovincial Forest Fertilization Program (Anon. 1973c). Included among those of the Canadian Forestry Service were the nine experiments of the present report.

1969 JACK PINE FERTILIZATION EXPERIMENTS: DRYDEN, ONTARIO

Nine experiments (Winston 1974) were established in northwestern Ontario on the limits of the Dryden Paper Co. Ltd. in 55-year-old jack pine stands. The choice of jack pine as the test species for this series was made on several grounds. First, it is a major source of raw material for the pulp and paper industry of northern Ontario, being second only to spruce in annual volume cut. Second, it occurs in extensive even-aged stands which are amenable to mechanized silviculture. Third, in terms of ease of regeneration, relative freedom from disease or major insect pests, and rapidity of growth, it has the highest potential for intensive management of all of the northern Ontario coniferous pulpwood species. Fourth, and perhaps most important, it is commonly associated with sites of low fertility while it makes its most rapid growth on sites of high fertility.

The choice of the semimature age class, i.e., stands approximately 10 years from rotation age, was made on economic grounds, to reduce to the lowest practical level the carrying charges on money invested in fertilization. It should be remembered also that *all* jack pine stands to be harvested between now the year 2000 are already well established.

Eight of the experiments were located 35 km northeast of Dryden, Ontario, four in each of McIlraith and Breithaupt townships (lat. 50°02'N; long. 92°32'W) of Kenora District; an additional experiment was conducted 11 km southwest of Dryden approximately 6 km west of the Contact Bay portion of Wabigoon Lake at lat. 49°42'N; long. 92°56'W.

The eight experiments northeast of Dryden are located in the Upper English River Section (B. 11) and the single experiment southwest of Dryden in the Lower English River Section (B. 14) of the Boreal Forest Region (Rowe 1972).

The overall climate is modified-continental with the McIlraith and Breithaupt groups of experiments being in the English River and the Contact Bay experiment in the Rainy River--Thunder Bay climatic regions of Chapman (1953). Average lengths of growing season (based on a 5.5°C index) for the two regions respectively are 160 and 170 days; the growing season extends roughly from May through September. Mean total precipitation as measured at Dryden (Anon. 1973b) is approximately 70 cm annually, with approximately 60% of this falling during the growing season. Potential evapotranspiration, using the most recent climatic normals (Anon. 1973a, 1973b) calculated after the manner of Thornthwaite and Mather (1957) is 54.1 cm; this compares well with the estimate of Chapman (1953) some two decades earlier.

All experiments are located within the Dryden Site District of Site Region 4S (Wabigoon Lake) (Hills 1955). The eight northern experiments are located within the Bluett Landscape Unit on an outwash land type conforming to Stokes sand (Zoltai 1965, 1974). The experiment southwest of Dryden is located within the Eagle Land Unit on a till land type conforming to Zoltai's (1965, 1974) Avery silty sand.

GENERAL METHODS

Field

The experiments were demarcated in the summer of 1968. All living trees in measurement plots were identified with numbered metal tags. The breast-height position was marked with paint.

In the fourth week of May, 1969, DBH of all numbered trees was measured with metal diameter tapes.

Weighed quantities, corresponding to preselected application rates (details of individual experiments appear below) of commercial grade fertilizers were broadcast by hand in a two-or-more-pass systematic pattern to ensure uniformity of coverage.

Analysis of Data

The growth response evaluation consisted of detailed examination of the following variables: DBH, DBH increment, basal area (BA), BA increment, total volume, total volume increment, merchantable volume, and merchantable volume increment.

In the field, data were recorded on computer forms specially designed for direct key punching. At establishment, besides plot identification data, the number and DBH of each tree were recorded. In addition, five or six sample trees were selected from each plot for height measurements; these sample trees were chosen randomly, one tree per 2.54-cm or 5.08-cm diameter class. At remeasurement, the DBH of each tree was recorded on tally sheets which showed the tree number and DBH at establishment. A quick check was made to ensure that the remeasured DBH was not less than that at establishment. Some sample heights were also obtained to check if the height-over-DBH relationship, as obtained at establishment, had changed significantly as a result of treatment. Since a significant difference was not detected, height data from both measurements were pooled and the following height-over-age function was fitted:

$$H = a + b\,DBH + c\,(DBH)^2$$

where: H is total height,
DBH is diameter at breast height, and
a, b, c are regression constants.

The above regression equation was fitted separately to the data within the nine experiments, then applied to the DBH measurements to calculate the height of each tree.

The total and merchantable volume of each tree was obtained from DBH measurements and calculated heights using Honer's (1967) volume equations for jack pine. Increments of DBH, BA, total and merchantable volume were calculated by subtracting establishment values from those at remeasurement. Plot and treatment means were then calculated for each of the following response variables: DBH, BA, total volume, merchantable volume, and their respective increments.

The above response variables were subjected to analysis of variance to test treatment effects at 95% and 99% significance levels. Treatment means were also ranked and compared for significant differences, using Duncan's New Multiple Range Test.

Analysis of Soil

Soil pits were dug and samples collected in the vicinity of the McIlraith Township group of experiments, the Breithaupt Township group and the experiment southwest of Dryden near Contact Bay. Samples were air dried. Soil organic matter content was estimated using a Walkley-Black wet combustion procedure. Following peroxide oxidation of organic matter, texture was determined mechanically by a Boyoucos hydrometer method. Soil pH was measured in a 1:10 soil:water mix using a glass electrode pH meter. Total N was determined using a semi-micro Kjeldahl digestion procedure with a copper-selenium catalyst, followed by steam distillation and titrimetric estimation of ammonia. Following extraction with Bray and Kurtz

No. 1 extractant, available soil P was estimated using a molybdophosphoric blue colorimetric procedure. Cation exchange capacity (CEC) was determined by ammonium saturation using 1 *N* NH_4OAc (pH7), followed by H displacement. Exchangeable cations were determined following 1 *N* NH_4OAc (pH7) extraction: K, by flame emission spectroscopy using a Perkin Elmer Model 290 spectrophotometer; Ca and Mg both in the presence of lanthanum oxide by atomic absorption spectroscopy using a converted form of the same instrument.

MCILRAITH TOWNSHIP EXPERIMENTS

Four experiments were located in close proximity to one another in McIlraith Township in a single continuous jack pine stand on material identified as Stokes sand (Zoltai 1965), an outwash of very low base status consisting principally of granitic light-colored feldspars and quartz. Coarse (> 2 mm) fragments occupied approximately 20% of the soil volume. Selected physical properties are presented in Table 1.

Table 1. Physical properties of the soils

				< 2 mm fraction %			
Horizon	Depth	Bulk density	% > 2 mm	Sand	Silt	Clay	Texture
		Stokes sand (McIlraith Township)					
Ae	0-4	1.05	0	81	18	1	loamy sand
Bh	4-20	1.19	0-25	83	15	2	loamy sand
Bc	20-35	1.39	0-25	85	6	9	loamy sand
C	35+	1.55	0-25	87	8	5	loamy sand
		Stokes sand (Breithaupt Township)					
Ae	0-6	1.26	0	73	21	6	sandy loam
Bh	6-20	1.24	0	80	16	4	loamy sand
Bc	20-34	1.44	0	86	13	1	sand
		Avery silty sand (Contact Bay)					
Ae	0-3	1.20	20	58	35	7	sandy loam
Bf	3-28	1.14	20	70	26	4	sandy loam
Bg	28-51	--	20	65	31	4	sandy loam

In terms of chemical concentrations (Table 2), the soil on this site exhibited the lowest concentrations of all elements except P, which was the highest. Similarly, this profile generally exhibited the lowest CEC and organic matter content.

Table 2. Mean chemical properties of Stokes sand (McIlraith Twp) with standard deviations

Horizon	N (%)	P (ppm)	K	Ca	Mg	C.E.C.	pH	Organic matter (%)
			(m.e./100g)					
L	0.756±0.040	78.6±33.9	9.62±4.09	20.64±4.13	5.60±1.20	85.7±37.9	4.2±.1	91.2± 3.0
F	0.835±0.147	62.7±28.0	2.13±0.31	18.59±3.14	3.22±0.60	59.8±13.5	4.2±.1	68.7±13.3
H	0.623±0.115	33.9±12.7	1.25±0.49	9.33±2.64	1.58±0.57	47.3±13.1	4.2±.2	32.9± 8.9
Ae	0.032±0.008	14.2± 9.5	0.11±0.05	1.07± .07	0.16± .07	7.2± 2.4	4.6±.1	1.2± 0.5
Bh	0.022±0.007	11.0± 3.2	0.05±0.01	0.70±0.24	0.08±0.02	3.2± 0.8	5.7±.2	0.6± 0.2
Bc	0.010±0.003	19.6± 4.0	0.05±0.02	0.35±0.14	0.06±0.03	1.7± 0.6	5.7±.1	0.3± 0.1
C	0.005±0.001	21.7± 4.9	0.02±0.01	0.23±0.01	0.04±0.01	1.0± 0.1	5.4±.2	0.1± 0.04

The stand was pure, even-aged jack pine of fire origin, approximately 55 years of age when the experiments were begun. Stand mensurational characteristics including information on numbers of stems, BA, DBH and height are presented in Table 3. Species of ground flora identified in detailed tallies of two 1-m^2 quadrats per plot in 1969 are indicated in Table 4.

Available information and rationale for testing are highlighted for each experimental description.

Experiment--Low-level Urea

A review of world literature suggested that N was the element whose lack was most limiting to tree growth in the boreal forest. Consequently, it was felt that application of this element was most likely to evoke a growth response in semimature jack pine stands. Evidence also suggested that, in acid media, conifers prefer N supplied in the ammonium (NH_4^+) form as opposed to the nitrate (NO_3^-) form. This, together with the fact that NH_4^+ - N is less subject to leaching loss than is NO_3^- - N, led us in this experiment to use urea, the NH_4^+ fertilizer with the highest analysis (45% N) commonly available.

It was presumed that the growth response pattern of semimature jack pine to fertilizer addition would be similar to the familiar sigmoidal biological growth or response curve. Since economic considerations undoubtedly favor using the smallest quantity of fertilizer consistent with the optimum economic return, we thought that emphasis should be placed on ascertaining the shape of the lower portion of the response curve. Consequently, in this experiment, we concentrated on testing response to lower levels of N.

Objective: To elucidate the pattern of response of a semimature, closed jack pine stand on a sandy outwash site in northwestern Ontario to increasing levels of N supplied as urea.

Method: An experiment consisting of five N treatments (expressed on element basis), 0 kg N/ha, 28 kg N/ha, 56 kg N/ha, 112 kg N/ha, 224 kg N/ha, with N supplied as urea, and five replications of each treatment, for a total of 25 square 0.08-ha treatment plots, each with an inner 0.04-ha measurement plot, arranged in a Latin square design with plots contiguous to one another (the portion of the treatment plot exterior to the measurement plot serving as a buffer), was established in this stand. Initial DBH measurements were made in late May, 1969. Weighed quantities of

Table 3. Number of trees per ha, total basal area (BA) per ha, DBH and its range, and mean heights for the nine experiments prior to treatment, 1969

Experiment	Trees/ha	BA/ha (m^2)	DBH mean	DBH range	Mean ht (m)
		McIlraith Township			
Low-level urea	1893	24.4	12.4	4.6-25.1	13.9
Time of urea application	2578	21.6	9.9	2.3-21.1	11.7
Sucessive urea applications	1934	24.1	12.2	5.1-23.4	14.0
Methods of urea application	1389	25.2	14.7	7.1-29.7	15.1
		Breithaupt Township			
Thinning and fertilization	1746	22.8	12.4	5.3-25.4	13.9
Phosphorus, potassium and nitrogen	1918	24.3	12.4	6.4-23.4	13.6
Nitrogen, phosphorus and magnesium	1752	24.8	13.2	6.6-23.9	14.4
Different nitrogen fertilizers	1946	22.9	11.9	5.1-24.4	12.6
		Contact Bay			
Nitrogen, phosphorus and potassium	1472	34.2	16.8	6.4-30.2	16.6

Table 4. Occurrence, by experiment, of lesser plant species in 55-year-old jack pine prior to treatment, 1969

	McIlraith Twp				Breithaupt Twp				Contact Bay
Species	Low-level urea	Time of urea application	Successive urea applications	Method of urea application	Thinning and fertilization	Phosphorus, potassium and nitrogen	Nitrogen, phosphorus and magnesium	Different nitrogen fertilizers	Nitrogen, phosphorus and potassium
LICHENS									
Cladonia rangiferina (L.) Web.	*	*			*			*	
Cladonia alpestris (L.) Rabenh.		*							
Cladonia mitis Sanst.	*	*							
MOSSES									
Dicranum polysetum SW.	*	*	*	*	*	*	*	*	*
Hypnum crista-castrensis Hedw.			*		*		*		
Pleurozium schreberi (BSG.) Mitt.	*	*	*	*	*	*	*	*	*
Hylocomium splendens (Hedw.) BSG.									*
VASCULAR CRYPTOGAMS									
Equisetum sylvaticum L.									*
Lycopodium obscurum L.									*
Lycopodium complanatum L.	*			*					*
Lycopodium annotinum L.				*	*	*	*	*	
Dryopteris spinulosa (O.F. Muell.) Watt								*	
Pteridium aquilinum (L.) Kuhn									*

(continued)

Table 4. Occurrence, by experiment, of lesser plant species in 55-year-old jack pine prior to treatment, 1969 (continued)

Species	McIlraith Twp: Low-level urea	McIlraith Twp: Time of urea application	McIlraith Twp: Successive urea applications	McIlraith Twp: Method of urea application	Breithaupt Twp: Thinning and fertilization	Breithaupt Twp: Phosphorus, potassium and nitrogen	Breithaupt Twp: Nitrogen, phosphorus and magnesium	Breithaupt Twp: Different nitrogen fertilizers	Contact Bay: Nitrogen, phosphorus and potassium
FLOWERING PLANTS									
Oryzopsis pungens (Torr.) Hitch	*	*	*				*	*	
Oryzopsis asperifolia Michx.	*	*							*
Clintonia borealis (Ait.) Raf.	*		*	*					*
Maianthemum canadense Desf.	*	*	*	*	*	*	*	*	*
Cypripedium acaule Ait.			*					*	
Goodyera repens (L.) R. Br.		*	*	*		*	*		
Goodyera tesselata Lodd.			*						
Salix spp.			*				*		*
Corylus cornuta Marsh.				*					*
Alnus crispa Ait. Porsh	*	*	*	*	*	*	*	*	*
Anenome quinquefolia L.	*	*	*			*	*		*
Coptis trifolia (L.) Salisb.									*
Ribes glandulosum Grauer								*	
Ribes triste Pall.									*
Amelanchier sp.		*			*		*	*	.
Fragraria virginiana Duchesne		*							*
Potentilla tridentata Ait.		*						*	
Rubus pubescens Raf.		*							*
Rubus idaeus L.								*	
Rosa acicularis Lindl.	*	*	*	*					

(continued)

Table 4. Occurrence, by experiment, of lesser plant species in 55-year-old jack pine prior to treatment, 1969 (concluded)

Species	Low-level urea	Time of urea application	Successive urea applications	Method of urea application	Thinning and fertilization	Phosphorus, potassium and nitrogen	Nitrogen, phosphorus and magnesium	Different nitrogen fertilizers	Nitrogen, phosphorus and potassium
Epilobium angustifolium L.			*	*					*
Aralia nudicaulis L.	*		*	*		*	*		*
Cornus canadensis L.	*	*	*	*	*	*	*	*	*
Moneses uniflora (L.) Gray									*
Chimaphila umbellata (L.) Bart.	*	*	*			*	*	*	*
Pyrola virens Schweigger				*				*	*
Pyrola secunda			*						
Ledum groenlandicum Oeder			*	*		*	*		*
Epigaea repens L.	*			*					
Arctostaphylos uva-ursi (L.) Sp.	*	*	*	*	*		*	*	
Gaultheria hispidula (L.) Bigel	*	*	*		*	*			
Vaccinium angustifolium Ait.	*	*	*	*	*	*	*	*	*
Vaccinium myrtilloides Michx.	*	*	*	*	*	*	*	*	*
Trientalis borealis Raf.			*					*	*
Apocynum androsaemifolium L.	*	*	*	*			*		
Melampyrum lineare Desr	*	*	*	*	*	*	*	*	
Galium triflorum Michx.									*
Diervilla lonicera Mill.	*	*	*	*	*	*	*	*	*
Linnaea borealis L.	*	*	*	*	*	*	*	*	*
Solidago bicolor		*		*	*		*	*	
Aster macrophyllus L.				*					*

commercial-grade prilled urea (45% N) were hand-broadcast uniformly over the forest floor in amounts appropriate to the experimental design in late May, 1969. Remeasurements of DBH were made 4 years later in May, 1973.

Results: Growth, in terms of incremental response variables (Table 5), generally increased with increasing rate of N application. A slight depression in BA, increment, total volume increment and merchantable volume increment associated with the 28 kg N/ha treatment did occur but this was not significantly different from control. Differences, statistically significant from controls at the 95% confidence level, occurred in mean DBH increment, BA increment, total volume increment and merchantable volume increment at the two highest treatment levels, i.e., 112 kg N/ha and 224 kg N/ha. The highest level of application in this experiment, 224 kg N/ha (corresponding to an application rate of 498 kg of urea per hectare), produced a statistically significant net gain over controls of 6.80 m^3/ha in terms of total volume or 6.68 m^3/ha in terms of merchantable volume.

Table 5. Four-year growth response of 55-year-old jack pine on Stokes sand (McIlraith Township) to increasing levels of nitrogen fertilizer supplied as urea

Treatment (kg N/ha)	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha	Merch. vol. increment (m^3/ha)
Control	0.67	2.45	20.00	20.10
N28	.70	2.38	19.72	19.67
N56	.73	2.72	21.92	22.10
N112	.83*	3.00*	24.71*	24.58*
N224	.88*	3.28*	26.80*	26.78*

* Statistically significant difference at the 95% confidence level

Experiment--Time of Urea Application

Fertilizers were applied to most experiments in May since it was felt that the nutrients should be provided at the beginning of the growing season for immediate use in the initial flush of growth. However, operational constraints may make an early spring application impractical.

Thus it was felt desirable to evaluate the effects on response resulting from fertilizing at different times of year. In addition, nutritional benefits may accrue, for example, from a July application by prolonging the growth flush, or similarly a September (fall) application would have the fertilizer in place, and incorporated into the soil for the next year's use. In this regard, it should be noted, as the fertilizers were all applied in the same year (1969), the fall application was, in effect, one growing season later than the other two treatments. This will be taken into account at the time of final evaluation.

Objective: To compare growth responses of semimature jack pine, on a sandy outwash site in northwestern Ontario, to N as urea applied at different times during the growing season and at different rates.

Method: The experimental design was a 3 x 3 factorial with four replications. The total number of plots was 36, arranged in blocks for each replication. Measurement and treatment plots are one and the same, square, 0.04 ha, with shared boundaries. Application dates and rates were as follows:

Application date	Application rate
May 27	0 kg N/ha
July 23	84 "
Sept 17	252 "

Nitrogen was broadcast-applied as commercial-grade prilled urea and initial measurements of DBH were completed in late May, 1969. Remeasurements of DBH were completed in late May, 1973.

Results: Table 6 presents increments of DBH, BA per ha, and total and merchantable volume per ha. Significant differences between rates were obtained from the May and September applications but not from the July application. In relation to time no significant differences were discernable, i.e., for equivalent levels there were no significant differences between May and July, May and September or July and September. The response period should be noted, as it was a full four growing seasons for May, three and a half for July and only three for September. In terms of growth-over-controls the July treatments were not significant at either level whereas the May and September treatments were significant for the 252 kg N/ha application rate. For the May and September 252 kg N/ha treatment, mean annual increments attributable to fertilizer, for the appropriate 4- and 3-year response periods, respectively, are approximately the same.

Treatment	Tot. vol. incr. minus control	Merch. vol. incr. minus control
May N 252	2.64 m^3/ha/yr	2.77 m^3/ha/yr
Sep N 252	2.55 "	2.60 "

Table 6. Growth response of 55-year-old jack pine on Stokes sand (McIlraith Township) to levels of nitrogen as urea applied at different times during the first growing season

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.58	2.42	16.50	17.11
May N84	.74	3.29	21.97	23.14
May N252	.94*	3.87*	27.04*	28.18*
Control	.56	2.63	18.31	18.94
July N84	.64	2.97	20.63	21.56
July N252	.81	3.42	24.16	24.99
Control	.64	2.38	16.49	17.30
Sep N84	.71	2.79	19.17	19.94
Sep N252	.84	3.47	24.12*	25.10

* Statistically significant difference at the 95% confidence level

Experiment--Successive Urea Applications

Economic considerations suggest that fertilizers should be applied in a single dose; however, there remains the possibility that the same dose applied over 2 or even 3 years might be more efficiently utilized by the crop, and that the resultant increased return on investment would justify such an approach. Evidence from various investigators tends to support the theory that fertilizer growth responses are short-lived. Applying fertilizer over a period of time might have the effect of prolonging the response. Moreover, trees previously fertilized might better be able to compete for additional nutrient.

Objective: To determine responses of a semimature jack pine stand, on a sandy outwash site in northwestern Ontario, to urea fertilizer applied either as a single dose or as an equivalent amount split variously over 2 or 3 years.

Method: The experiment was set forth as a completely randomized 2 x 4 factorial with four replications arranged in blocks for each replicate. Treatment and measurement plots were one and the same, square, 0.04 ha with shared boundaries. Nitrogen was supplied as commercial-grade prilled urea in either a single or a split dose.

Application rate	Time
0 kg N/ha	all in the first spring
202 "	½ in first spring, ½ in second
	½ in first spring, ½ in third
	1/3 in each spring for 3 consec. years

Initial DBH measurements were completed late in May, 1969. The 1969 applications were made in late May, the 1970 applications in early June and 1971 applications in mid-July. Remeasurement of DBH was completed in early June, 1973.

Results: Increments of mean DBH, BA per ha, and total and merchantable volume per ha are presented in Table 7. Despite the design and large number of controls (since 0 kg/ha applied in any combination is still 0 kg/ha), it is evident there was no statistically significant difference among the various groups of controls or among time combinations for the treated series. The single dose and the first—second year split produced effects differing significantly from those of their own controls. This experiment suffers, however, from the same time bias as the previous experiment with the single dose treatment, since it has all its fertilizer in place the full 4 years. In terms of growth-over-control, this treatment appeared the most beneficial whereas the various splits appeared less beneficial. With generally decreasing responses in terms of growth-over-controls from the single application to the three-way split, there is a suspicion that time did bias the result.

A summary of the main results is set out on the next page.

Treatment	Tot. vol. incr. minus control	Merch. vol. incr. minus control
N 202	9.72 m^3/ha	9.98 m^3/ha
N 101 N 101 N 0	7.69 "	7.82 "
N 101 N 0 N 101	5.44 "	5.41 "
N 67 N 67 N 67	4.65 "	4.64 "

It is emphasized, however, that differences between treatments are not statistically significant.

Table 7. Four-year growth response of 55-year-old jack pine on Stokes sand (McIlraith Township) to equivalent doses of urea fertilizer split variously over 1, 2 or 3 years

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.58	2.24	17.60	17.79
N202	.89*	2.78*	27.32*	27.77*
Control	.58	2.12	16.76	16.84
N101 N101 NO	.81*	3.09*	24.45*	24.66*
Control	.61	2.19	17.28	17.43
N101 NO N101	.74	2.88	22.72	22.84
Control	.69	2.50	19.62	19.77
N67 N67 N67	.81	3.07	24.27	24.41

* Statistically significant difference at the 95% confidence level

Experiment--Method of Urea Application

Traditionally most fertilizers have been applied by aircraft over forested land. However, such a method may not place the fertilizer correctly for the best uptake by the crop nor is this method perfected technically. For certain agricultural crops, reports are now available indicating the benefits to be gained from actual fertilizer placement in the soil. Similarly, under certain climatic conditions, considerable quantities of urea-N have been lost when surface applied through volatilization as ammonia (NH_3). Consequently, this experiment was established to determine whether the placement of urea can significantly increase tree growth when compared to the response obtained from surface application.

Although aerial fertilizer application appears at present to be the most attractive method of fertilizing large tracts of forest land, changes in silvicultural techniques may be prompted if fertilizer placement proves advantageous since plantations and strip thinnings in natural stands facilitate movement of machinery capable of fertilizer placement.

Objective: To compare growth response of semimature jack pine, on a sandy outwash site in northwestern Ontario, to N as urea at different rates placed differently.

Method: The experiment was set forth as a 3 x 3 completely randomized factorial with four replications. Nitrogen was applied as commercial-grade prilled urea at three rates, by three methods:

Application rate	Placement method
0 kg N/ha	broadcast
76 "	covered furrows
151 "	covered holes

Furrows were continuous, 15 cm deep and 2.4 m apart. Holes were 15 cm deep, and arranged at 2.4 m x 2.4 m spacing. Treatment plots and measurement plots were one and the same, square, 0.04 ha and arranged in a grid pattern with contiguous plot boundaries. Initial measurements of DBH were made in late May, 1969; treatments were applied in early June, 1969. Remeasurements of DBH were completed in early June, 1973.

Results: Increments of DBH, BA per ha, and total and merchantable volume per ha are presented in Table 8. Analysis of variance yielded no significant differences related to either urea application rate or method of application for any of the parameters studied.

Table 8. Four-year growth response of 55-year-old jack pine on Stokes sand (McIlraith Township) to urea fertilizer applied at three levels by three different methods

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Tot. vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.66	25.65	18.42	18.17
Furrows	.58	23.92	22.47	22.10
Holes	.66	26.86	20.45	20.11
N76 Broadcast	.81	25.52	15.60	15.41
N76 Furrows	.71	26.53	19.77	19.38
N76 Holes	.58	27.87	19.81	19.59
N151 Broadcast	.76	24.95	17.76	17.43
N151 Furrows	.76	24.79	17.49	17.15
N151 Holes	.71	25.60	19.21	18.97

BREITHAUPT TOWNSHIP EXPERIMENTS

Four experiments were located in close proximity to one another in Breithaupt Township northeast of Dryden in a single continuous jack pine stand on soil material similar to that encountered in McIlraith Township and similarly classed as Stokes sand (Zoltai 1965).

The material differed from that in McIlraith Township chiefly by being stonefree. Selected physical properties are presented in Table 1. In terms of chemical properties, the Breithaupt Township profile (Table 9) in relation to the one sampled in McIlraith Township (Table 2) exhibited, horizon by horizon, generally higher concentrations of total N and exchangeable K, and markedly lower concentrations of available P. Organic matter content and CEC in the Breithaupt profile were generally higher, horizon by horizon, than in the McIlraith profile.

The stand, of fire origin, was of even-aged, close jack pine approximately 55 years of age at the beginning of the experiments. Stand mensurational characteristics are presented in Table 3. Species of ground flora present at the beginning of the experiment are presented in Table 4.

Experiment--Thinning and Fertilization

Jack pine stands are often overstocked. In such stands a reduction in the number of trees per unit area by thinning can provide increased light and water for the remaining trees which then can expand both their roots and photosynthetic surface. The addition of fertilizers also increases the readily available supply of nutrients. Thus, on an individual tree basis, thinning is expected to magnify growth response resulting from fertilizer alone.

A reduction in the number of stems ensures that growth response is concentrated on fewer stems; this permits a more rapid growth of trees into larger size classes. With the recent trend to greater mechanization of timber harvesting, the production of forests with fewer but larger trees could be very important in reducing harvesting costs.

Objectives: To study the effect of different intensities of thinning-from-below, and different levels of N and P supplied as urea and triple superphosphate, singly and in combination, on the growth of semimature jack pine on a sandy outwash site in northwestern Ontario.

Method: The experiment was set forth as a 3 x 3 x 2 completely randomized factorial with two replications, consisting of three intensities of thinning-from-below, three levels of N supplied as commercial-grade prilled urea, and two levels of P supplied as triple superphosphate, all expressed herein on element basis.

Table 9. Mean chemical properties of Stokes sand (Breithaupt Township) with standard deviations

Horizon	N (%)	P (ppm)	K	Ca	Mg	C.E.C.	pH	Organic matter (%)
			(m.e./100g)					
L	0.985±0.127	54.2±21.4	5.93±.85	20.63±2.49	6.95±.76	57.2± 3.6	4.7±.2	93.9±0.6
F	0.918±0.142	35.8±14.8	3.63±.50	15.41±2.01	3.58±.50	67.2± 3.0	4.4±.2	87.8±3.4
H	0.570±0.181	25.2± 6.9	1.80+.34	9.16±2.66	1.75±.45	51.6±10.3	4.3±.2	52.7±9.2
Ae	0.053±0.006	10.9± 3.6	0.38±.11	0.68±0.20	0.18±.07	6.6± 0.5	4.4±.2	2.1±0.3
Bh	0.062±0.005	2.9± 1.7	0.35±.11	0.54±0.15	0.12±.02	7.6± 0.6	5.2±.1	2.2±0.4
Bc	0.016±0.005	9.2± 4.7	0.23±.05	0.33±0.08	0.08±.01	3.2± 0.5	5.6±.2	0.6±0.3
C	0.009±0.003	17.6± 3.4	0.23±.05	0.22±0.08	0.06±.02	1.4± 0.1	5.6±.2	0.3±0.1

Prethinning basal area removed	Urea	Triple superphosphate
0%	0 kg N/ha	0 kg P/ha
20%	151 "	45 "
40%	303 "	

Treatment plots were square, 0.08 ha, with inner 0.04-ha measurement plots, and were arranged in a block pattern with shared boundaries. Buffer strips were provided by the portion of the treatment plot exterior to the measurement plot. Initial measurements of DBH were made in late May, 1969. Applications of urea and triple superphosphate were made in early June. Thinning operations also were carried out in early June. Merchantable stem material to a 7.62-cm top was removed from the measurement plot. Slash was left in place. Remeasurements of DBH were made 4 years later in early June, 1973.

Results: Analysis of variance revealed significant differences related to thinning (T) and N application for the four incremental parameters and, in addition, interaction between N and P in terms of total and merchantable volume increment. Increments by treatment, of mean DBH, BA, total and merchantable volume, are presented in Table 10. Mean DBH increment increased significantly with fertilization in the absence of thinning under the high N treatment only. Thinning, in the absence of fertilization, produced significantly greater mean DBH increments and, with fertilization, resulted in some of the significantly greatest DBH increments in any of the experiments of the series. Under no thinning regime did the addition of P to N fertilization produce a significant difference in mean DBH increment. Mean BA increment, total volume increment, and merchantable volume increment, that is, in each case, the increment put on the residual trees, increased generally with fertilizer treatment. Only under the heaviest thinning regime and without N did the residual trees fail at least to equal the growth of the untreated controls. In general, in terms of stand volume, thinning did not significantly alter increment. Fertilizers at equivalent levels evoked similar responses in absolute terms regardless of thinning regime. Gains over controls for both total and merchantable volume for the three best treatments were as follows:

Table 10. Four-year growth response of 55-year-old jack pine on Stokes sand (Breithaupt Township) to various combinations of thinning from below and nitrogen and phosphorus fertilization

Treatment	Increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.61	2.09	16.34	16.46
P45	.69	2.47	19.38	19.43
N151	.76	2.73	22.05*	21.79*
N151 P45	.81	2.89*	22.66*	22.69*
N303	.86*	3.05*	24.58*	24.32*
N303 P45	.79	2.86*	21.91*	22.23*
T20	.84*	2.09	16.87	16.65
T20 P45	.81	2.28	17.92	17.96
T20 N151	1.17*	2.67	21.47*	21.25
T20 N151 P45	1.07*	2.75	21.76*	21.67*
T20 N303	1.17*	3.12*	24.75*	24.61*
T20 N303 P45	1.09*	2.93*	23.68*	23.37*
T40	.89*	1.54	12.51	12.31
T40 P45	1.07*	1.87	14.87	14.78
T40 N151	1.40*	2.42	19.25	19.10
T40 N151 P45	1.37*	2.44	19.61	19.40
T40 N303	1.35*	2.62	21.38*	21.01
T40 N303 P45	1.35*	2.09	17.32	16.91

* Statistically significant difference at the 95% confidence level

Treatment	Tot. vol. incr. minus control	Merch. vol. incr. minus control
T 20 N 303	8.41 m^3/ha	8.15 m^3/ha
N 303	8.24 "	7.86 "
T 20 N 303 P 45	7.34 "	6.91 "

It might be noted that these results do not include the amounts of wood removed by thinning.

Experiment--Phosphorus, Potassium and Nitrogen

It was recognized that elements other than N may be in deficient supply in these soils. Alternatively, in the spirit of Liebig's classic "Law of the Minimum" (i.e., yield is increased chiefly by increasing the availability of the minimum factor, and when this factor is no longer minimum, another factor may become so), it was postulated that with N requirement met, P and K may become limiting.

Phosphorus availability to plants depends on several characteristics of the soil system, such as aeration, compaction, moisture, soil particle size, temperature, pH value, availability of other nutrients, and the amount of organic matter present.

Potassium, unlike other essential macro-nutrient elements, is not known to be incorporated into any organic compound, but is believed to function as an osmotic regulator. It occurs in trees mainly in a soluble ionic form and is leached readily from the foliage. Because of the ease with which it is washed out of organic matter by precipitation, K may be recycled several times by the tree cover in the time required to decompose the organic matter.

Objective: To determine responses of a semimature jack pine stand on a sandy outwash site to various combinations of P and K with and without N, and thus provide data for the estimation (considering that fertilizer prices will vary) of the most profitable combination of these fertilizers for similar stands on similar sites in northwestern Ontario.

Method: The experiment took the form of a 4 x 4 x 2 completely randomized factorial with P supplied as triple superphosphate, K as muriate of potash and N as commercial-grade prilled urea, as follows:

Triple superphosphate	Muriate of potash	Urea
0 kg P/ha	0 kg K/ha	0 kg N/ha
22 "	58 "	151 "
45 "	117 "	
90 "	175 "	

Treatment plots were square, 0.08 ha, with interior 0.04-ha measurement plots. The plots were arranged in a grid pattern with shared plot boundaries, buffer strips being provided by the portion of the treatment plot external to the measurement plot. Initial measurements of DBH were made in late May, 1969. All fertilizers were applied in early June, 1969. Remeasurements of DBH were made in early June, 1973.

Results: Significant differences in DBH increment, BA increment, total and merchantable volume increments, related to N treatment, were indicated by analysis of variance (Table 11). In addition, the interaction of N and P for DBH increment was also significant. In the absence of additional N, no combination of P or K fertilizer at any level was able to produce an effect on growth sufficiently great to raise it significantly above growth on the control plot. With N fertilizer alone there was a marked effect on growth in terms of all parameters, although there were no statistically significant differences between the treatment and the control. In general, in the presence of N fertilizer, but not without it, growth appeared to increase with increasing P application. Successive additions of K to the N and P treatments appeared to produce a variable effect; in the absence of P (but with N) there was increasing growth, but at higher levels of P, with or without N, decreasing growth. In no cases were interactions of K with P, or K with N, significant.

It might be noted that in this experiment with a treatment supplying 151 kg/ha of N, and 67 kg/ha of P, (the equivalent to 336 kg/ha of urea and 336 kg/ha of triple superphosphate), growth-over-controls in terms of both total and merchantable volume was greater than with any other treatment in any experiment, being nearly 13 m^3/ha, or in conventional timber measure, over 2 cords, stacked volume per acre in 4 years, or roughly ½ cord/acre/yr extra.

Treatment	Tot. vol. incr./control	Merch. vol. incr./control
N 151 P 67	12.85 m^3/ha	12.91 m^3/ha
N 151 P 22 K 175	11.83 "	12.06 "
N 151 P 67 K 58	11.14 "	11.04 "

Table 11. Four-year growth response of 55-year-old jack pine on Stokes sand (Breithaupt Township) to various combinations of phosphorus, potassium and nitrogen fertilizers

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.59	2.48	19.35	19.50
K58	.74	2.69	20.77	21.14
K117	.79	2.55	19.98	19.93
K175	.81	2.61	20.55	20.34
P22	.69	2.11	16.26	16.58
P22 K58	.79	2.70	21.06	21.17
P22 K117	.64	2.52	19.80	19.64
P22 K175	.66	2.73	21.19	21.37
P45	.74	2.75	21.47	21.58
P45 K58	.69	2.67	21.02	20.96
P45 K117	.66	2.42	19.06	18.97
P45 K175	.71	2.59	20.30	20.27
P90	.61	2.45	18.89	19.23
P90 K58	.64	2.73	20.69	21.12
P90 K117	.71	2.27	17.83	17.78
P90 K175	.64	2.21	17.29	17.37
N151	.84	3.12	24.25	24.56
N151 K58	.84	2.98	23.29	23.40
N151 K117	.89*	3.31*	25.86*	25.77
N151 K175	.94*	3.56*	27.70*	27.96*
N151 P22	.97*	3.57*	27.77*	28.00*
N151 P22 K58	.97*	3.32*	25.58	25.89
N151 P22 K117	.89*	3.85*	30.33*	30.17*
N151 P22 K175	.99*	4.02*	31.18*	31.56*
N151 P45	1.09*	3.44*	26.82*	27.07*
N151 P45 K58	.79	3.59*	28.10	28.14*
N151 P45 K117	.94*	3.37*	26.11*	26.22*
N151 P45 K175	.99*	3.72*	28.74*	29.16*
N151 P67	1.09*	4.13*	32.30*	32.41*
N151 P67 K58	.99*	3.89*	30.49*	30.54*
N151 P67 K117	.94*	3.76*	29.80*	29.50*
N151 P67 K175	.89*	2.91*	22.67	22.87

* Statistically significant difference at the 95% confidence level

Experiment--Nitrogen, Phosphorus and Magnesium

In the previous experiment P, K and N were evaluated, whereas in this experiment it was felt necessary to consider potential limitation of Mg. Magnesium is a macroelement essential in the structure of chlorophyll and acts in intermediary metabolism as an enzyme activator.

Objective: To determine responses of a semimature jack pine stand on a sandy outwash site in northwestern Ontario to Mg fertilizer with and without N and P, singly and in combination.

Method: The experimental design was a 3 x 3 x 2 (split plot with Mg) factorial with two replications. Application rates were as follows:

Urea	Triple superphosphate	Magnesium oxide
0 kg N/ha	0 kg P/ha	0 kg Mg/ha
151 "	22 "	62 "
303 "	45 "	

N was supplied as commercial-grade prilled urea, P as triple superphosphate and Mg as magnesium oxide. Treatment and measurement plots, one and the same, were square, 0.08 ha, randomized in two blocks for N and P with minus-Mg and plus-Mg treatments for each N-P combination adjacent to each other (i.e., 'split plot' design). Initial measurements of DBH were made in late May, 1969. Fertilizers were applied early in June, 1969. Remeasurement of DBH was completed in early June, 1973.

Results: Analysis of variance revealed highly significant differences related to N treatment for DBH increment, BA increment and total and merchantable volume increment. Also, the interaction of N and P for BA increment and total and merchantable volume increment proved statistically significant. Increments of DBH, BA per ha, and total and merchantable volume per ha are presented in Table 12. Examination of these data indicates clearly a response to N but with a very slight suggestion (none, statistically) of additional response associated with application of N over and above 151 kg/ha. The best total and merchantable volume responses in terms of growth over controls were:

Treatment	Tot. vol. incr. minus control	Merch. vol. incr. minus control
N 303 P 45 Mg 62	9.55 m^3/ha	9.56 m^3/ha
N 303 P 22	8.26 "	8.10 "
N 151 P 45 Mg 62	7.92 "	7.94 "

Statistically, no additional volume could be attributed to the addition of either P or Mg.

Table 12. Four-year growth response of 55-year-old jack pine on Stokes sand (Breithaupt Township) to magnesium with and without nitrogen and phosphorus singly and in combination

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.61	2.20	17.75	17.69
Mg62	.66	2.08	16.80	16.75
P22	.66	2.61	21.11	21.11
P22 Mg62	.74	2.63	21.27	21.27
P45	.66	2.54	20.45	20.57
P45 Mg62	.61	1.94	15.64	15.53
N151	.81*	3.03*	24.61*	24.50
N151 Mg62	.74	3.16*	25.67*	25.58*
N151 P22	.94*	2.88*	23.41*	23.26*
N151 P22 Mg62	.84*	2.66	21.36	21.50
N151 P45	.84*	3.07*	24.77*	24.79*
N151 P45 Mg62	.86*	3.16*	25.67*	25.63*
N303	.86*	3.16*	25.64*	25.53*
N303 Mg62	.79*	2.97*	23.94*	23.87*
N303 P22	.89*	3.21*	26.01*	25.79*
N303 P22 Mg62	.86*	3.12*	25.07*	25.07*
N303 P45	.99*	3.05*	24.70*	24.64*
N303 P45 Mg62	.99*	3.37*	27.30*	27.25*

* Statistically significant difference at the 95% confidence level

Experiment--Different Nitrogen Fertilizers

Controversy still exists concerning the most efficient N fertilizer for jack pine forest on sandy soils. The present experiment was designed to test response to four nitrogen fertilizers: urea, urea formaldehyde, ammonium sulphate, and ammonium nitrate.

Urea was selected for its high N content (45%), which permits low handling and application costs. Urea is readily soluble in water and rapidly hydrolyzes to NH_4^+ ions, eventually forming ammonium carbonate. Ammonium is a form of N which can be readily assimilated by the forest crop. Urea increases the pH of soil solutions and raises the P and dissolved organic matter levels of soil solutions. Leaching losses of fertilizer are minimal with urea applications because of low nitrification rates associated with boreal forest soils. The conversion of NH_4^+, plus the increase in pH in the zone of application of the fertilizer, may create conditions where fertilizer loss through NH_3 volatilization occurs. The NH_4^+-salts, ammonium sulphate $(NH_4)_2SO_4$), and ammonium nitrate (NH_4NO_3), do not raise the pH of the soil and hence are less subject to gaseous loss.

Ammonium sulphate, which has a N content of 21%, is also soluble in water and produces readily absorbed NH_4^+ ions. Ammonium sulphate has been shown to release K and Ca from the forest floor because, under natural conditions, leaching is limited by the concentration of mobile anions, and hence the addition of $(NH_4)_2SO_4$ supplies $SO_4^=$ anions as carriers for K and Ca. The displaced ions are available for plant uptake.

Ammonium nitrate has a N content of 33%. This fertilizer has the advantage of supplying N in the two forms (NH_4^+ and NO_3^-) most readily absorbed by vegetation. Nitrate fertilizers require very little moisture to go into solution and thus may be beneficial on dry sites. Nitrate, which is the most mobile form of N, could promote rapid assimilation.

Urea-formaldehyde has a N content of 38%. Although at present this is a high-cost fertilizer, the cost factor is secondary to the determination of the biological effect. The low water solubility of urea-formaldehyde provides available N slowly. By controlling the rate of solution, the N can be provided in an available form for a longer period of the growing season.

<u>Objective</u>: To compare responses of a semimature jack pine stand on a sandy outwash site in northwestern Ontario to similar applications of the following N fertilizers: urea, urea-formaldehyde, ammonium nitrate, ammonium sulphate.

Method: The experimental design was a 4 x 2 factorial with four replications. Treatment and measurement plots were one and the same, square, 0.04 ha, with shared boundaries, arranged in separate blocks for each replicate. As the objective was to compare fertilizers among themselves, an untreated control was not included. Nitrogen at equivalent rates (element basis) was supplied in four forms at the following rates:

Urea	Urea formaldehyde	Ammonium nitrate	Ammonium sulphate
90 kg N/ha	90 kg N/ha	90 kg N/ha	90 kg N/ha
224 "	224 "	224 "	224 "

Initial measurements of DBH were carried out in late May, 1969. Fertilizers were broadcast applied in early June, 1969. Remeasurements of DBH were completed in early June, 1973.

Results: Increments of DBH, BA per ha, and total and merchantable volume per ha are presented in Table 13. Analysis of variance yielded no significant difference between means for any treatment or level.

Table 13. Growth response of 55-year-old jack pine on Stokes sand (Breithaupt Township) to comparable levels of four nitrogen-containing fertilizers.[a]

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
U90	.84	2.93	22.01	22.30
UF90	.74	2.73	20.44	20.75
AN90	.86	3.09	23.09	23.40
AS90	.84	2.99	22.59	22.79
U224	.86	3.27	24.88	24.94
UF224	.79	3.07	23.00	23.30
AN224	.91	3.26	24.88	24.92
AS224	.86	2.81	21.14	21.40

[a] U urea
UF urea formaldehyde
AN ammonium nitrate
AS ammonium sulphate

CONTACT BAY EXPERIMENT

A ninth experiment was located southwest of Dryden, on Avery silty sand (Zoltai 1965), a till of very low base status, with a high proportion of the sand and stone content being dark colored basic fragments. Coarse (>2 mm) fragments occupy approximately 20% of the soil volume. Selected physical properties are presented in Table 1. Compared with Stokes sand in McIlraith or Breithaupt townships, Avery silty sand has a high silt at the expense of sand content. In terms of chemical concentrations (Table 14), Avery silty sand exhibits higher total N content, organic matter content, CEC and exchangeable Ca and Mg than does either of the Stokes profiles (Tables 2, 9).

Essential differences between Avery and Stokes soils, in terms of N cycling, were suggested in the report of Morrison and Foster (1974). The faster rate of organic matter breakdown on the Avery site, and the resultant faster rate of N release, were presumably fostered by the more favorable moisture conditions of this site. Conversely, on the Stokes soils, cycling of N appears to be restricted by a slower rate of organic matter breakdown and a much greater buildup of humus during the middle life of the stand.

The stand in the experimental area was closed, even-aged jack pine of fire origin, approximately 55 years of age (1969). Data on stocking, DBH and height are presented in Table 3. Ground flora species present in 1969 and identified from detailed tallies of two 1-m^2 quadrats per plot are indicated in Table 4.

Experiment--Nitrogen, Phosphorus and Potassium

It was recognized that the site whereon this experiment was established differed from that of the others in productivity and in type. In an experiment on Stokes sand in Breithaupt Township, N, P and K fertilizers were tried in combination, since it was recognized that while N is the element likely to be in critical supply, other elements could become limiting when the N requirement is met. The rationale behind the following experiment was similar, since it was recognized that response from one site should not be assumed to be indicative of response from another.

<u>Objective</u>: To determine responses of a semimature jack pine stand on a till site to various combinations of N, P, and K fertilizers, and thus provide basic data for the estimation of the most profitable combination of N, P and K fertilizers for similar stands on similar sites in northwestern Ontario.

Table 14. Mean chemical properties of the Avery silty sand with standard deviations

Horizon	N (%)	P (ppm)	K	Ca	Mg	C.E.C.	pH	Organic matter (%)
			(m.e./100g)					
L	0.834±0.082	55.8±20.6	5.54±1.05	25.55±3.36	8.74±1.57	65.3±3.3	5.3±.2	89.0±4.9
F	0.966±0.124	50.8±17.1	3.98±0.79	22.70±4.80	4.97±1.41	58.9±9.1	5.1±.3	73.3±7.2
H	0.545±0.127	30.9±10.2	1.74±0.26	13.68±3.73	2.30±0.67	38.5±8.4	5.0±.2	31.8±7.6
Ac	0.085±0.031	5.7± 1.9	0.43±0.14	2.67±0.63	0.54±0.19	9.3±0.9	5.0±.2	3.2±0.2
Bf	0.088±0.018	2.1± 1.3	0.32±0.06	1.96±1.02	0.30±0.08	9.0±1.3	5.3±.2	2.9±0.4
Bg	0.013±0.003	8.1± 2.8	0.23±0.04	0.34±0.12	0.06± .02	2.4±0.5	5.3±.2	0.8±0.2

Method: A completely randomized factorial experiment consisting of all combinations of the following N, P and K treatments (expressed on element bases) with N supplied as commercial-grade prilled urea, P as triple superphosphate and K as muriate of potash, for a total of 36 treatments, was chosen:

Urea	Triple superphosphate	Muriate of potash
0 kg N/ha	0 kg P/ha	0 kg K/ha
76 "	45 "	117 "
151 "	90 "	
227 "		
303 "		
378 "		

The assumption was made that third-order interactions would not be significant, and thus might be considered the error term. Treatment plots were square, 0.08 ha, with inner 0.04-ha measurement plots, the whole being arranged in a block design with shared treatment-plot boundaries. Buffers were thus provided by the portion of the treatment plot exterior to the inner measurement plot. Initial DBH measurements were made in late May, 1969. Applications of fertilizer were made by hand, care being taken to ensure uniform coverage, in early June, 1969. Remeasurements of DBH were made 4 years later in early June, 1973.

Results: Increments of mean DBH, BA, total and merchantable volume by treatment are presented in Table 15. Significant differences among N treatments occurred for increments of BA, and total and merchantable volume, although none of the means representing fertilized plots proved significantly greater than controls. While not statistically significant, some of the more prominent gains over control in terms of both total and merchantable volume increment were as follows:

Treatment	Total vol. incr. minus control	Merch. vol. incr. minus control
N 378 P 90 K117	9.82 m^3/ha	9.71 m^3/ha
N 378 P 90	9.95 "	9.49 "
N 151 P 90 K117	9.15 "	8.78 "

Table 15. Four-year growth response of 55-year-old jack pine on Avery silty sand to various combinations of nitrogen, phosphorus and potassium fertilizers

Treatment	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
Control	.66	2.33	19.95	19.60
K117	.46	1.87	16.57	16.22
P45	.66	2.57	22.48	21.94
P45 K117	.51	1.96	17.43	17.05
P90	.38	1.32	11.57	11.29
P90 K117	.51	2.25	19.38	19.54
N76	.64	2.54	21.64	21.21
N76 K117	.81	2.87	24.85	24.20
N76 P45	.58	2.44	21.28	20.96
N76 P45 K117	.56	2.30	19.67	19.14
N76 P90	.86	2.97	25.49	24.98
N76 P90 K117	.76	3.03	26.70	26.12
N151	.84	2.88	21.14	20.93
N151 K117	.81	3.22	28.19	27.49
N151 P45	.64	2.93	25.91	25.43
N151 P45 K117	.66	2.83	24.03	23.38
N151 P90	.61	2.64	23.45	22.91
N151 P90 K117	.76	3.31	29.10	28.38
N227	.51	2.02	17.81	17.41
N227 K117	.74	3.03	26.77	26.05
N227 P45	.89	3.14	27.36	26.72
N227 P45 K117	.61	2.42	21.27	20.80
N227 P90	.46	1.97	17.38	17.01
N227 P90 K117	.76	2.58	22.11	21.68
N303	.76	2.85	25.03	24.52
N303 K117	.56	2.89	25.35	24.84
N303 P45	.58	2.40	21.25	20.86
N303 P45 K117	.86	3.02	26.08	25.53
N303 P90	.79	2.73	23.52	23.24
N303 P90 K117	.64	2.63	23.21	22.77
N378	.74	3.04	27.02	26.42
N378 K117	.71	2.86	24.87	24.46
N378 P45	.76	2.72	23.48	23.01
N378 P45 K117	.53	2.24	19.70	19.23
N378 P90	.84	3.46	29.90	29.09
N378 P90 K117	.86	3.42	29.77	29.31

Inspection of all data (Table 15) revealed no clearcut trends, except a generally increasing growth response to increasing levels of N supplied alone, along with some suggestion (again, not statistically significant) that P in addition to N, or K in addition to N, might promote additional growth. There is no real evidence to suggest that P or K either alone or in combination with each other, without N, will increase growth. There is some suggestion that they may even retard growth. Shortly after remeasurement, several plots in this experiment sustained severe damage in a windstorm. A subsequent salvage operation extended into a sufficient number of other plots to necessitate the termination of the experiment.

DISCUSSION

Forest fertilization is a form of technology and, as such, is not only amenable to improvement in itself but is also influenced by and, indeed, depends upon other technologies. As far as forest fertilization is concerned, silvicultural technology is only in its infancy. In fact, many of the most prominent advances made thus far, such as the development of high-analysis fertilizers like urea, ammonium nitrate or triple superphosphate, were made in disciplines far removed from silviculture. As there is no reason to believe that technological development in the fields of silviculture, chemistry, aerodynamics, or in any of the other fields that impinge upon forest fertilization will cease, it is necessary to view forest fertilization at its present stage, as only a stage in a continuum of development. Nevertheless, it is a stage through which it might well be necessary to pass before further development can take place.

Changes in the technological base are evident even in the short period between the first establishment of these Dryden experiments and the present writing -- changes such as the increasing availability of "forestry grade" urea, the development of sulphur-coated urea, experimental N sources such as IBDU (isobutylidene diurea), the greater use of helicopters and the development of loading and spreading equipment. Within the field of silviculture itself much has been learned over the past several years, both from these and from other experiments. A new generation of silvicultural field experiments, for example, could confidently delete certain proposed practices and investigate new ones.

The economic climate is even more changeable. During 1974, for example, the price of urea fertilizer increased markedly. At the same time, however, so did woods labor costs and hauling costs, and consequently the cost of wood and the price of paper.

The aim of this report is not simply to elucidate the input-output variables of jack pine fertilization as a static system but to learn to handle a changing system. To this latter end much of the work in forest fertilization at the Great Lakes Forest Research Centre has been directed. A management model or computer simulator for jack pine with appropriate fertilizer, thinning, fertilizer-plus-thinning and economics subroutines, was developed and reported elsewhere (Hegyi 1974a, Hegyi and Tucker 1974). An in-depth economic analysis of the present experiments, with emphasis on economic tools and the rationale for evaluating fertilizer response, was also made and reported elsewhere (Tucker 1974). Biological aspects of fertilization have also received attention (Morrison and Foster 1974).

What has been learned thus far from the present experiments? First, N was the only element which, when singly applied, readily elicited a statistically significant response in terms of BA, total volume or merchantable volume growth-over-controls. Furthermore, while various combinations of P with N, K with N, Mg with N, P and K with N, P and Mg with N or thinning with N exhibited significantly greater growth than did the controls, in only one case did the addition of a second element, in this case P, produce an effect on growth significantly greater than the effect of N alone. Even in this case, however, the result was inconclusive as N alone did not produce an effect differing from the controls in a statistically significant manner. Inspection of the data, however, revealed some suggestion of greater growth due to the addition of P, although this was neither statistically significant nor consistent. This is in general agreement with the earlier observation of Morrison and Foster (1974) concerning the relationship of N and P to jack pine growth in this area.

The most economically advantageous treatment as estimated by Tucker (1974) in terms of net present worth, and using cost data pertinent to these experiments, was a combination of N and P. The average standing merchantable volume in the northern area (i.e., on the Stokes sand site in McIlraith and Breithaupt townships) was approximately 120 m^3/ha. This figure was estimated by pooling and averaging initial volumes of all plots in the 55-year-old stand at the time of experiment establishment. Four years added approximately 18 m^3/ha to this figure (estimated from appropriate control plots), whereas with the better treatments 30 m^3/ha was added, for net gains due to treatment of approximately 12 m^3/ha in 4 years. On the Avery silty sand site at Contact Bay, the average standing volume at age 55 was approximately 230 m^3/ha; growth of controls over 4 years was an additional 20 m^3/ha, whereas growth under treatments equivalent to those above produced approximately 25 m^3/ha, for a net gain of 5 m^3/ha during the same time period. These latter estimates were based, however, on a limited number of plots. In terms of general orders of magnitude, the best responses of jack pine on sandy outwash sites in the present study were somewhat better than responses to fertilizer by similar-aged stands of black spruce; Quebec recorded 8 m^3 growth-over-controls in 5 years (Weetman 1968), and Newfoundland stands showed 9 m^3 growth-over-controls in 4 years (Van Nostrand and Bhure 1973).

While averages are useful for orientation, progress requires that the factors contributing to the variable response be identified. Chief among these are rate of application and site quality. The general relationship between growth-over-controls and rate of application, utilizing data pertinent to May-applied urea and sandy outwash sites only, was presented by Morrison and Foster (1974). While the unstratified data showed considerable scatter, there was generally increasing response to urea up to 303 kg N/ha, although some of the largest increases in terms of growth-over-controls for urea only were associated with an application of 252 kg N/ha.

In relation to site, in terms of growth-over-controls, examination of the data suggests a generally inverse relationship between site index and response, with the greatest increases, both percentage and absolute, on the poorest sites, and the smallest increases on the best sites. This is generally consistent with a theory of N-deficiency. Therefore, it would seem more advantageous, if the present trends continue to be borne out, to consider N fertilization of jack pine principally on poorer sites.

In one experiment, N from different sources, viz. urea, urea-formaldehyde, ammonium nitrate and ammonium sulphate, were compared. No statistically significant differences in responses to equivalent N levels were detectable nor did there appear to be any trends. It should be remembered that this comparison was limited to one site condition and four sources. It is not inconceivable that on other site conditions detectable differences might have occurred. Weetman and Algar (1974) reported that a 40-year-old jack pine stand in Quebec showed an apparent preference for ammonium nitrate over urea, although the response was measured in terms of such parameters as needle weight, N concentration of needles, N content of needles and combinations thereof, and BA. In general, of the four compared, urea is the highest in N, being 45% as opposed to 38% for urea formaldehyde, 33% for ammonium nitrate and 21% for ammonium sulphate; these figures require adjustment when comparing fertilization costs on the basis of equivalent weights of N applied. Thus, while the quoted 1975 price per unit weight of fertilizer, F.O.B. at Sault Ste. Marie, Ontario, is in the order urea formaldehyde > urea > ammonium nitrate > ammonium sulphate, the estimated cost per unit weight of N applied (being made up of both material cost and handling cost) is in the order ammonium sulphate > urea formaldehyde > ammonium nitrate > urea.

As for placement of urea fertilizer, no clear-cut advantage could be ascribed to any one method, although the lack of detectable differences may be due to the generally small response associated with the relatively high site index. For practical purposes, broadcasting still appears to be the most efficient method, although an approximation of the hole-placement method, had it proved desirable, might have been achieved through aerial application of fertilizers at the same rate per ha, only in the form of large self-burying balls.

There are many factors to be considered in relation to timing of fertilizer application, two of which are examined in separate experiments in the present series: month of application, and single dose versus various split applications. The experiment, carried out with urea at two levels plus control, applied in May, July and September, revealed significant differences between control and high N treatment *rates* for May and September, but no difference between *times*. The magnitude of the response was substantially (though not in a statistically significant manner) greater for the May treatment than for comparable July or September treatments. When adjusted over three growing seasons rather than four growing seasons, however, the response of the September high N treatment was only slightly less than that of the May high N treatment. A similar pattern was not evident with lower N treatment. From an economic viewpoint, the September treatment has the disadvantage that investment is carried a further 8 to 9 months before treatment can affect growth.

A second time-related aspect of fertilization investigated in the present series was that involved in the experiment comparing various split applications of urea. Only for the single dose and the half first spring—half second spring split were statistically significant differences of treatment over controls elicited. No statistically significant differences between *times* were detected, although the *single-dose treatment* did appear to give more favorable results than did the various *split treatments*. The economic appraisals of split treatments must take into consideration not only magnitude of response, but also factors influencing cost of treatment, including those favorable to split doses (principally lower carrying charges as a result of having at least part of the fertilizer on the ground for a shorter period of time), and those unfavorable to split doses (principally increased flying time).

While regulating the forest by optimizing rotation length and protecting against fire, insects and disease can increase the wood supply in general, silvicultural means of economically increasing growth in mid- or late-rotation (as opposed to the beginning of a rotation when improved stock can be planted, spacing can be optimized, and the regeneration period can be shortened) are limited chiefly to fertilization, thinning and combinations thereof. Thinning by itself, in the experiment where thinning and fertilization were tried in combination, did not increase the percentage of volume growth over controls (merchantable volume increment x 100/standing merchantable volume). That is, the percentage volume growth remained roughly the same regardless of thinning regime. In terms of absolute volume growth, the higher thinning intensity, being the 40% reduction in standing basal area, resulted in a generally reduced increment because of the depletion of growing stock. Presumably, then, the benefits of thinning relate to the harvesting of mortality, and the increasing of crop tree mean DBH. Fertilization, on the other hand, added roughly similar amounts by treatment regardless of thinning regime, the best effect in general being with N alone at 303 kg/ha. In the case of the higher thinning regime this increment accrued to fewer stems, yielding possible benefits in terms of reduced harvesting costs. While there seems little likelihood that thinning-from-below, as was incorporated into the experiment mentioned above, will become an operational practice in semimature jack pine stands managed for pulpwood, a thinning practice with possibilities for commercial application in such stands is strip or corridor thinning (Mattice and Riley 1975). Such a practice opens the possibilities for fertilizing leave-strips from racks with large hopper-equipped surface vehicles.

SUMMARY

Although too much reliance should not be placed on these data since they are fourth- and not tenth-year data (and indeed, no hard and fast recommendations are intended), certain general trends are in evidence. First, it would appear that chiefly N and, when N demand is satisfied, P, are the elements limiting growth in this area. The best treatment in terms of growth-over-controls, in fact, was a combination of 151 kg N/ha and 67 kg P/ha supplied as urea and triple superphosphate, respectively. It is evident from the series of experiments as a whole that response was greatest on the poorest sites and least on the best sites. From a biological viewpoint, no one N fertilizer type appeared superior to others, although urea would appear to have an economic advantage. Again from a biological viewpoint, broadcast application was as effective as or superior to other methods of placement; furthermore, it is presumed that it would enjoy a considerable economic advantage as well. It was evident, too, that spring application was as effective as or superior to application later in the growing season. There is no evidence that splitting the application will increase the effectiveness of treatment. Evidence suggests that a single application of fertilizer is most effective. Economic consideration would likely favor the one-application treatment as well.

Owing to the work involved in fertilizer experimentation, only a limited number of treatments could be incorporated into the various experimental designs. Other factors needing examination include weather

and soil-moisture conditions at time of application, ages of stands to be fertilized, and relation between stocking and response. In addition, there are technological innovations to be tested. These would include new fertilizers, fertilizers in combination with other new silvicultural techniques, and improved means of applying fertilizers.

With respect to the general place of fertilization in jack pine forest management in northern Ontario, it should be emphasized that fertilization is a silvicultural tool only, and in fact a tool in its developmental infancy. Its application hinges on economic considerations. Tucker (1974), in demonstrating the economic feasibility of some of the treatments of the present series, was able to do so only by involving the allowable cut effect. Even within this allowable cut framework, economic factors such as stumpage price, treatment costs, extraction costs, and costs in relation to other methods of securing additional wood all have to be taken into consideration. With fertilization in its early stages of development, however, it is presumed that there will be considerable room for improvement.

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