AN APPROACH TO PREDICT NUTRIENT STATUS AND GROWTH RESPONSE OF FERTILIZED JACK PINE BY FOLIAR DIAGNOSIS

by

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ABSTRACT

A factorial experiment testing N, P and K fertilizers, and a series of simpler, two-treatment (control and NPK) fertilizer trials were established in a range of jack pine stands to determine the application of a foliar analysis technique for predicting potential growth response of stands to fertilization. The technique was based on a foliar diagnostic system, and involved the simultaneous comparisons of first season responses in dry weight, nutrient concentration and nutrient content of foliage in a single graphical display. Preliminary diagnosis revealed that N was the major growth limiting nutrient on the majority of the sites. The technique was therefore tested with foliar N response data, and individual stands were ranked according to potential responsiveness to fertilizer additions. It is recommended that actual (longterm) growth responses be compared with predicted responses to test the accuracy of the technique.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF ILLUSTRATIONS

Page

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INTRODUCTION

The conventional fertilization field trial generally requires five or more year's observation to accurately evaluate the growth response and economic return obtainable from fertilization (Rennie, 1972). Several rapid methods for assessing and indexing the nutrient status of stands have been suggested to eliminate the need for lengthy and costly field trials, and to more wisely allocate fertilizer and silvicultural treatments to forest stands. These methods include soil analysis (Wilde, 1958), comparison of growth rates of stands (Armson, 1974), visual symptoms and plant tissue analysis (Morrison, 1974). In evaluating the use of these methods in forestry, Morrison (1974) concluded that aside from the conventional fertilization field trial, plant tissue analysis seemed to be the method most promising in forestry application. Thus, several studies have used growth and nutrient parameters of foliage to predict the effectiveness of fertilizer treatments (Keay *et al.*, 1968; Weetman and Algar, 1974; Tamm, 1974; Turner and Olson, 1976; Coyne and van Cleve, 1977). Such an approach is based upon a causal relationship that exists between foliar biomass response and stemwood volume increments (Tamm, 1974). Thus, if foliar growth and foliar nutrient status of a stand can be reliably evaluated, prescription of forest management practices such as fertilization can be precisely made.

This thesis examines the nutrient status and response potential of some of the largest jack pine (*Pinus banksiana* Lamb.) plantations and managed stands in the Beardmore-Nipigon area of northern Ontario after fertilization. Earlier studies of fire origin black spruce (Picea mariana (Mill.) B.S.P.) suggested that nitrogen availability in the soil may be the critical limiting factor in this area (Clemmer, 1977). This hypothesis could be extended to plantation jack pine since responses of natural jack pine stands to nitrogen fertilization have been observed in the boreal forest of Canada (Weetman et al., 1976; Morrison et al., 1976, 1977).

OBJECTIVES AND APPROACH

The main objective of the study reported here was to develop a rapid predictive technique for evaluating the potential responsiveness of jack pine stands to fertilization using foliar analysis.

The approach adopted was to develop and modify a foliar diagnostic system proposed by Timmer and Stone (1978) into a predictive technique which would estimate response of trees to fertilizer application. The technique would be tested and demonstrated on data from two sets of foliage samples obtained from actual fertilization trials in the first season after treatment.

To test the effectiveness of the proposed technique it was hoped that each set of foliage samples would exhibit nutrient stresses varying from deficiency to sufficiency; thus reflecting a full range of possible growth responses in trees. One data set was obtained from foliage sampled sequentially during the growing season in an intensively monitored fertilization trial (later termed base trial) established in 1977. The other set of data was obtained from single, autumnal samples of foliage collected from a series of simpler (satellite) trials, established on a range of site and stand conditions, in the following year (1978).

The experimental design of the base trial (a complete factorial testing N, P and K fertilizers) also provided a strong statistical base for making diagnostic interpretations; a preliminary step before response prediction in foliar analysis (see Literature review). Individual satellite trials (consisting of only 2 treatments) did not have such diagnostic capability. However, since standardized treatments were involved it was hoped that results from the base trial could be linked with those of the satellite trials by comparing foliar growth and nutrient response data.

LITERATURE REVIEW

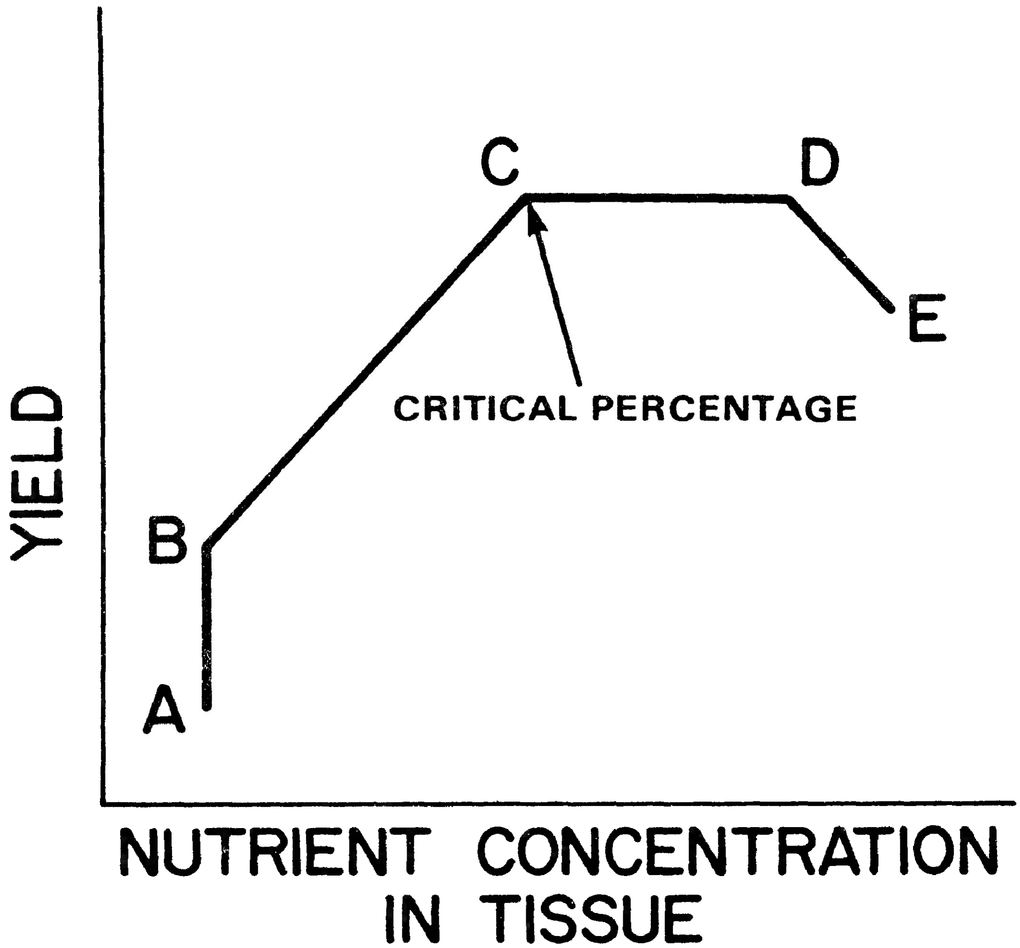
EARLY DEVELOPMENT OF FOLIAR ANALYSIS

Foliar analysis is based on the concept that the plant itself can be an accurate indicator of nutrient availability in the soil (Smith, 1962). Foliar analysis has become a well established method for interpreting nutritional deficiencies in agricultural and horticultural crops, but has only recently gained significance in diagnosing nutrition requirements of forest stands (van den Driessche, 1974).

Lavender (1970) notes that early studies into the quantitative and chemical analysis of plants were initiated by de Sausure in 1804, followed by Liebig in 1840. Despite the precedents, it was not until 1905 that Hall suggested that chemical analysis of plant material might prove useful in evaluating fertilizer responses. Further work in this field was discouraged for another twenty years due to the difficulties of establishing standards by which plant analysis studies may be compared (Lavender, 1970). After this period, research was aimed primarily at standardizing sampling techniques to control variability due to 1) age of sampled organ, 2) season, 3) position in crown, 4) shading, 5) fruiting, 6) weather conditions and to develop analytical and interpretive methodology (e.g. Lowry and Avard, 1969; Leaf, 1973; van den Driessche, 1974).

The basis for interpretation of foliar analysis lies in the relationship between foliar nutrient concentration and growth. This relationship can be depicted graphically in a typical growth response curve (Armson, 1973) and was demonstrated earlier in pot cultures by Mitchell (1939) and in mature forest stands by Mitchell and Chandler (1939). Macy (1936) felt that the central concept in interpreting such a curve lay in the fact that there was " a critical percentage of each nutrient in each kind of plant, above which there is luxury consumption and below which there is poverty adjustment, which is almost proportional to the deficiency until minimum percentage is reached". The basic yield curve can be divided into four distinct phases. When nutrient transport into the plant is just sufficient to keep pace with increase in yield, nutrient levels are maintained at a minimum percentage (A to B, Figure 1). Nutrient deficiency occurs when both yield and and tissue nutrient concentration increase (B to C, Figure 1) and corresponds to Macy's (1936) poverty adjustment range since yield responds positively to the added nutrient. The critical nutrient percentage (Point C, Figure 1) of plant tissue may be termed the optimum nutrient concentration since maximum yield is obtained with a minimum input of nutrients. An increase in tissue nutrient concentration beyond Point C does not improve plant yield, and is considered luxury consumption (C to D, Figure 1). Higher concentrations (D to E, Figure 1) can be detrimental or toxic to growth as yield is reduced with increasing concentration levels. Ulrich (1968) held that Macy's critical percentage was too specific and therefore defined a critical nutrient level, as a range of concentrations, in contrast to the fixed percentage defined by Macy (1936).

Swan (1969) and Wilde (1958, 1966) established ranges of some critical foliar concentrations for individual coniferous species. However



SECTION	CHANGE IN YIELD	CHANGE IN NUTRIENT CONCENTRATION	STATUS
A → B	+	0	MINIMUM PERCENTAGE
B → C	+	+	DEFICIENCY
C → D	0	+	LUXURY CONSUMPTION
D → E	−	+	TOXICITY

Fig. 1. Generalized representation of yield as a function of nutrient concentration in tissue of plants.

the application of these values to natural stands was limited because the concentration levels were developed under ideal conditions in pot cultures. Generally it is difficult to extrapolate results from pot trials to field conditions since in pot trials the trees are grown only to seedling size, in an artificial climate, and in a disturbed soil (Mead and Pritchett, 1971). Greenhouse studies may give excellent information on the nutrition of seedlings, but the results are not necessarily applicable to mature trees growing under natural conditions (Tamm, 1964).

Nutrient composition in plant tissue may be expressed in relative terms such as <u>concentration</u> (i.e. percentage or ppm of oven-dry weight) or in absolute terms such as <u>content</u> per fascicle, leaf or plant. Content may reflect plant uptake of an element more accurately since it is expressed on a plant or organ basis. Interpretation of foliar analysis results have usually been based on foliar elemental concentrations alone (see reviews by Leaf, 1973; van den Driessche, 1974), even though diagnosis may often be obscured by dilution effects (Timmer and Stone, 1978). In as much as dilution associated with seasonal leaf expansion was recognized by some early workers (McHargue and Roy, 1932; Sampson and Samisch, 1935), possible dilution induced by fertilization response was not recognized until much later (Steenbjerg, 1951; Leaf <u>et.al.</u>, 1970), and was sometimes confused with antagonisms (Cain, 1959). Interrelationships between individual needle growth and changes in foliar nutrient composition were recently ellucidated by Tamm (1974), Weetman and Algar (1974) and Timmer and Stone (1978). To account for confounding effects such as dilution and luxury uptake, it was suggested that three leaf parameters such as dry weight, nutrient concentration and nutrient content should be used in foliar analysis studies to more accurately explain fertilizer responses.

Absolute nutrient content in foliage can be expressed by several methods. Sampson and Samisch (1935) expressed content per 1000 square inches of leaf area, while more recent studies have expressed content on a per needle basis, since needle weight can be measured more quickly and usually more accurately than leaf area (Leaf, 1973; Weetman and Algar, 1974).

Richards and Bevege (1972) clearly distinguished between the diagnostic use of foliar analysis, which involved identification of factors that influence growth, and its predictive use to forecast growth responses after fertilization. Obviously, successful response prediction can not take place without prior knowledge of the specific limiting nutrient (i.e. foliar diagnosis). In fact diagnosis and response prediction should be undertaken as separate complimentary analyses (Morrison, 1974). Hence the approach adopted in this study was to conduct diagnosis before attempting to predict fertilizer response from foliar analysis data.

FOLIAR DIAGNOSIS

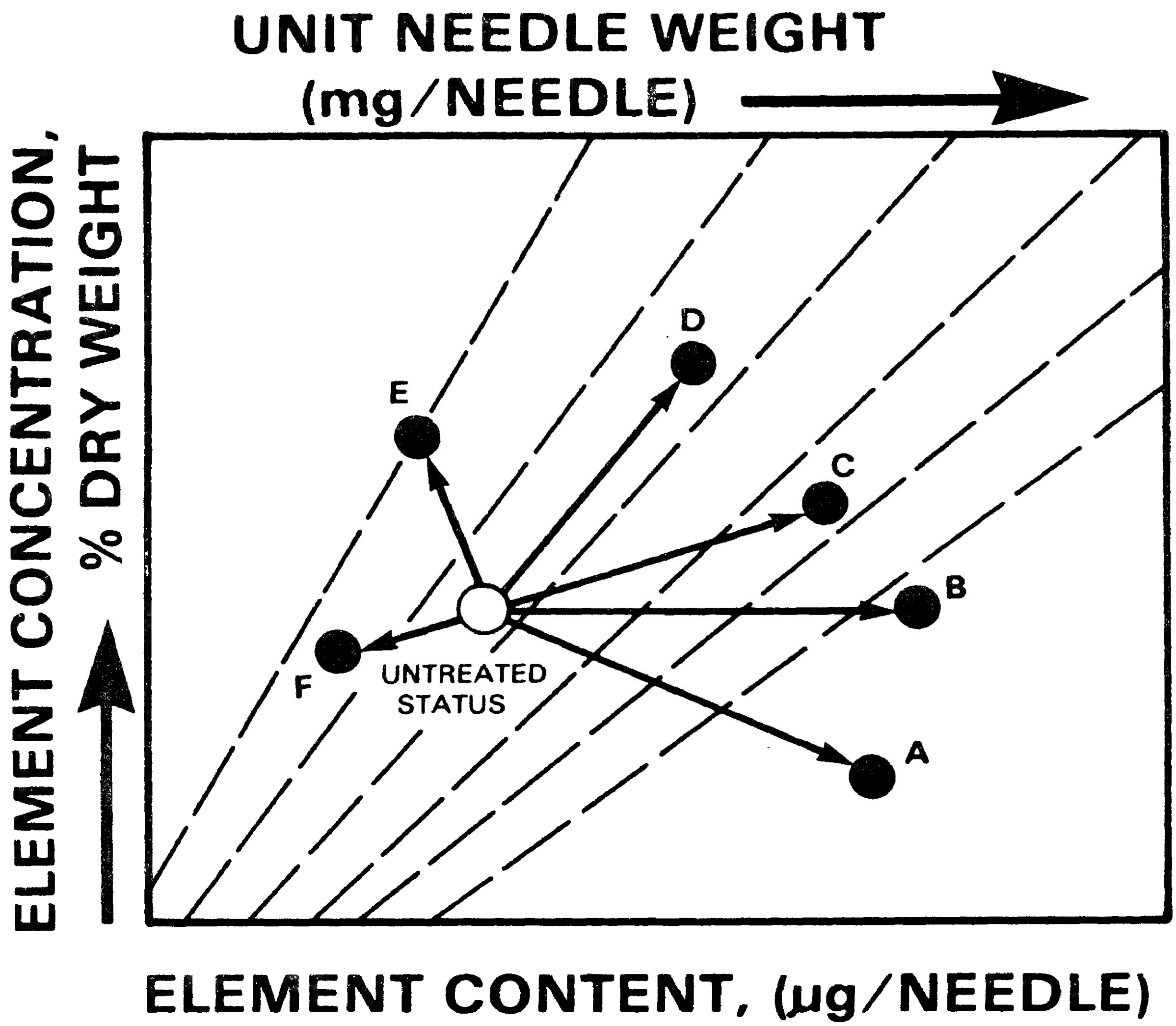
As discussed previously, accurate interpretation of foliar analysis requires a thorough understanding of the interrelationship between foliage dry weight, nutrient concentration and nutrient content. Yet often diagnosis is based on separate and independent assessments of these parameters (Leyton, 1957; Keay *et al*., 1968; Wells, 1970) which may complicate simple recognition of their interrelationships.

Timmer and Stone (1978) developed a diagnostic system which involved simultaneous comparison of these three foliar parameters by combining them in a single display as in Figure 2. Foliar responses are depicted by arrows joining the control or untreated status (open symbols) with the treated status (shaded symbols) of the stand. Interpretations are based on changes in elemental concentration, content and dry weight of foliage following fertilization (as shown in Figure 2), and may apply to applied nutrients or to any others. Provided that shoot growth is determinate, and that foliage dry weight response is closely correlated with fertilizer growth response, the direction of the arrow (Figure 2) simplifies interpretation of nutrient status by identifying instances of dilution (A), sufficiency (B), deficiency (C), luxury uptake (D), toxicity (E) and antagonisms (F) (Timmer and Stone, 1978).

This graphical approach was used for diagnostic purposes in this study, and also formed the basis for a proposed technique for predicting the response potential of stands, which will be discussed later (in Materials and Methods section).

USE OF FOLIAGE FOR PREDICTING FERTILIZER RESPONSES

Keay _et al_. (1968) has suggested earlier that strong correlations between initial needle weight increments and subsequent stemwood increases have value in permitting rapid estimates of future fertilizer growth responses. Biomass and dimensional parameters of leaves such as weight, size and surface area have been used successfully to characterize treatment responses in other fertilization studies (Brix and Ebell, 1969; Weetman and Algar, 1974; Tamm, 1975; Miller and Miller, 1976; Turner and Olson, 1976; Coyne and van Cleve, 1977). Generally foliar biomass



DIRECTION OF SHIFT	RESPONSE IN			CHANGE IN	
	NEEDLE WEIGHT	NUTRIENT		NUTRIENT STATUS	POSSIBLE DIAGNOSIS
		CONC.	CONTENT		
A	+	−	+	DILUTION	NON—LIMITING
B	+	O	+	UNCHANGED	NON—LIMITING
C	+	+	+	DEFICIENCY	LIMITING
D	O	+	+	LUXURY CONSUMPTION	NON—TOXIC
E	−	++	±	EXCESS	TOXIC
F	−	−	−	EXCESS	ANTAGONISTIC

Fig. 2. Schematic relationships between nutrient concentration, nutrient content and dry weight of needles following fertilization (adapted from Timmer and Stone, 1978).

increment is closely correlated with tree volume increment (Tamm, 1974) and this relationship seems to hold for other growth parameters as well (Table 1). In one instance Calvert and Armson (1975) have noted poor correlations between leaf weight and height growth of 5 year-old planted jack pine. Weak correlations were most likely related to the early stage of development of the plantation (Armson, 1979).

In fertilization studies, individual weight of needles tends to be used more often than leaf surface area as a response parameter since it is easier to determine, and correlates well with leaf surface area (Gordon and Gatherum, 1967; Mellor and Tregunna, 1972). Individual leaf weight has an important advantage as a response parameter in that significant responses can be detected within one growing season after fertilizer treatment (Brix and Ebell, 1969; Turner and Olson, 1976; Miller and Miller, 1976) as opposed to 3 to 5 years needed for the more conventional response parameters of DBH, basal area or volume (Rennie, 1972).

For determinate species, correlations between leaf weight and stemwood response are higher during the first growing season following treatment than later seasons, since bud primordia are initiated during the previous growing season (Timmer and Stone, 1978). Evaluation of treatment responses for determinate species beyond the first season would have to follow procedures used by (Brix and Ebell, 1969; Miller and Miller, 1976) which account for the change in the number of needles or shoots induced by fertilization.

Since needle weight has proven to be a reliable index of tree

Table 1. Simple correlation coefficients between first season needle dry weight and subsequent growth response: from other fertilization trials with coniferous species.

Species	Age (years)	Response Period (yrs)	Response Variable	r#	n	Data Source
Japanese larch	8	2	Height	.79**	9	Leyton (1957)
Maritime pine	13	2	Log basal area	.82**	27	Keay *et al.* (1968)
Loblolly pine	7	2	Height	.87*	6	Wells (1970)
Loblolly pine	7	2	Basal area	.95**	6	Wells (1970)
Balsam fir	15	2	Leader length	.89**	17	Timmer and Stone (1978)
Balsam fir	15	2	Shoot length	.88**	17	Timmer and Stone (1978)
Jack pine	40	3	Basal area	.80*	12	Weetman and Algar (1974)
Red pine	38	5	Volume	.95	4	Leaf *et al.* (1970,1975)
Douglas fir	20	5	Volume	.76*	7	Ebell (1972)

*, **= Significant at 0.05 and 0.01 levels respectively

#= calculated by the author

growth response in many fertilization field trials (Table 1), it was employed as a preliminary response variable in this study. Actual growth responses will be obtained by remeasurement of the trees after a suitable response period (3-5 years), and will provide an opportunity to evaluate the reliability of using foliage dry weights as an index for forecasting future growth response of trees to fertilization.

MATERIALS AND METHODS

THE STUDY AREA

Location

The study area was located in the Superior (B.9) and Nipigon (B.10) Sections of the Boreal Forest Region (Rowe, 1972) near Beardmore, 200 kilometers northeast of Thunder Bay, Ontario. The base trial was established in a 29 year-old jack pine plantation near the eastern shore of Lake Nipigon (49° 39' N, 88° 05' W)(Figure 3). The majority of the satellite trials were situated northeast of the base trial, while others were located in the central and southern sectors of the district.

Climate

The climate of the area is characterized by long winters, by a mean annual precipitation of 740 mm, and an 80 day frost-free period (Chapman and Thomas, 1968). The average growing season is 152 days (Rowe, 1972) and extends from mid-May to mid-September. For the MacDiarmid weather station (Figure 3), monthly normals for precipitation and temperature are listed in Table 2. Climatic data for the two seasons following fertilization are also shown (Table 3).

Stand Descriptions

The plantation in which the base trial was located, was established on wind-blown, medium to fine sands. The original stand consisted of mature jack pine and some residual black spruce. The site was logged

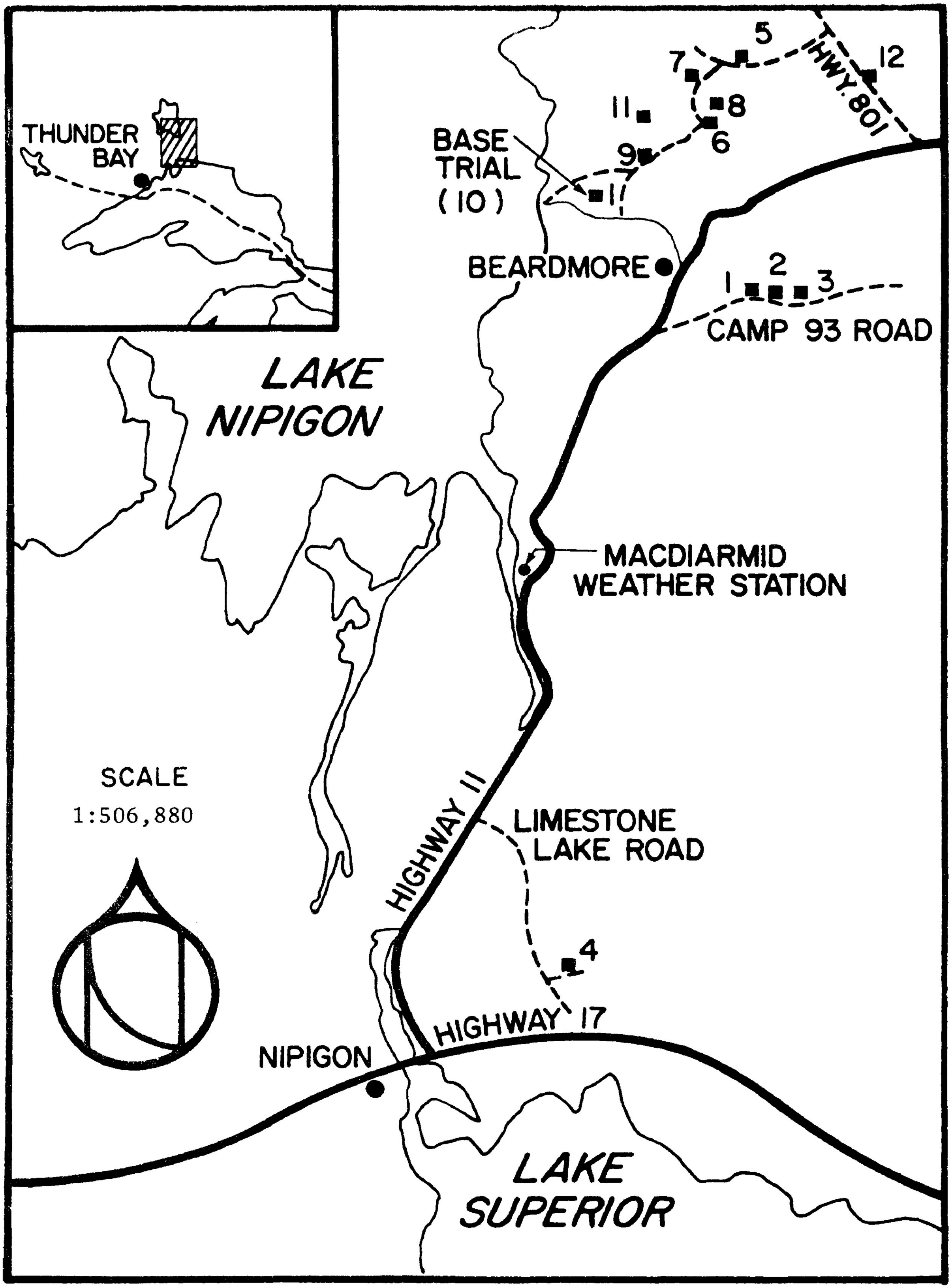


Fig. 3. Location of base trial and satellite trials within the study area.

Table 2. Thirty year climatic normals for the MacDiarmid weather station (Source: Environment Canada, 1975a, 1975b)

Month	Precipitation (mm)	Average Monthly Temperature (°C)	Avg. Monthly Maximum Temperature (°C)
May	67	7.2	12.4
June	90	13.7	18.9
July	75	17.0	22.1
August	79	16.2	21.1
September	91	10.8	15.3
October	73	5.1	9.8

Table 3. Monthly climatic indices for the MacDiarmid weather station for the 1977 and 1978 growing seasons (Source: Ontario Ministry of Natural Resources, 1978).

Year	Month	Precipitation (mm)	Average Monthly Temperature (°C)	Avg. Monthly Maximum Temperature (°C)
1977	May	42	11.5	18.3
	June	155	13.4	19.3
	July	43	16.5	23.6
	August	169	17.1	18.4
	September	87	11.4	16.8
1978	May	73*	12.8*	18.6
	June	77	12.8	17.2
	July	71	16.8	22.7
	August	104	16.2	21.5
	September	26	11.2	15.7

* = Monthly average based on May 10-31 instead of complete month.

and severely burnt by wildfire removing all residual slash and vegetation in the process (Marek, 1977).

The present plantation has a density of 1888 stems per hectare (Figure 4) and has average trees 12.9 m high with a DBH of 13.5 cm. Total basal area of the stand amounts to 26.2 m^2/ha with a gross volume of 182 m^3/ha (based on average of all trees within 24- 15 X 15m treatment plots). Current annual height increments, periodic annual basal area and volume increments for the untreated stand are provided in Figure 5 (see Establishment Procedures, page 28 for methods). Initially the stand exhibited a rapid height growth, which stabilized somewhat between age 10 and 15 and declined thereafter. Basal area increment peaked at approximately 12 years of age and then dropped off sharply, presumably due to increased crown closure. Sheath volume increment increased linearly for 20 years before tapering off, suggesting that intense competition limited growth at this stage of stand development.

As can be seen from Table 4 the satellite trials were located on a wide range of stand conditions which ranged in age from 10 to 55 years. Generally height growth of young jack pine is more rapid than maturing jack pine (U.S.D.A., 1965) which also seems evident from this data (Table 4) since higher height increments are associated with the younger trials. Stands with densities between 4000 and 6000 stems per hectare (Trials 4, 6, 7 and 8) produced larger volume increments, while trials of lower densities (Trials 5, 9 and 10) yielded smaller volume increments. This spectrum of satellite trials provided a suitable framework to test the responsiveness of different stands to fertilizer additions.

Fig. 4. The 29 year-old jack pine plantation where the base trial was located.

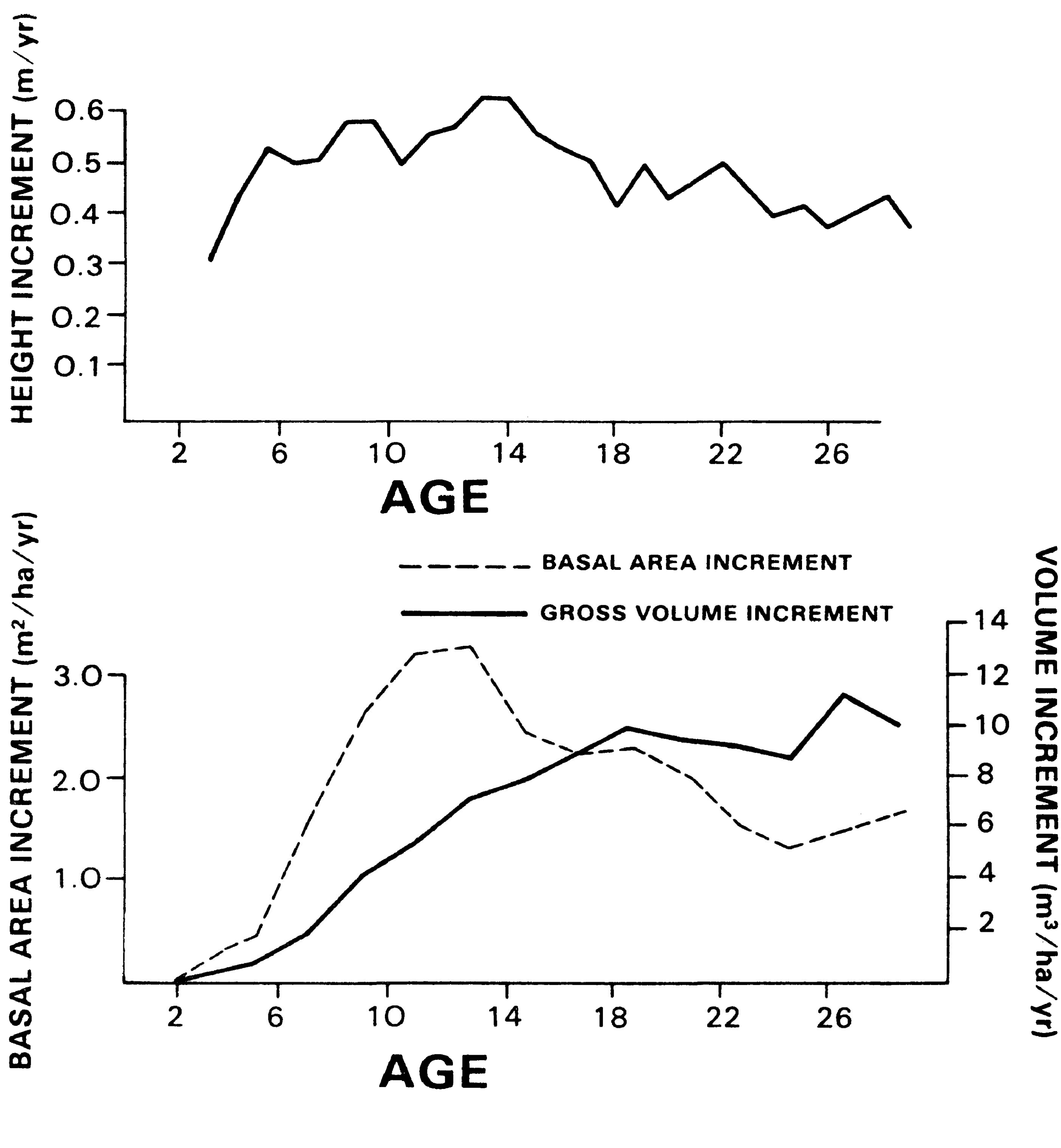


Fig. 5. Current annual height increment, periodic annual basal area and volume increment of unfertilized trees sampled at the base trial.

Table 4. Growth characteristics of sample trees from the base and satellite trials.

Trial	Age (years)	DBH (cm)	Height (m)	Density (stems/ha)	Basal Area (m^2/ha)	Gross Volume (m^3/ha)	PHI[1] (m/yr)	PBA[2] (m^2/ha/yr)	PVI[3] (m^3/ha/yr)
1	11	4.88	4.26	13200	10.4	75.8	0.66	---	---
2	14	5.10	6.33	8700	17.3	72.2	0.58	---	---
3	14	2.81	4.27	25000	15.5	74.9	0.36	---	---
4	16	8.27	7.62	4300	23.2	97.9	0.64	5.8	16.7
5	20	10.88	9.41	1438	13.0	67.3	0.52	2.3	5.9
6	20	7.69	10.10	5500	25.6	142.2	0.52	2.4	12.5
7	20	7.47	10.45	6050	26.4	153.0	0.50	2.4	12.8
8	20	7.66	10.92	6800	30.1	187.8	0.54	3.3	18.6
9	27	11.30	12.26	2033	20.1	132.4	0.45	2.0	9.7
10*	29	13.46	12.92	1888	26.2	182.3	0.40	1.6	10.6
11	33	9.31	13.85	4675	31.8	235.2	0.43	2.1	13.6
12	54	14.87	17.60	2400	41.1	382.7	0.35	1.3	12.7

1 = Periodic annual height increment
2 = Periodic annual basal area increment
3 = Periodic annual volume increment

Site Characteristics

The fine sandy soil of the base trial is an Orthic Humo-Ferric Podzol (Can. Dept. Agr., 1978) overlain by a thin surficial L-F-H layer which was partially covered by a carpet of feather mosses (Pleurozium schreberi (BSG.) Mitt., Polytrichum juniperinum Hedw., Ptillium crista-castrensis Hedw. de not.)(Figure 6). A profile description is given in Table 5; chemical and physical properties for each horizon are listed in Table 6.

This Podzol exhibited typical iron enrichment in the B horizon and greater cation exchange capacity in horizons containing larger amounts of organic matter and clay (Table 6). A distinct two-tiered root system was evident, with many fine feeder roots in the forest floor, and in the IIC horizon (Table 5). Apparently the trees were able to utilize the favourable growing conditions of the IIC horizon. In contrast to the solum, the IIC horizon had higher contents of silt and clay (thus better moisture retention) and generally higher levels of nutrients (except for P, see Table 6). Soil pH and base saturation also increased with depth (Table 6) presumably due to natural leaching processes.

The soil of the base trial is also representative of the soils of the satellite trials since all, except two, were established on similar Humo-Ferric Podzols. The two exceptions (Trials 2 and 5) were established on more recently deposited wind-blown sands, and were classified as Regosols (Can. Dept. Agr., 1978).

The diversity and composition of ground vegetation varied highly between trials (Table 7). Trials of lower density (e.g. trials 5 and 9)

Fig. 6. Typical soil profile of the base trial.

Table 5. Soil profile description of the base trial

Horizon	Depth (cm)	Description
L	4-1½	Green feather mosses and dead feather mosses; some fine undecomposed needles. Abrupt smooth boundary; 2-3 cm thick.
F-H	1½-0	Very dark brown (10 YR 2/2 m) semi-decomposing mosses and litter; fibrous, many micro to very fine roots; abrupt, smooth boundary; 2-4 cm thick.
Ae	0-5	Gray (10 YR 6/1 m) sandy loam; single grain; non sticky, loose (m); few fine roots; abrupt smooth boundary; 3-6 cm thick; pH 3.9.
Bf	5-15	Yellowish brown (10YR 5/8 m) sandy loam; single grain; non sticky(m); many medium to coarse roots; gradual wavy boundary; 8-12 cm thick; pH 4.8.
IC	15-75	Light yellowish-brown (2.5 Y 6/4 m) loamy sand; single grain; non-sticky, loose (m); very few fine roots; abrupt smooth boundary; 50-70 cm thick; pH 5.4.
IIC	75-82	Pale olive (5Y 6/3 m) silt loam; single grain; very sticky, plastic, friable; abundant fine roots; clear wavy boundary; 6-8 cm thick; pH 5.7.
IIIC	82+	Light olive gray (5Y 6/2 m) silt loam; single grain; slightly sticky, very friable; no roots. ph 7.6.

Table 6. Physical and chemical analysis of horizons from the Humo-Ferric Podzol at the base trial.

Horizon	Sand (%)	Silt (%)	Clay (%)	N[1] (%)	P[2] (ppm)	Exchangable K	Exchangable Ca	Exchangable Mg	CEC[3]	Fe[4] (%)	BS[5] (%)	OM[6] (%)	pH
						(m.e./ 100 grams of soil)							
Ae	62	33	5	0.040	8.3	0.04	0.2	0.09	2.77	0.18	15.5	1.03	3.9
Bf	64	32	4	0.038	21.1	0.05	0.2	0.08	3.04	0.29	15.5	1.39	4.8
IC	78	19	3	0.005	51.4	0.04	0.2	0.11	1.53	0.16	26.9	0.23	5.4
IIC	29	57	14	0.020	0.1	0.04	7.8	0.45	2.97	0.22	40.7	0.34	5.7
IIIC	37	60	3	0.012	15.3	0.02	7.4	0.42	1.37	0.17	72.9	0.13	7.6

1 = Total nitrogen

2 = Available phosphorus

3 = Cation exchange capacity

4 = Free iron oxides

5 = Base saturation

6 = Organic matter

Table 7. Common ground flora found at the base and satellite trials (from Gordon, 1979).

Species	Trial 1	2	3	4	5	6	7	8	9	10	11	12
<u>Mosses</u>												
Pleurozium schreberi (BSG.) Mitt.				*		*	*	*		*	*	
Polytrichum juniperinum Hedw.	*	*		*	*		*			*		
Ptilium crista-castrensis Hedw.						*		*		*	*	*
Dicranum polysetum Sw.										*	*	
<u>Lichens</u>												
Cladina rangiferina (L.) Harm.					*				*			
Cladina mitis (Sandst.) Hale W. Culb.					*				*			
Cladonia deformis (L.) Hoffm.					*				*			
Cladonia gracilis (L.) Wild.					*				*			
Cladonia cristatella Tuck.					*							
Usnea strigosa (Ach.) A. Eat.												*
Hypogymnia physodes (L.) W.Wats.												*
<u>Other Plants</u>												
Lycopodium clavatum L.										*		
Rubus idaeus L.				*								
Cornus canadensis L.						*	*	*		*	*	*
Vaccinium angustifolium Ait.	*	*	*		*	*	*	*	*		*	
Vaccinium myrtilloides Michx.								*			*	
Maianthemum canadense Desf.				*		*	*				*	*
Linnaea borealis L.									*		*	*
Diervilla lonicera Michx.							*			*		
Epigaea repens L.		*			*							
Oryzopsis pungens (Torr.) Hitchc.	*							*				
Coptis groenlandica (Oeder) Fern.								*				
Fragaria virginiana Duscnesne	*											

were associated with Cladonia, Cladina and Vaccinium species, while older established stands, with complete crown closure, exhibited a more diverse ground vegetation. The base trial (Trial 10) was dominated by feather mosses (Pleurozium, Polytrichum, Ptillium and Dicranum species) as were many of the older trials, probably due to higher crown closure. Younger stands (Trials 1, 2 and 3) with relatively thin F and H layers had sparse ground vegetation; a dense mat of needles was more common.

ESTABLISHMENT PROCEDURES

A randomized block experiment, consisting of twenty four 15 X 15m plots, was established in the base trial during the spring of 1977 to test factorial combinations of N, P and K fertilizers. Each plot contained between 40 and 50 trees and was partitioned into blocks with five meter buffer strips between individual plots (Figure 7). All trees were numbered with aluminum tags and were measured for diameter at marked points at breast height. Fertilizers were broadcast manually over the forest floor on 19 May 1977. Individual plots were subdivided into 3 equal areas with 1/3 of the fertilizer dosage applied to each area to insure an even distribution of fertilizer over the entire plot. Nitrogen was applied as urea, phosphorus as triple superphosphate and potassium as muriate of potash at 0 and 100 kg of element per hectare (See Appendix I for nature, analysis and make of fertilizers).

Needle growth response and leaf nutrient composition were monitored closely following treatment. A bi-weekly sampling schedule was adopted for June, July and August followed by monthly sampling for September and October. This schedule kept pace with the relative growth development of the foliage. Single shoot samples, containing both current and year-

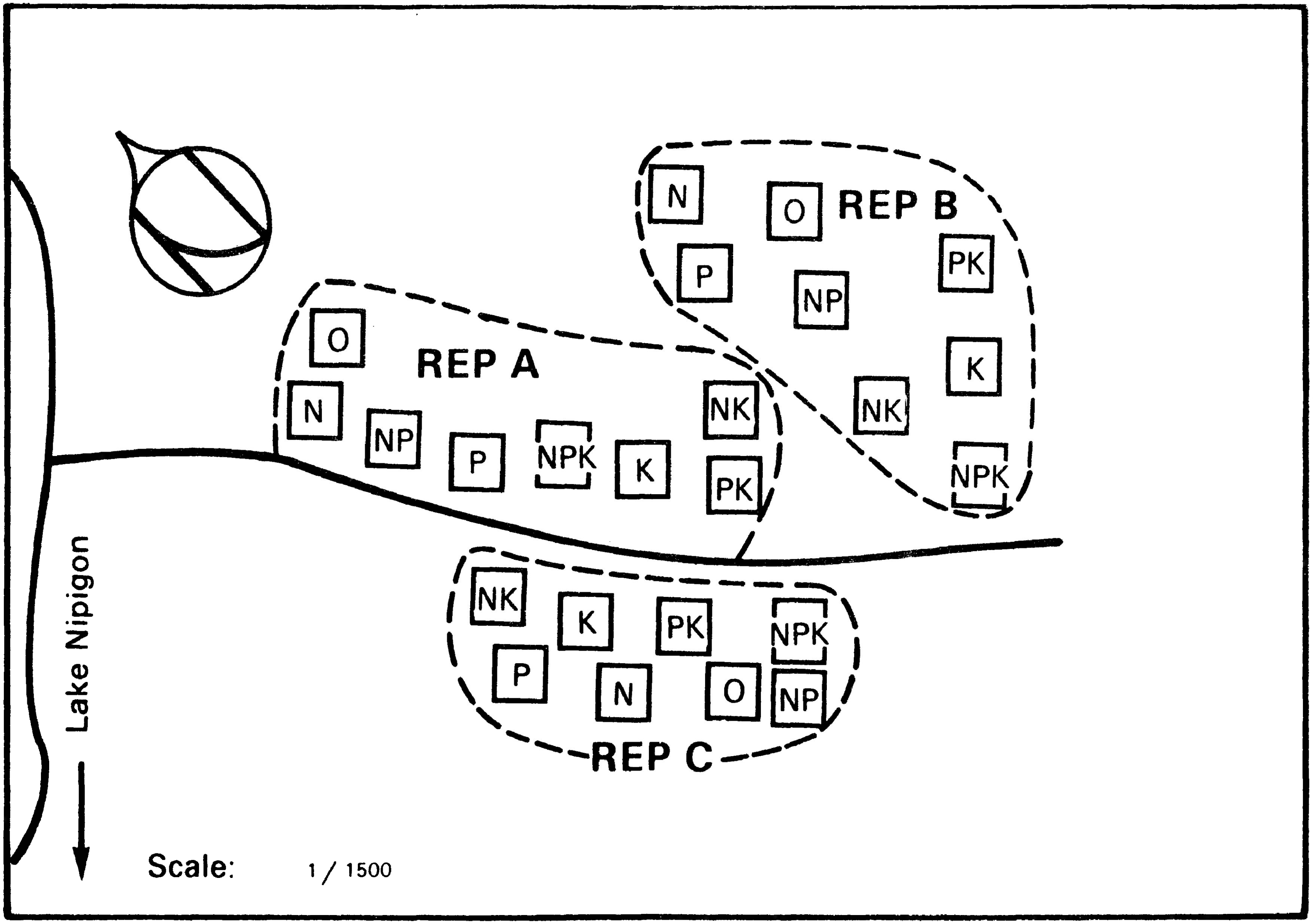


Fig. 7. Location of blocks and individual plots within the base trial.

old foliage, were taken from the upper third portion of the crowns of eight different trees and composited within each plot for subsequent laboratory analysis.

Each satellite trial consisted of a control and mixed treatment (100 kg each of N, P and K/ha) plot, replicated twice. All trials were established and fertilized between 23 May and 19 June 1978 with the same fertilizer material used in the base trial. Plot sizes varied from 0.0064 to 0.04 hectares according to stand density; a minimum of 50 trees were included in each. Diameter at breast height of all trees were measured before treatment, with remeasurement to be made in 5 years. Foliage samples of 1977 current foliage were taken before fertilization to establish pre-treatment nutrient levels. A second composite sample of 1978 current foliage was taken after fertilization from each plot on 6 October 1978, after the stands had entered dormancy.

Two trees of mean DBH, and two trees each at $\pm$ one standard deviation from DBH were destructively sampled outside the control plot of each trial to determine previous height, basal area and volume growth of each stand (see Table 4, Figure 5). Cross-sectional disks were cut at 50 cm intervals and internodal lengths were measured for each tree. Volume increment was based on the summation of sheaths from each 50 cm bolt. Sheath volume was determined by subtracting the inner bolt volume from the outer bolt volume. Taper was accomodated by averaging the radii from the top and bottom of each bolt (Eiber, 1979).

LABORATORY ANALYSIS

Soil Analysis

Samples were air-dried, sieved and stored for further analysis. The following analytical methods were employed on the fine-earth fraction of the soil:

1) Particle size by Bouyoucos hydrometer method (Day, 1965).

2) Soil reaction by soil-water paste method (Doughty, 1941).

3) Organic matter by loss-on-ignition (MacDonald, 1977).

4) Total N by semi-micro Kjeldahl digestion and distillation (Bremner, 1965).

5) Available phosphorus by extraction with 0.002 N H_2SO_4 buffered at pH 3 (Truog, 1930). Phosphorus in the extract was determined photometrically.

6) Free iron oxides by dithionite method (Olson, 1965).

7) Cation exchange capacity and base saturation by leaching with barium and ammonium acetate (Jackson, 1958).

8) Exchangeable K, Ca and Mg by extraction with 1N ammonium acetate (pH = 7)(Jackson, 1958). Base element concentrations were determined on a model 151 Instrumentation Laboratories atomic absorption spectrophotometer. Anion interferences were eliminated using strontium chloride as a solvent.

Analysis of Foliage

Current and one year-old needles were separated from the samples and dried at 70°C in forced-draft ovens for 24 hours. From each composite sample, 300 randomly chosen, oven-dried needles were weighed. The remaining sample was cleaned by hand and ground through a Wiley mill. The ground foliage was then packaged and put into labelled envelopes for storage. Ground samples were analyzed by the following procedures:

1) Nitrogen by semi-micro Kjeldahl digestion and distillation (Bremner, 1965).

2) Total phosphorus by the vandate-yellow method (Jackson, 1958).

3) Base element concentrations were determined on a model 151 Instrumentation Laboratories atomic absorption spectrophotometer using 1.0 g tissue dry weight samples in 1N HCl solution (MacDonald, 1977). Anion interferences were eliminated using strontium chloride as a solvent.

STATISTICAL ANALYSIS

Dry weight and chemical analysis data of foliage were averaged for each plot and were analysed on an IBM 360 computer using SPSS (Statistical Packages for the Social Sciences). Base trial data were subject to a 2 X 2 X 2 (N X P X K) factorial analysis of variance, while data pertaining to the satellite trials were analysed using a 2 X 12 (Treatment X Trial) factorial analysis of variance.

FERTILIZER RESPONSE PREDICTION

A technique for predicting the responsiveness of forest stands to fertilization was designed specifically for this study. It was developed from the foliar diagnostic system of Timmer and Stone (1978) which was based on a graphical technique first employed by Krauss (1965, 1967). The system was modified to allow response comparisons between different stands instead of different treatments within one stand. In as much as nutrient levels and dry weight of needles vary substantially from stand to stand (Tamm, 1964), it was necessary to insure that comparisons were made on a common base. This was accomplished by assessing only relative responses amongst individual stands, hence only treatment effects (i.e. differences between treated and untreated plots within a stand) were compared.

Thus, in Figure 8 the response in needle nutrient concentration and nutrient content are represented on the Y and X axis respectively. The origin depicts the common base, the initial (untreated) status of each stand. The dashed lines from the origin are lines of equal needle weight response.

For demonstrative purposes, A, B and C represent three stands suffering from a low, medium and high state of nutrient stress, respectively. Responses to the right or left of the Y-axis represent increases or decreases, respectively, of leaf weight. Provided that response in individual needle weight is closely correlated with future tree growth response (see Literature Review) interpretation is as follows: for stand A the large response in foliar concentration coupled with the small change in foliar content is indicative of luxury uptake of the nutrient in question. Since needle growth response was small, the stand is presumably not responsive to fertilizer additions. In contrast, stand C exhibited large increases in unit leaf weight and nutrient content which is indicative of a very responsive stand. Nutrient concentration responses were not as high as stand A since needle growth diluted concentration levels substantially. Thus, the magnitude of the angular shift of treated plots from the Y-axis signifies the first season's needle response and could provide a measure of the response potential of each stand to fertilizer additions.

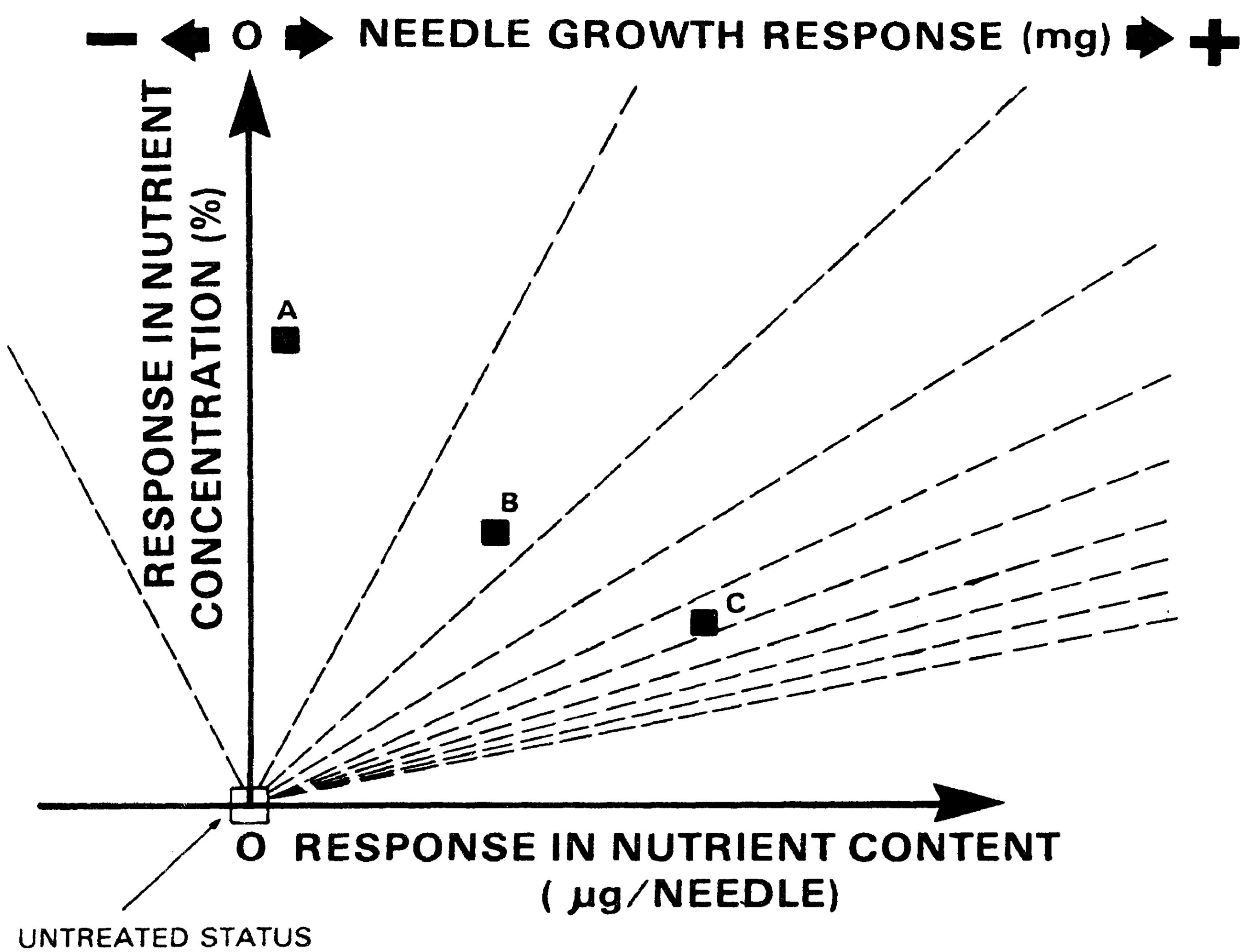


Fig. 8. Relative response of foliar nutrient concentration, nutrient content and dry weight of individual stands after fertilization (Response = differences between treated and untreated plots within a stand. Points A, B and C represent three stands suffering from a low, medium and high state of nutrient stress, respectively.)

RESULTS AND DISCUSSION

Response data from this study are presented sequentially, starting with a detailed examination of the seasonal patterns of growth and nutrient composition of foliage observed at the base trial, and followed by an assessment of foliar responses of the satellite trials. Since the identification of the major limiting nutrient (s) is a necessary and preliminary step in predicting fertilizer growth response in plants, this section will focus initially on the diagnosis of the nutrient status of the experimental stands.

PRELIMINARY DIAGNOSIS

Base Trial Results

Seasonal trends of dry weight and nutrient status of needles are shown in Figures 9-13. Analysis of variance revealed few significant treatment effects in the response data, hence only main effects are examined (Table 8, Figures 9-13). In contrast with the few responses obtained from P and K fertilization, N applications induced frequent changes in the foliage (Table 8). Nitrogen fertilization increased not only foliar dry matter production and N composition, but also the uptake of the other macro-nutrients such as P, K, Ca and Mg in the needles. This type of response pattern suggests a preliminary diagnosis of N deficiency in this stand, which becomes more apparent with a detailed examination of the seasonal patterns of individual leaf

Table 8. Analyses of variance of the [illegible], nutrient concentration and content of foliage sampled throughout the growing season.

Response Parameter	Main Effect	Sampling Date						
		June 15	June 28	July 13	Aug 3	Aug 23	Sept 23	Oct 21
Needle Dry Weight (mg)								
Current foliage	N	--	*	--	*	*	**	***
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Year-old foliage	N	--	--	--	--	--	--	--
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Concentration (%)								
Nitrogen	N	--	*	***	***	***	--	***
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Nitrogen (year-old foliage)	N	--	*	***	***	***	--	***
	P	--	--	--	--	--	*	--
	K	--	--	--	--	--	--	--
Phosphorus	N	--	--	--	--	--	--	--
	P	--	--	--	--	***	--	***
	K	--	--	--	--	--	--	(-)**
Potassium	N	--	--	--	--	--	--	--
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Calcium	N	--	--	--	--	--	--	--
	P	--	--	*	--	--	--	--
	K	--	--	--	--	*	--	--
Magnesium	N	--	--	--	--	--	--	--
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Content (ug/needle)								
Nitrogen	N	--	*	*	***	***	***	***
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--
Nitrogen (year-old foliage)	N	--	--	--	***	*	--	--
	P	--	--	(-)*	--	--	--	--
	K	--	--	--	--	--	--	--
Phosphorus	N	--	--	--	--	--	--	**
	P	--	--	--	--	--	--	**
	K	--	--	--	--	--	--	--
Potassium	N	--	--	--	--	--	--	**
	P	--	--	--	--	--	*	--
	K	--	--	--	--	--	--	--
Calcium	N	--	--	--	--	*	*	*
	P	--	--	*	--	(-)*	*	--
	K	--	--	--	--	*	--	--
Magnesium	N	--	--	--	--	--	--	*
	P	--	--	--	--	--	--	--
	K	--	--	--	--	--	--	--

*, **, *** = significant at 0.05. 0.01 and 0.001 % respectively.

parameters.

Effect of Fertilization on Dry Weight of Needles

Nitrogen fertilization significantly increased dry weight of current-year needles over the season, but not that of the older foliage (Table 8, Figure 9). Additions of phosphorus and/or potassium did not improve dry matter production of current or year-old foliage (Table 8). The main effect of N was a 20.1% increase in first season dry weight of current needles. Since +N current needles and -N year-old needles were of similar weights at the end of the growing season (Figure 9), N fertilization resulted in needle weights at the end of the first season which were only achieved after two years of growth in the untreated stand. Similar leaf weight responses were observed by Weetman and Algar (1974) with semi-mature jack pine in Quebec, which was also N deficient.

There was a rapid build-up of new leaf tissue early in the growing season (Figure 9). Differences between main effects of N increased as the season progressed, and became larger in the latter part of the season (Figure 9), suggesting that N deficiency occurs late in the summer and continues into the fall.

Effect of Fertilization on Foliar Nitrogen

Nitrogen fertilization resulted in increases of both concentration and content of foliar nitrogen (Table 8). However, P and K additions failed to change the overall N status of the foliage. Higher levels of N in current needles occured within three weeks of treatment (Figures 10 and 11, Table 8) and remained high for the duration of the season.

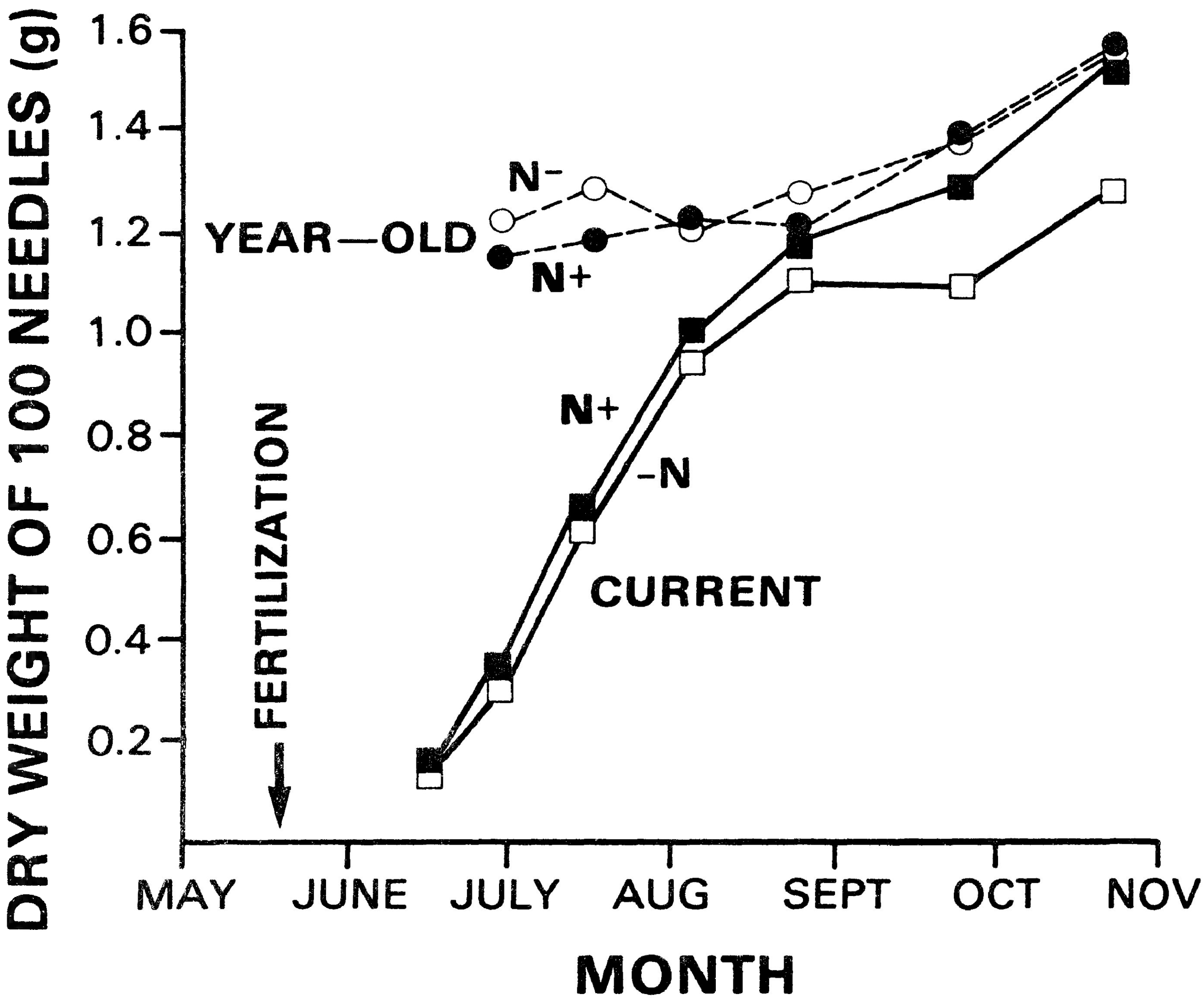


Fig. 9. Main effects of N on dry weight of needles during the growing season.

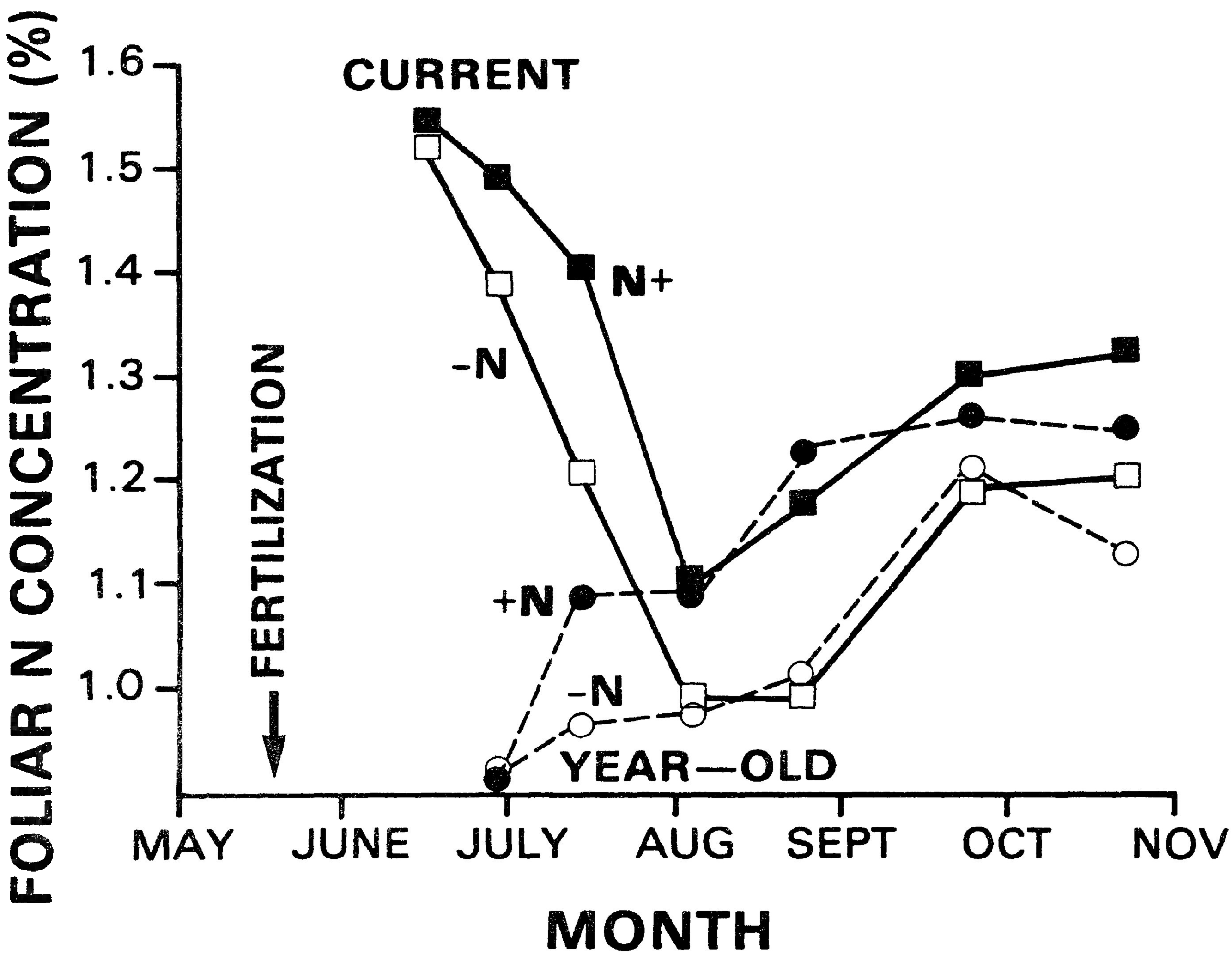


Fig. 10. Main effects of N on foliar N concentration during the growing season.

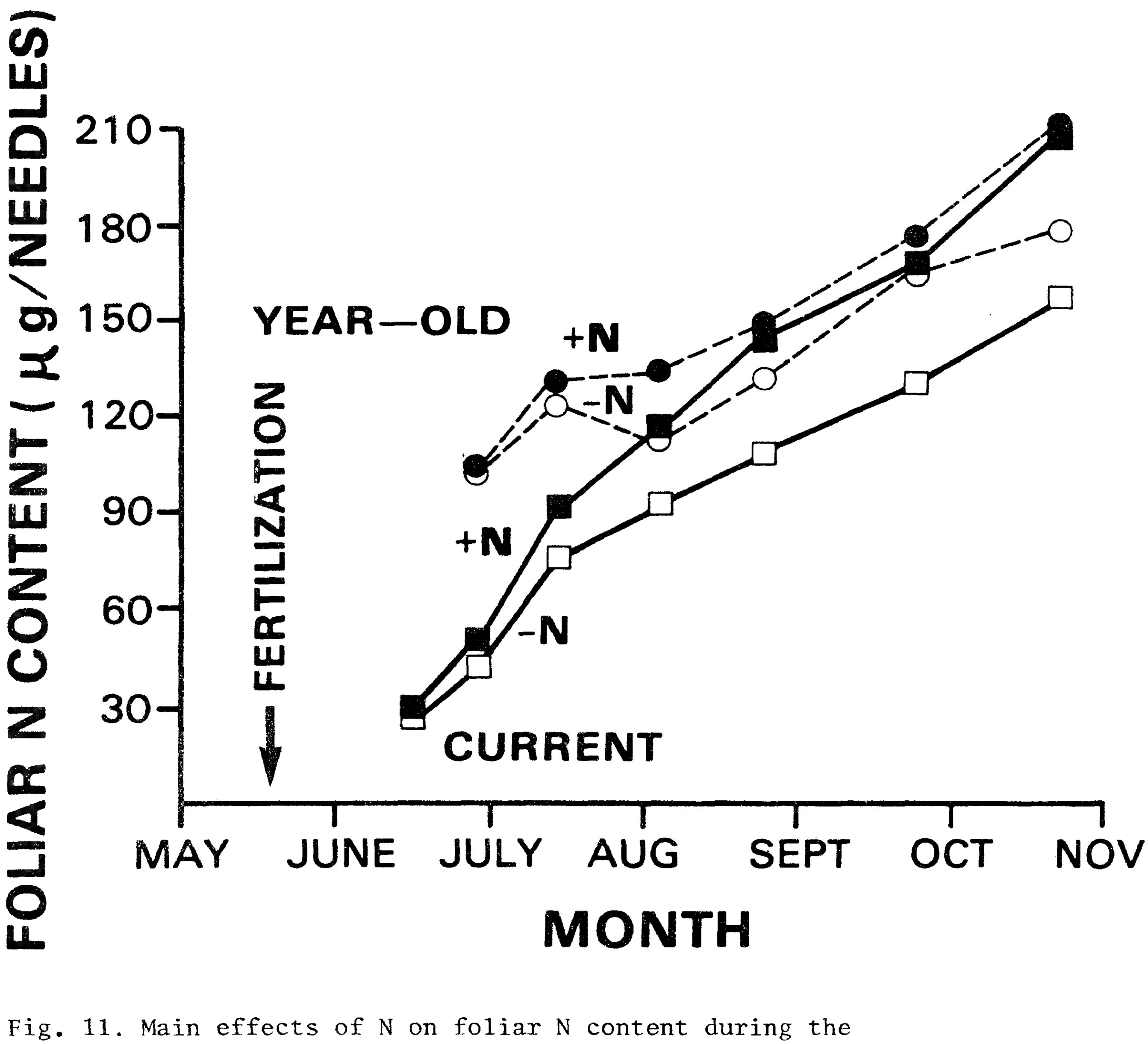


Fig. 11. Main effects of N on foliar N content during the growing season.

Concentration levels were severely diluted in June and July during the period of active needle elongation, but recovered in the latter part of the season (Figure 10) when needle growth slowed (Figure 9). Additions of N seemed to delay and reduce dilution of foliar N concentrations of new needles somewhat, presumably because of the increase in N availability in the soil (Figure 10).

The accumulation of N in the new needles showed a consistent and progressive rise throughout the growing season (Figure 11). The first significant response was evident at the end of June (Table 8), which preceded the response of dry weight of needles by about 6 weeks. This initial increase in uptake was most likely temporary luxury consumption or an early build-up of foliar N before subsequent growth.

It seemed that there was significant internal translocation of nitrogen from the old to the new tissue in the -N treatments only. This was shown by the sharp drop in N content of year-old foliage sampled in late July (Figure 11). This transfer coincided with the occurance of the lowest seasonal concentration of N in current needles (Figure 10), and also with a similar decline in needle growth rate (Figure 9). The simultaneous occurance of these events probably signified the onset of N deficiency in this stand during the growing season.

The absence of a corresponding internal transfer in the +N treatments at this time probably indicated that the N fertilized trees were adequately supplied with nitrogen during this stage of growth. Thus, critically low concentrations of N during the active growing season may trigger internal translocation between needles, and may also be a sensitive index of the actual critical nutrient level of N for this particular stand. In fact the lowest N concentration (0.97%) falls within the range of "moderate deficiency" (0.80 to 1.20) suggested by Swan (1969) for jack pine foliage. It has been suggested that the best time to determine critical nutrient levels of trees was during periods of rapid growth, after reserves were depleted and nutrient demands were greatest (Waring and Youngberg, 1972). Thus the lowest seasonal concentration value for N in foliage (0.97%) may provide a more accurate indicator of the critical concentration level in the stand rather than dormant season concentration levels (the more conventional time for foliage sampling).

Effect of Fertilization on Foliar P, K, Ca and Mg

Nitrogen fertilization did not affect uptake of foliar P, K, Ca and Mg significantly for most of the season, except during the months of September and October (Figure 12). The end-of-season build-up of these macro-nutrients was not accompanied by increases in concentration levels (Table 8). Apparently, transport of P, K, Ca and Mg to the foliage during the latter part of the season was just sufficient to keep pace with leaf expansion resulting from N fertilization. Nitrogen fertilization maintained needle growth and nutrient uptake late into the growing season which tends to support suggestions that fertilization can actually extend the active growing period of trees (Gessel, 1962; Larson and Gordon, 1969; Armson, 1977).

Phosphorus fertilization increased both concentration and content of P in the needles (Figure 13, Table 8), but did not increase leaf

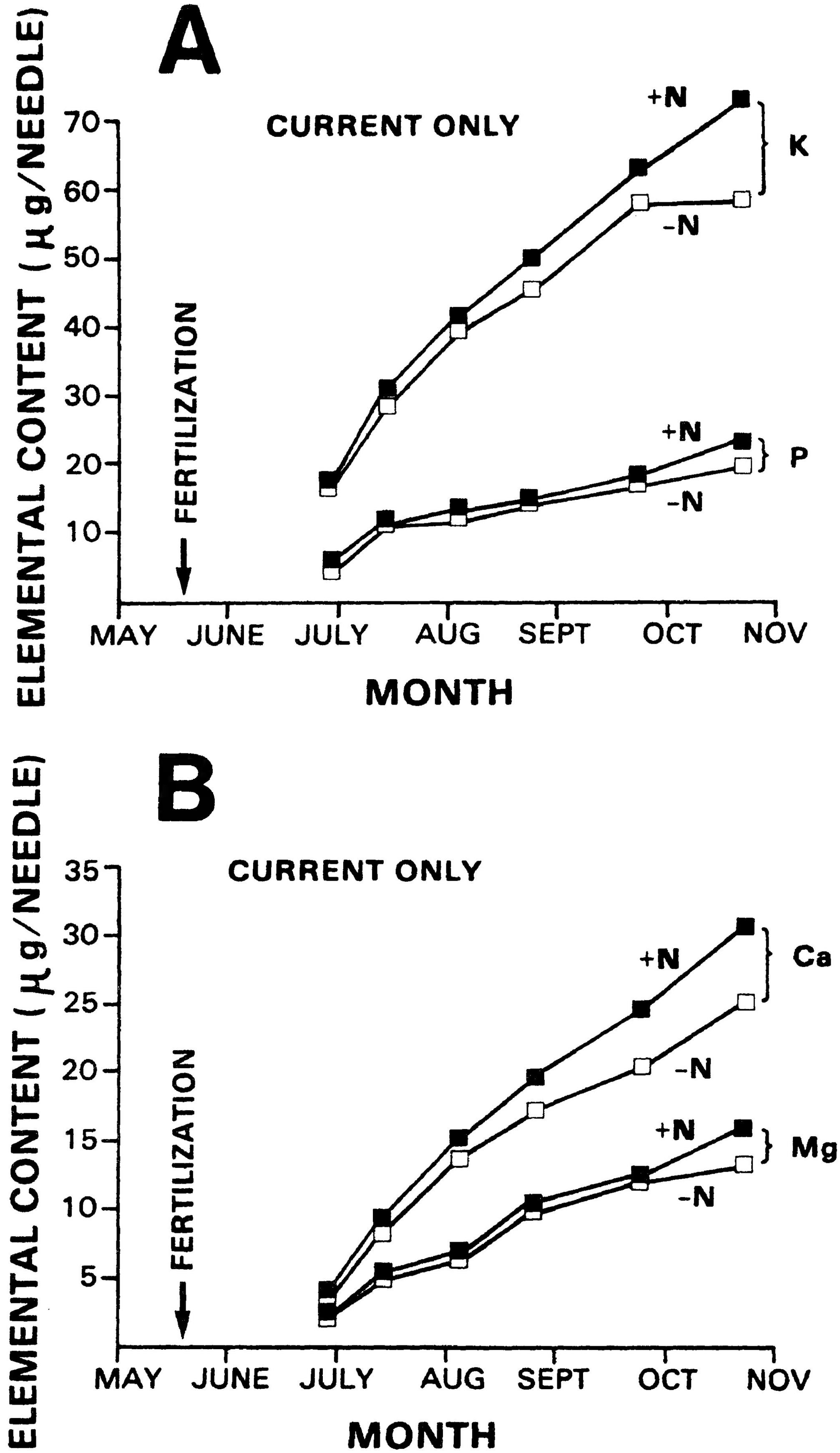


Fig. 12. Main effects of N on A) foliar K and P content and B) foliar Ca and Mg content during the growing season.

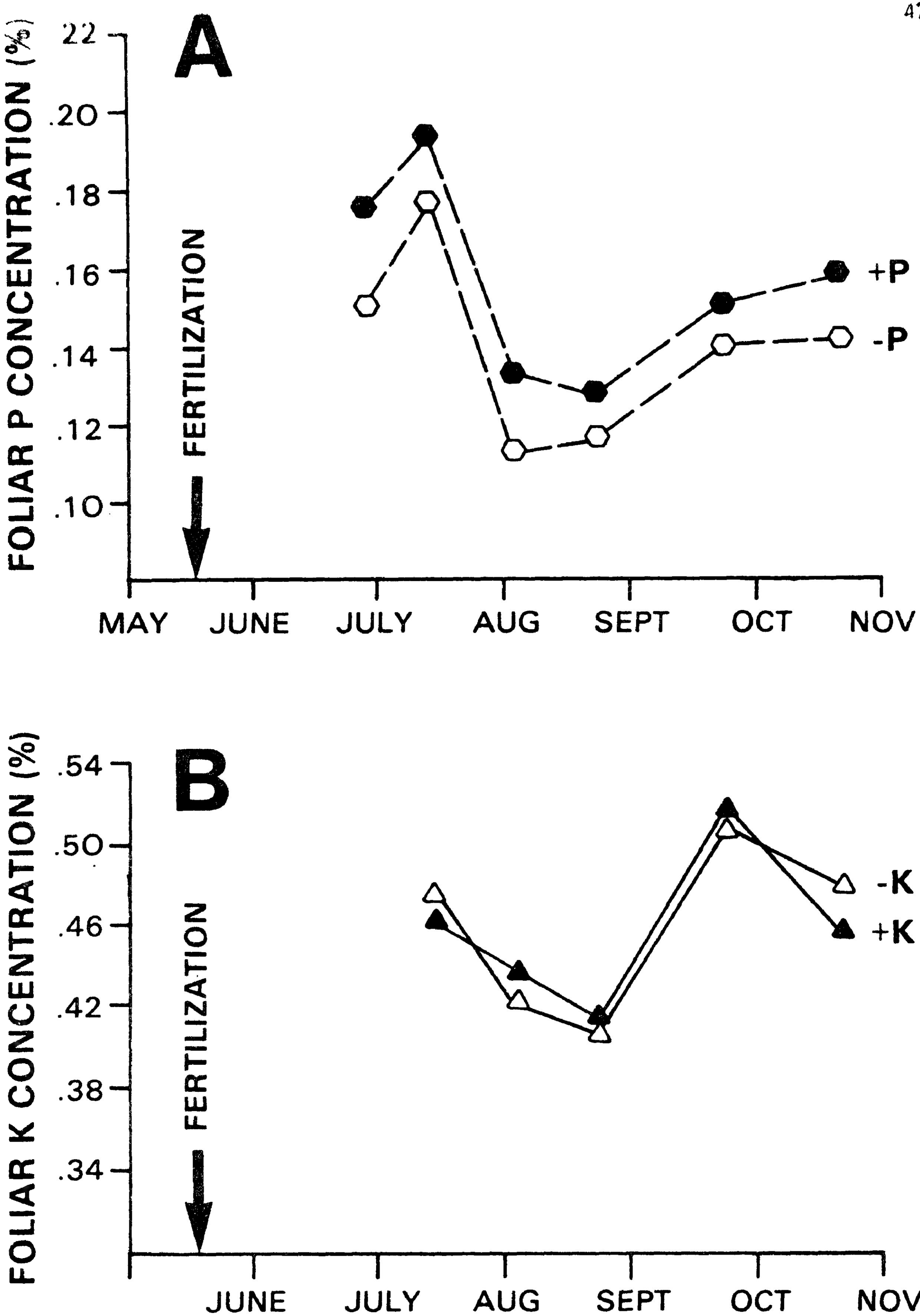


Fig. 13. A) Main effects of P on foliar P concentration during the growing season.
B) Main effects of K on foliar K concentration during the growing season.

dry matter production. Most likely phosphorus was assimilated as luxury consumption. Additions of K did not significantly influence foliar K levels (Figure 13, Table 8). As with foliar N, concentrations of P and K were diluted strongly during rapid needle growth early in the season but recovered in September and October (Figure 13).

Phosphorus and potassium fertilization did not significantly increase leaf weights and nutrient uptake in this plantation (Table 8). Of the three added nutrients, nitrogen seemed to be the only limiting nutrient on this site.

Application of Foliar Diagnostic System

Individual treatment responses were assessed by the technique of Timmer and Stone (1978) which tended to confirm the earlier diagnosis that N was the major growth limiting nutrient in the base trial. Only results from the final sampling date (October 21) were used since these would best reflect the cumulative fertilizer response for the whole season. Foliar dry weight, nutrient content and nutrient concentration are displayed simultaneously in the same graph for each element (Figures 14 to 18).

Foliar Nitrogen: The main effect of N (Table 8) resulted in a clear shift (+N arrow, Figure 14) into the poverty adjustment range (i.e. significant increases in needle nutrient concentration, nutrient content and dry weight (see Figure 2)) signifying N deficiency in this stand. Main effects of P and K were not significant for foliar N (Table 8) and were also not apparent in the distribution patterns of individual treatment means (Figure 14).

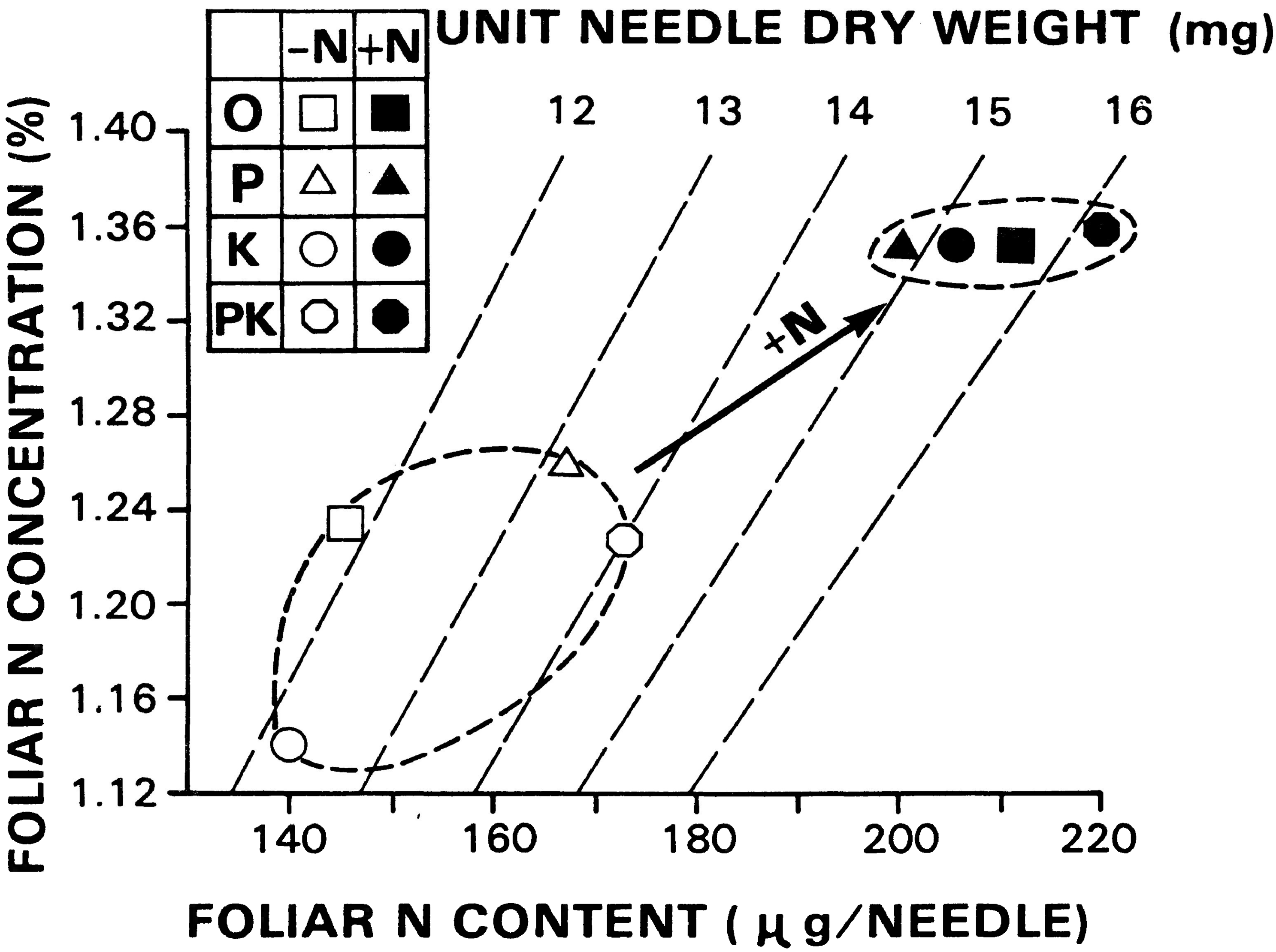


Fig. 14. The relationship between N concentration, N content and dry weight of current needles

Foliar Phosphorus: Main effects of P fertilization were significant for foliar P (Table 8) and are depicted by the (+P) arrow in Figure 15. This response in nutrient levels was not accompanied with a significant change in needle biomass (Table 8), indicating luxury uptake of P in the foliage (see Figure 2). Nitrogen fertilization only improved foliar P content (Table 8) as exemplified by the clustering of shaded (+N) and open (-N) symbols in Figure 15. Seemingly, N applications increased uptake of P in needles, a pattern which is also evident with the other macro-nutrients as seen in Figures 15-18.

Foliar Potassium, Calcium and Magnesium: Although foliar K was unchanged by K fertilization, additions of N significantly increased amounts of K, Ca and Mg in current needles (Table 8). Increases in needle weight and nutrient content without change in nutrient concentration characterizes minimum percentage (see Macy, 1936) and is represented by horizontal arrows (+N) in Figures 16-18. These response patterns signify sufficiency of K, Ca and Mg in this stand (see Figure 2). Apparently nutrient uptake to needle tissue kept pace with increased leaf expansion (induced by fertilization) preventing dilution of concentration levels.

In summary, P and K fertilization exhibited patterns of luxury consumption and minimum percentage in foliar P and K respectively. These are typical response patterns of added nutrients that were not deficient to the stand. On the other hand, N fertilization was associated with poverty adjustment which indicates that N was limiting

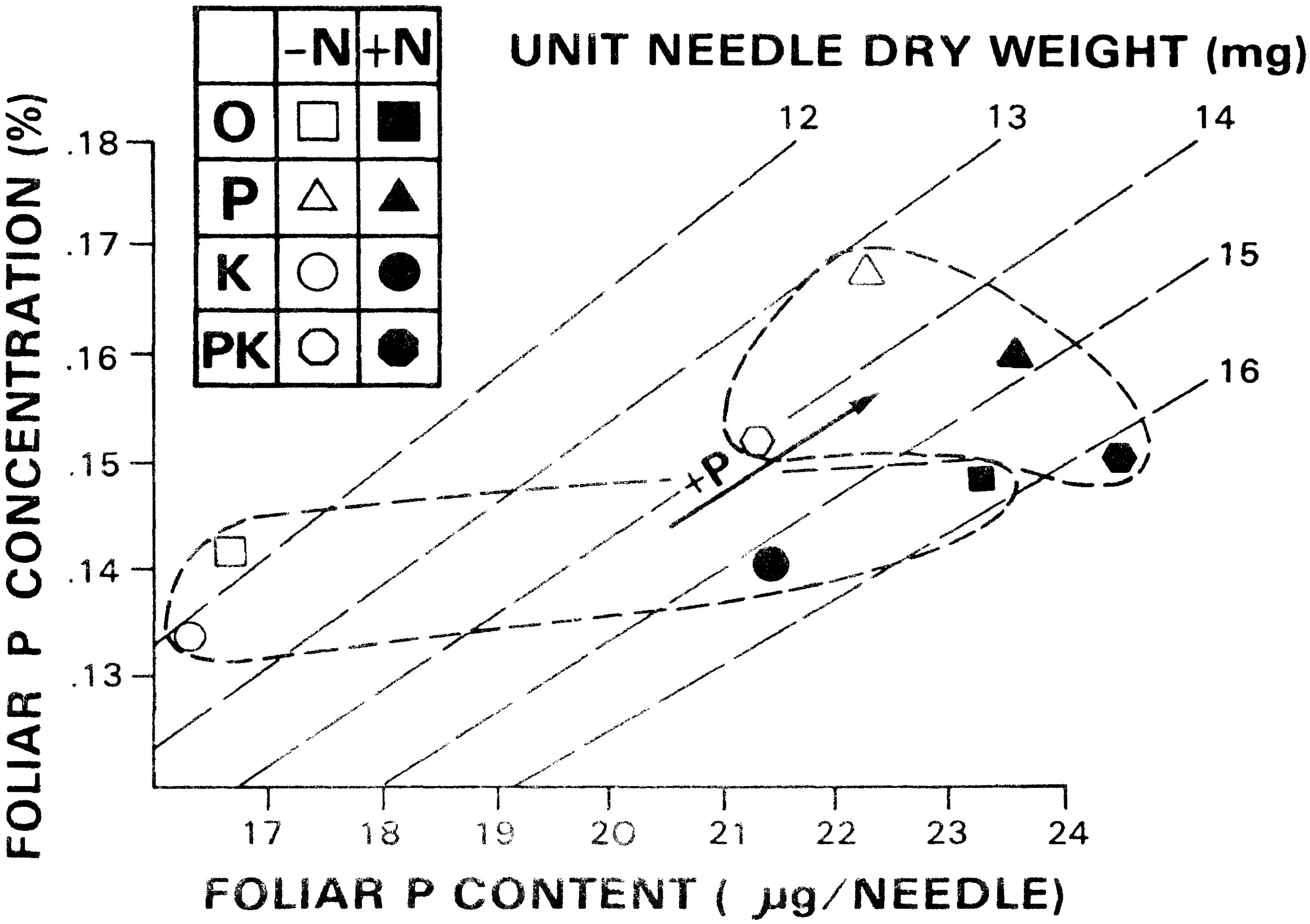


Fig. 15. The relationship between P concentration, P content and dry weight of current needles.

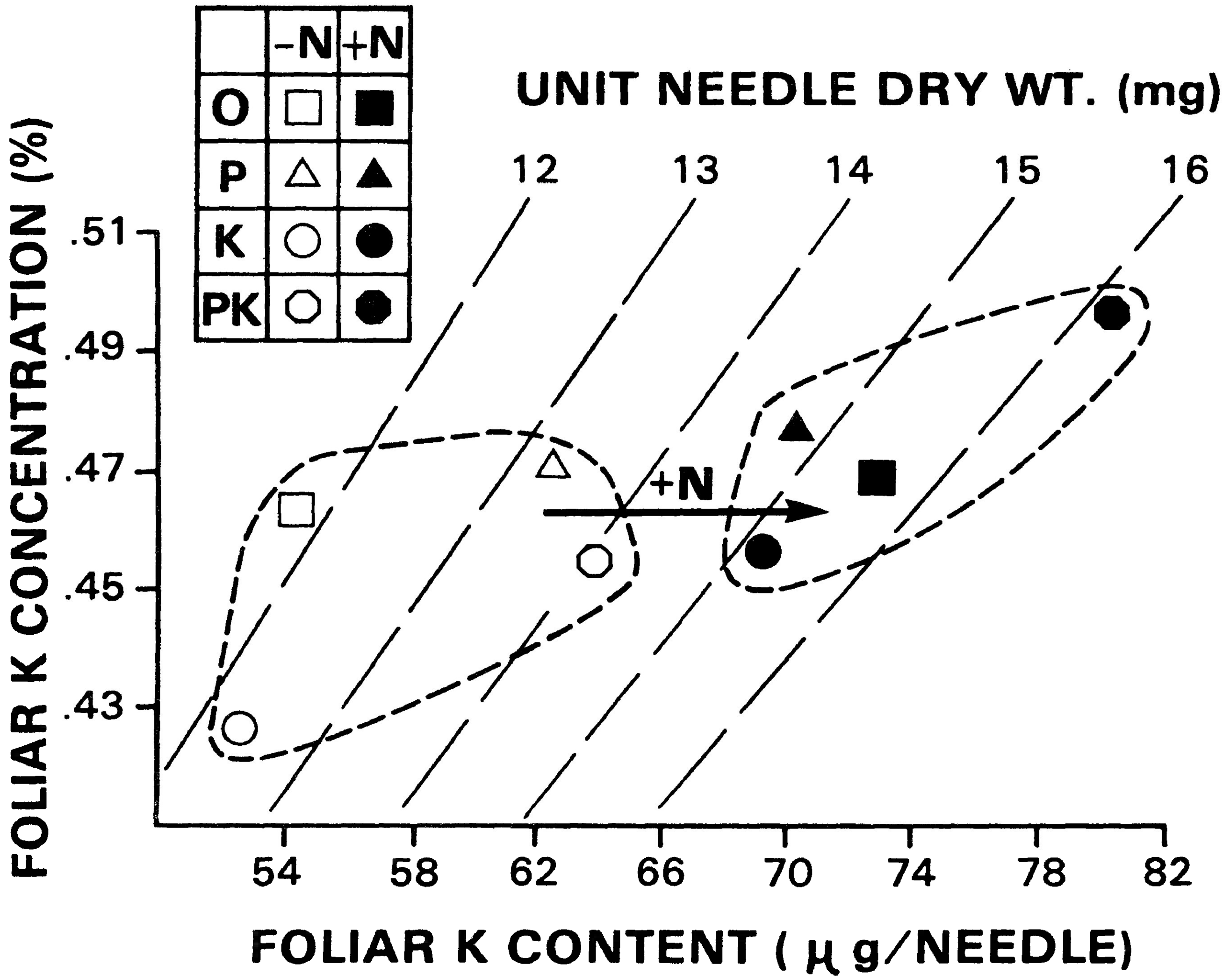


Fig. 16. The relationship between K concentration, K content and dry weight of current needles.

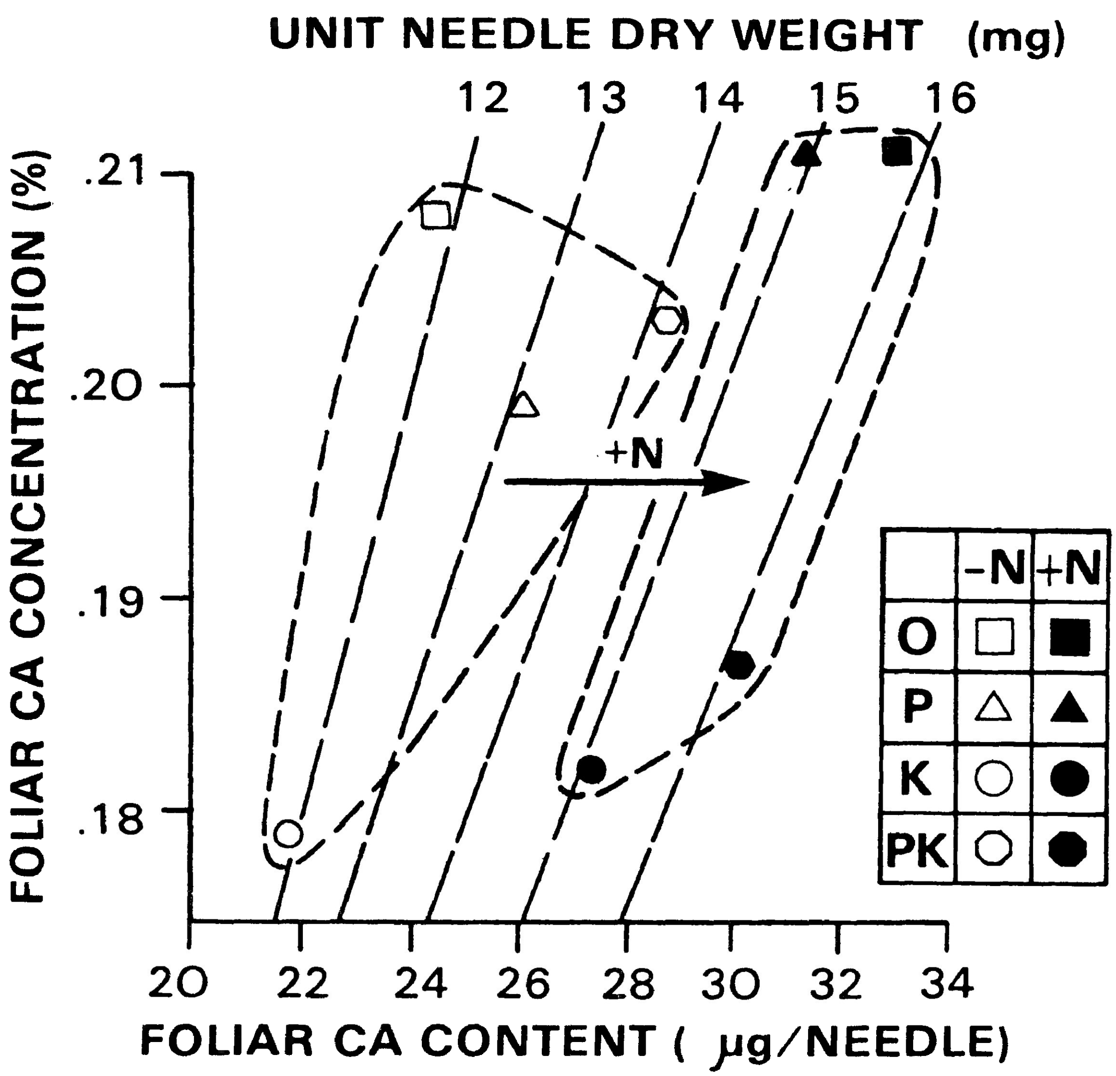


Fig. 17. The relationship between Ca concentration, Ca content and dry weight of current needles.

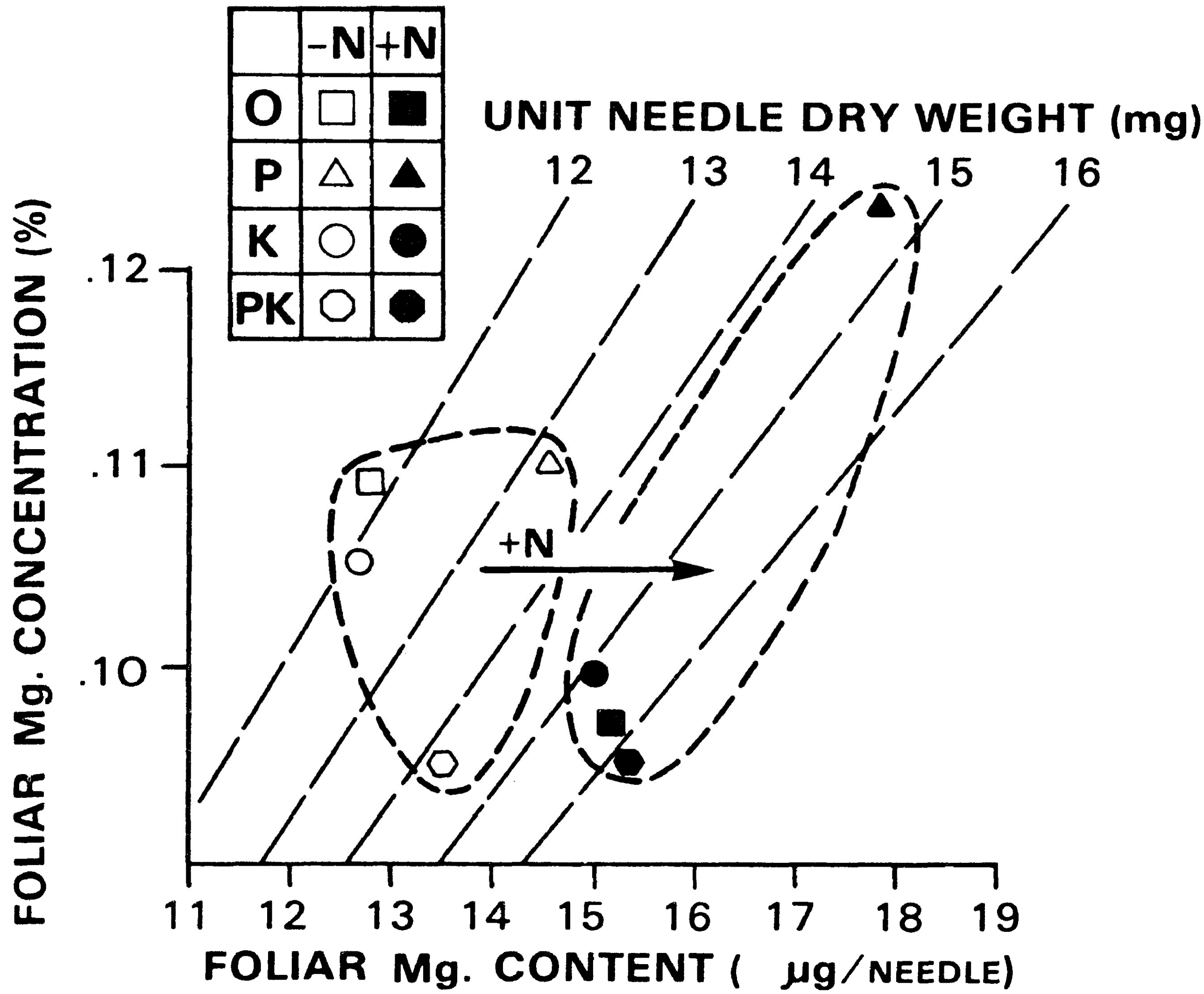


Fig. 18. The relationship between Mg concentration, Mg content and dry weight of current needles.

growth on the site. Furthermore, nitrogen applications also induced greater uptake of other foliar nutrients. It is interesting to note that these response patterns would have been difficult to recognize using assessment techniques based only on nutrient concentrations of foliage, indicating the importance of including other leaf parameters in diagnosis of foliar analyses.

Satellite Trial Results

Foliar responses were assessed only on fall-collected needles, since results at the base trial indicated that nutrient stress was more pronounced towards the termination of the growing season (Figures 9-12). Hence end-of-season sampling would improve sensitivity of diagnostic interpretations. Foliage sampling was also conducted in the spring, but only for the purpose of testing for pre-treatment differences between stands and treatment plots.

Effect of Fertilization on Foliage Dry Weight

Needle weight before fertilization did not differ significantly within treatments among the trials (Table 9). As expected however, differences for both fall and spring needle weights were large between trials since the trials were established on a wide range of site and stand conditions (Table 9, see also Appendix II for actual needle weight data). Dry matter production of current foliage was significantly raised by NPK fertilization (Table 9). Increases ranged from 0 to 29%, indicating a broad range of stand responses. Average leaf weights of all trials were increased by 9.5% as compared to an increase of 20.1% in the base trial.

Table 9. Analysis of variance of dry weight, nutrient concentration and nutrient content of current foliage from the satellite trials.

Source of Variation:	Main Effects: Trial		Main Effects: Treatment	
Sample Date:	Spring	Fall	Spring	Fall
Needle Dry Weight (mg)	***	***	---	***
Nutrient Concentration (%)				
N	***	***	---	***
P	---	*	---	*
K	fna	***	fna	*
Ca	fna	***	fna	---
Mg	fna	***	fna	---
Nutrient Content (μg/needle)				
N	***	***	---	***
P	---	***	---	***
K	fna	***	fna	***
Ca	fna	***	fna	**
Mg	fna	***	fna	---

*, **, *** = Significant at 0.05, 0.01 and 0.001 levels respectively.

fna = Foliage not analyzed.

Effect of Fertilization on Foliar Nutrient Composition

As with dry weight, nutrient composition of fall and spring sampled foliage differed significantly among trials (Table 9), while between treatment differences of pre-fertilization foliar N and P did not. Mixed NPK additions raised only foliar concentrations of N, P and K while levels of Ca and Mg remained unchanged.

Application of Foliar Diagnostic System

It appears that response patterns derived from this single mixed fertilizer application induced complex changes in the growth and nutrient composition in needles of these stands (Table 9, Appendix II). At first glance these may be difficult to interpret, since effects of neither N, P nor K can be isolated statistically, as was possible with the base trial data. However diagnostic and predictive interpretations were conducted on the satellite data with the aid of using base trial nutrient responses as models. The earlier diagnosis obtained from the factorial experiment (base trial), that N was the major deficient nutrient, could logically be extended to the satellite trials. This prognosis could be confirmed by evaluating foliar responses from the satellite trials by the technique of Timmer and Stone (1978). Simultaneous comparisons made on a relative basis for all nutrient responses (Figure 19 A) show that N is the most deficient because it exhibits the steepest shift into the zone of poverty adjustment, followed by P and then K. Using base trial responses as models, comparisons of individual N and NPK treatments indicate similar response patterns (Figures 19 B & C) as in the satellite trials. Consequently on an overall basis, N seems to be the major growth limiting nutrient of these trials,

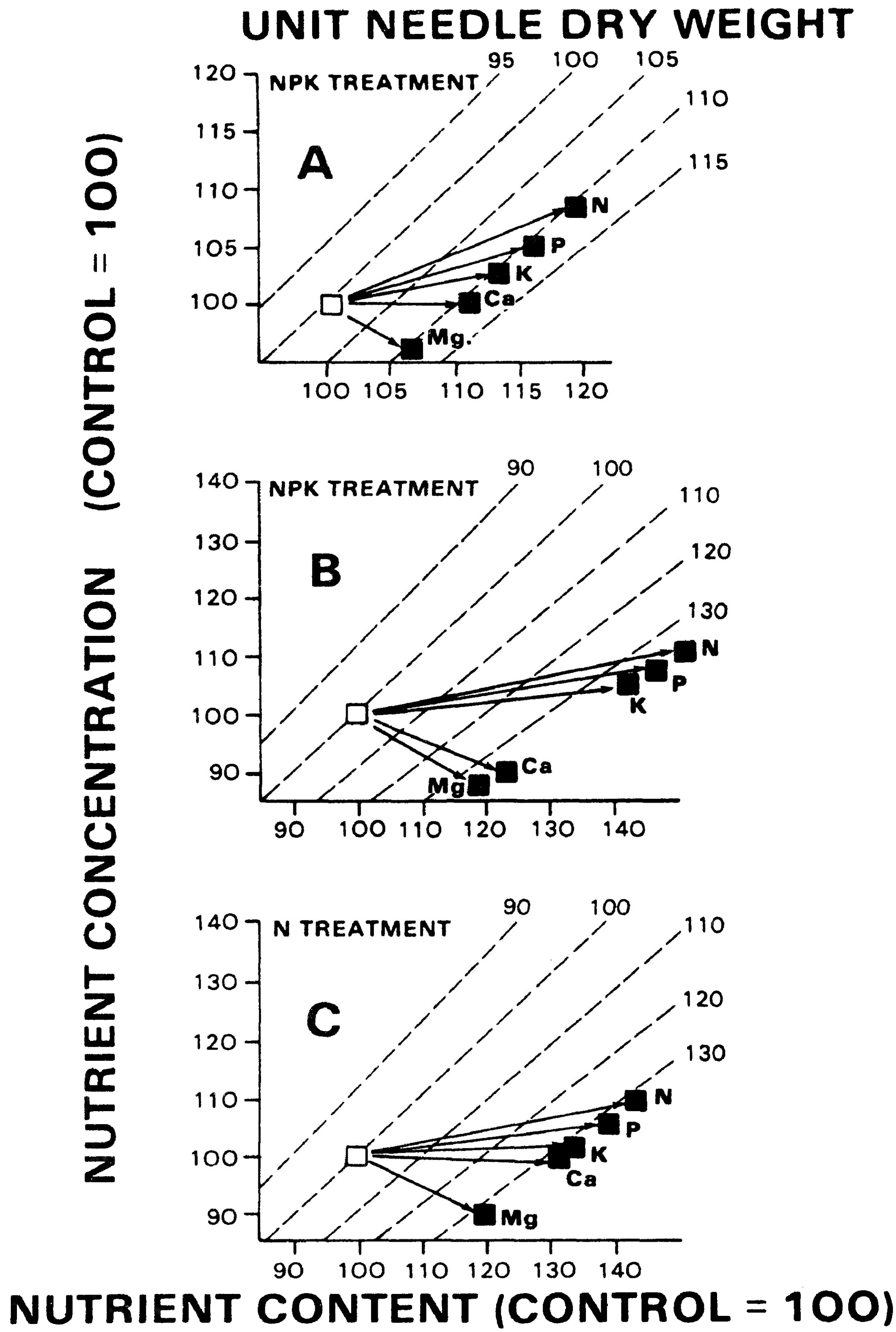


Fig. 19 . Relative response of foliar nutrient concentration and foliar nutrient content after fertilization for:
A) NPK treatment, satellite trials.
B) NPK treatment, base trial.
C) N treatment, base trial.

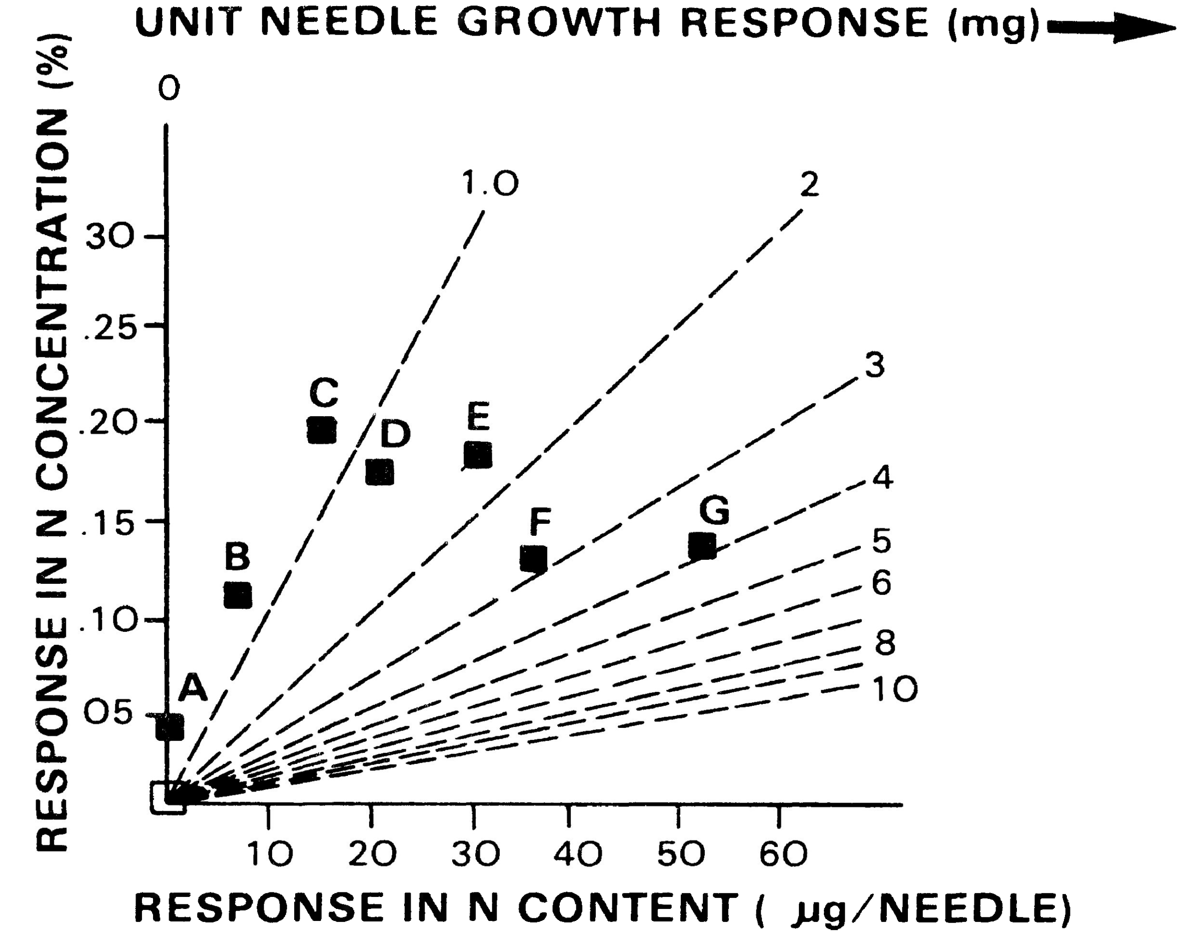
although specific responses of individual stands may differ somewhat. Variations in nutrient composition and dry weight of foliage exist between seasons (Leaf et al., 1970) and may confound the comparison between base and satellite trial nutrient response data. However, since comparisons are made in relative terms, inter-seasonal variation should be minimized. Only in the case of climate-fertilization interactions would such comparisons be jeopardized. An examination of climatic indices for the 1977 and 1978 growing seasons (Table 3) would suggest that few climatic differences existed between the two seasons. Furthermore, in a recent study of red pine (*Pinus resinosa* Ait.) foliar weight and nitrogen concentration (the major response parameters in this thesis) exhibited the least seasonal variability of the 18 other foliar variables studied (Bickelhaupt et al. 1979).

RESPONSE PREDICTION

Foliage response data from the base trial which display a range of N stresses (see pages 35 to 40) are initially used to test application of the proposed predictive technique (Figure 20); subsequently the technique will be demonstrated with response data from the satellite trials to illustrate its application under more operational conditions. The implicit assumption is that single, end-of-season foliage samplings from individual satellite trials will exhibit a similar range of nutrient stresses found in the series of foliage samplings obtained from the factorial base trial.

Base Trial

The base trial also provided the opportunity to assess the technique on a stand which was earlier diagnosed to be nitrogen deficient;



SAMPLING DATE	RESPONSE POTENTIAL
A 15 June 1977	LOW
B 28 June 1977	
C 13 July 1977	
D 3 Aug 1977	
E 23 Aug 1977	
F 23 Sept 1977	
G 21 Oct 1977	HIGH

Fig. 20. Relative response of foliar N concentration, foliar N content and needle dry weight of base trial foliage collected during the growing season. (Response = differences between +N treatments and -N treatments within the base trial)

a prerequisite for the proper application of this technique. Since foliage collections taken throughout the growing season exhibited a wide range of N stress in the needles (Figures 9-12) a prevailing low to high state of N deficiency would correspond with early spring to late fall foliage samplings respectively. To relate this data set to more practical and operational uses of the proposed technique it is important to consider that the individual samples from the sequence of foliage collections taken from the base trial during the growing season, could represent single, end-of-season foliage samples obtained from each of a group of candidate stands for fertilization treatment. These stands would be established on sites of differing N status, which could yield different responses to standardized fertilizer treatment. Thus plottings of sampling dates from the base trial (Figure 20) show that the large responses of needle growth of points F and G would be associated with stands of high response potential, while points A, B and C would identify stands of low potentials of response to fertilization. Hence if points A to G represented different candidate stands a similar ranking of potential responsiveness of stands would result.

Satellite Trials

The technique is further demonstrated with foliar analysis data from fall-collected samples of the satellite trials (Figure 21). The schematic diagram presents the response parameters (needle weight, foliar N concentration and foliar N content) obtained from the 12 satellite trials. Three trials (3, 4 and 10) responded highly to fertilization, whereas five trials (5, 7, 9, 11 and 12) did not respond substantially.

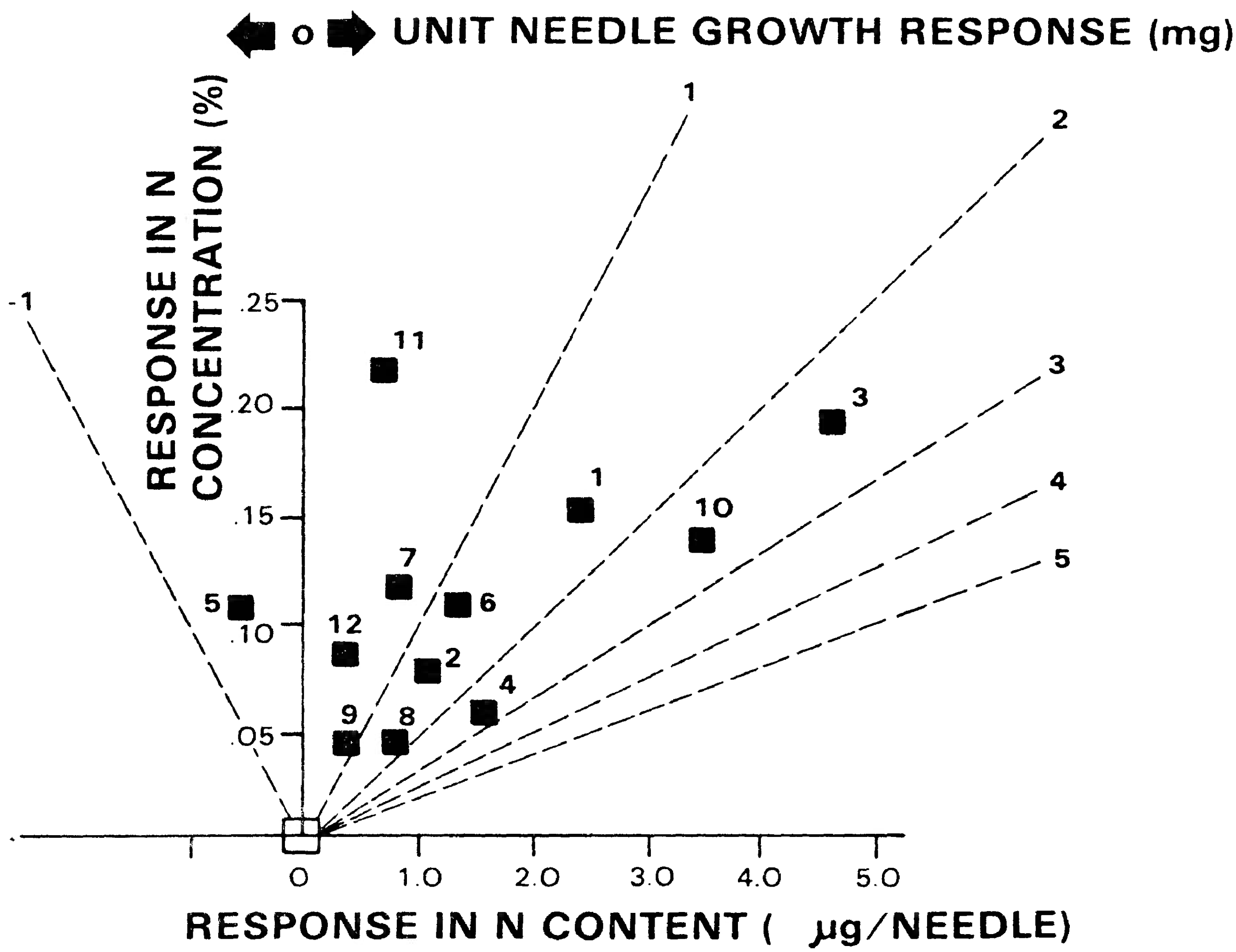


Fig. 21. Relative response of foliar N concentration, foliar N content and current needle dry weight of fall sampled satellite trial foliage (Response = difference between NPK treatment and control within each stand).

The lack of growth response in the latter group of stands probably indicates that N was not the major factor limiting growth, and that response may be inhibited by other nutrients or by other stand conditions such as age or density.

Interestingly, use of foliar concentration data alone would have produced misleading results with this type of assessment. Trial 11 produced the highest increase in foliar N concentration of all trials (Figure 21) yet N content and dry weight of needles appeared unchanged. Thus nitrogen may have been assimilated as luxury uptake and did not improve needle growth for this stand. Trial 4, on the other hand was very responsive to N additions, yet foliar N concentrations were not raised substantially. Apparently N concentration in needles of this particular stand were diluted by the increased growth caused by fertilization.

Thus far, individual stands have only been ranked into potential response classes based on dry weight responses of current needles (Figure 21). For forest management purposes it would be more useful to predict responses quantitatively in terms of height, basal area or volume. Dry weight of needles are well correlated with future tree growth responses (Table 1), thus response estimates for the species in question can be readily obtained. With jack pine for example, regression equations obtained from Weetman's and Algar's study (1974) indicate that the highly responsive trials (3, 4 and 10) would yield increases in basal area of 20 to 60% over a three-year period. Certainly for greater precision, specific prediction equations would need to be developed for local stand and site conditions. Thus, it is intended that these satellite trials be remeasured after a 3 to 5 year response period to determine actual tree growth responses. These responses will be used to develop local prediction equations based on initial dry weight response of foliage and future longterm stemwood increments. More importantly, actual growth responses will be compared with the predicted responses (made in this thesis), thus providing a measure of the accuracy of the diagnostic and predictive techniques employed in this study.

Although the approach in this study may be successful in confirming nitrogen deficiency of the base trial, its value for predicting the responsiveness of the satellite trials to fertilization cannot be ascertained until longterm basal area and volume responses are determined and correlated with the index. To improve sensitivity of the foliar analysis technique, the experimental design of the satellite trials may be in need of increased replication if more precise estimates of leaf weight responses are required. High variability of leaf size was encountered within the upper crowns of the trees, as jack pine frequently exhibits lammas growth, which is characterized by one or more periods of secondary flushing following the initial elongation of the terminal shoot (Rudolph, 1962). Since needle size varies highly between lammas and normal shoots (Rudolph, 1964) it is recommended that foliage sampling be restricted to a specific flush or shoot type, as has been the practice with multi-flushing pines (Pinus elliottii Engelm. var. elliottii, Pinus taeda L.) in the southern United States (Carter, 1967; Pritchett, 1968). More rigid standardization of foliage sampling procedures may improve response detection and may minimize treatment replication for field trials.

Identification of individual nutrient responses from the mixed fertilizer (NPK) additions tested in the satellite trials was difficult since response to separate elements can not be isolated. In circumstances where the limiting nutrient has already been identified (i.e. by previous fertilization experiments), it is not necessary to test multiple fertilizer treatments. Use of the limiting nutrient only as a treatment would simplify interpretation and improve predictability substantially.

It should be recognized that the proposed predictive technique (which is essentially based on foliage dry weight response) was designed primarily to evaluate fertilizer responses. Although density, age and other characteristics of stand development may influence responses to fertilization, these same factors may also affect needle growth behaviour and as such are integrated into the predictive system. In fact, examination of Table 1 indicates that first year needle growth is highly correlated with long term growth response of trees under a variety of species and ages of forest stands. Furthermore, the technique may have promise as a rapid method of assessing responsiveness of stands to other silvicultural treatments such as thinning, cleaning or brush control, which may alter soil nutrient supply indirectly. Of course further testing of the technique is needed under a variety of silvicultural and stand conditions to evaluate this type of application.

SUMMARY

A series of fertilization trials was established on a range of jack pine sites throughout the Beardmore-Nipigon area of northern Ontario to examine the effect of fertilization on dry weight and nutrient composition of leaves and to develop a rapid predictive technique for evaluating the potential responsiveness of young jack pine stands to fertilizer additions. The project consisted of an intensively monitored factorial experiment (base trial) testing N, P and K fertilizers, and a more extensively studied series of simpler two-treatment (control and NPK) satellite trials located in a range of jack pine stands and plantations.

At the base trial, seasonal patterns of nutrient composition and dry weight of current and year-old needles showed that nitrogen applications induce the most pronounced and most frequent changes in the foliage (Table 8, Figures 9-11). Fertilization with N not only increased dry weight and N composition of needles, but also stimulated uptake of other macro-nutrients such as P, K , Ca and Mg by extending the active growing season (Figure 12). Internal translocation of nutrients from year-old to current foliage was also detected for N but not for P and K (Figure 11). Foliar responses to P and K fertilization failed to improve growth and uptake of nutrients in the needles, except for P fertilization which induced luxury consumption of P in the foliage (Figure 15). Diagnostic interpretations from these foliar responses indicated that of the 3 elements added, N was the most limiting for growth of the stand (Figures 14-18).

First season, fall sampled foliage from the satellite trials showed that dry matter and nutrient composition was substantially increased by NPK additions (Table 9). Relative comparisons between foliar responses of satellite trials with those of the N and NPK treatments of the base trial (Figure 19) suggested that N deficiency was also prevalent in the satellite trials. A proposed foliar analysis technique for predicting the potential response of these stands was initially tested with foliage samples from the base trial exhibiting a known range of nutrient stress (Figure 20). In the next season the approach was further evaluated with single, end-of-season foliage samplings from the satellite trials (Figure 21). The technique is based on the assumption that initial needle weight response is highly correlated with future stem growth responses (Table 1). Simultaneous changes in needle dry weight nutrient concentration and nutrient content of each stand were compared in a single dispay (Figure 21). Individual satellite trials were ranked according to potential responsiveness to fertilization. To assess the accuracy of the proposed technique, it is recommended that the initial response projections be compared with actual stemwood responses after a suitable response period.

The technique seems to offer a low cost, rapid, yet reliable method for forecasting future fertilizer growth response and may have further application for predicting potential response of stands to other silvicultural treatments.

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APPENDICES

APPENDIX I

NATURE, ANALYSIS AND MAKE OF FERTILIZERS APPLIED IN STUDY

Fertilizer	Chemical Formula	Nutrient Elements (%) N	P	K	Ca	Type	Brand
Urea	$CO(NH_2)_2$	45	0	0	0	granular agricultural grade	NUTRITE
Triple Superphosphate	$Ca(H_2PO_4)_2H_2O$	0	20	0	12-14	granular agricultural grade	NUTRITE
Muriate of Potash	K_2O	0	0	45	0	granular agricultural grade	NUTRITE

APPENDIX II

MEAN NEEDLE DRY WEIGHT AND FOLIAR NUTRIENT CONCENTRATION OF TREATED AND CONTROL PLOTS OF INDIVIDUAL SATELLITE TRIALS

Trial	Needle Dry Weight(mg)		Nutrient Concentration(%) Nitrogen		Phosphorus		Potassium		Calcium		Magnesium	
	Control	Treated	Control	Treated	Control	Treated	Control	Treated	Control	Treated	Control	Treated
1	14.70	16.31	1.46	1.61	0.16	0.15	0.59	0.57	0.16	0.16	0.08	0.08
2	15.11	16.49	1.51	1.59	0.16	0.16	0.52	0.54	0.18	0.18	0.09	0.07
3	8.53	10.96	1.30	1.49	0.14	0.15	0.49	0.52	0.34	0.32	0.10	0.10
4	16.51	19.31	1.68	1.63	0.17	0.17	0.57	0.54	0.16	0.16	0.09	0.08
5	12.85	12.32	1.43	1.54	0.15	0.15	0.53	0.54	0.19	0.22	0.10	0.10
6	9.60	10.81	1.39	1.49	0.16	0.16	0.52	0.55	0.15	0.14	0.10	0.10
7	11.14	11.81	1.31	1.42	0.13	0.15	0.49	0.53	0.22	0.22	0.12	0.11
8	12.31	14.06	1.49	1.54	0.14	0.16	0.53	0.52	0.09	0.10	0.09	0.09
9	12.49	13.35	1.41	1.53	0.16	0.16	0.54	0.56	0.21	0.22	0.11	0.12
10	12.90	15.46	1.22	1.35	0.14	0.15	0.46	0.50	0.21	0.19	0.11	0.09
11	11.10	11.43	1.38	1.60	0.15	0.16	0.51	0.55	0.17	0.18	0.10	0.11
12	12.46	12.97	1.47	1.55	0.15	0.16	0.50	0.51	0.20	0.19	0.11	0.11

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