Project Record No. 2010

KEY POINTS FROM A TECHNICAL SESSION ON NITROGEN FERTILIZING RADIATA PINE HELD AT TOKOROA

I.R. Hunter, A.G.D. Whyte, R. Woollons

A. Gordon, D. Mead, M. Kimberley

Report No. 32 **September 1988**

AGENDA FOR TECHNICAL DAY ON NITROGEN

Held at NZFP Forests offices at Tokoroa on 21 Sept 1988

09 30	Welcome:	Mr Murray Macalonan
09 45	Introductory remarks:	Mr Rob Webster
09 55	Brief coffee break	
10 05	SESSION 1: What is known about N in radiata pine?	Mr I Hunter Dr D Mead
11 00	SESSION 2: How big a response to expect?	Mr I Hunter
12 30	Lunch	
13 00	SESSION 3: How long will the response last?	Mr M Kimberley Mr R Woollons
14 00	SESSION 4: Do the trees change shape?	Mr A Gordon Dr A Whyte Dr D Mead
15 00	SESSION 5: What next?	Dr S Carson

KEY POINTS FOR CO-OP DAY ON NITROGEN

Session 1: What is known about nitrogen in radiata pine?

1. Nitrogen is usually the most abundant element in above ground biomass.

2. N is concentrated in the needles and branches of the tree.

3. N is needed primarily for proteins and chloroplasts. If it is deficient needles will be yellow, from lack of chlorophyll, and small.

4. With the exception of K and Ca all other elements are present in less than 25% of the amount of N.

5. Trees appear to have efficient mechanisms for cycling N from older needles to younger needles. At least 50% of N is removed prior to needle-fall.

6. N does not cycle through the litter quickly. Less than 20% of N content is released over 2 years. Green needles resulting from thinning or pruning do not release N any more quickly.

7. At closed canopy trees can get at least 50% of the N they require for the new foliage from older needles being dropped. The rest must come from the soil or from decomposing litter.

8. We would therefore expect trees to be vulnerable to N deficiency if

a - there is not enough N being mineralised from the soil to supply the trees demands. This shortage can be transient.

b - they are in a period of growth when the quantity of young needles is greater than the old i.e. in their first 5 years.

c - they are given the opportunity to expand the quantity of new needles as happens to the crop trees after thinning

d - they have a young or raw litter layer as would occur up to age 10, and could re-occur at any time if the C:N ratio of the litter became unfavourable for decomposition.

e - something happens to remove the old needles before N can be salvaged from them e.g insect defoliation, pruning or fungal attack.

9. When nitrogen is applied to trees they respond by trying to produce more,larger needles. This will result in more growth unless:

a - some other nutrient is limiting

b - water, temperature or weed competition are overriding constraints

c - the canopy has no room to expand

10. There may be a change in the way photosynthate is allocated around the tree. More may go to stem and less to roots.

11. Uptake by the trees is quite low seemingly regardless of how the fertiliser is applied. Uptake seems to be between 10 and 25% only. Fertiliser that is not taken up seems to:

a - volatilise i.e. turn into gaseous nitrogen and join the 80% of the atmosphere that is N already. How much volatilises depends on soil acidity, fertiliser type and weather after fertilising. The amount is not known with any accuracy at all for forestry situations.

b - leach. Again the amount that leaches will depend on weed cover, soil pH , weather.

c - be taken up by soil fauna and incorporated in soil organic matter. While it is not lost thereby it becomes much less available.

12. The N that is taken up will be gradually lost to the canopy as needles are shed. This, and the gradual lack of room for canopy expansion, seem to explain the short-lived response to N typically observed. While much of the applied N is retained in the soil-plant system, it joins the more slowly cycling components and is dwarfed by them in quantity. Soils may contain 5000 kg/ha of N.

Session 2: How big a response to N fertilser can we expect?

The factors that determine the magnitude of the Fourth year basal area response are:

1. *The amount of nitrogen in the soil. The more nitrogen there is the smaller the response will be.*

2. *The amount of phosphorus in the soil. If the phosphorus is too low there will either be a nil response or a negative response to nitrogen fertiliser. Nitrogen fertiliser will expand the canopy and dilute the amount of P in the foliage. If it is diluted to below 0.11% there will not be enough P to provide energy to complete protein synthesis.*

3. *The amount of clay in the soil. Clay has a minor effect improving the response to N. This is probably because clay soils have two characteristics that improve the residence time of N fertiliser in the soil; they are less permeable therefore reducing leaching and they tend to be more acid thereby minimising volatilisation.*

4. *The age of the stand at time of fertilising. The response tends to parallel the underlieing base growth rate so for basal area it appears to peak at the time of peak basal area CAI i.e. at about age 6, while for volume it appears to peak at about age 12.*

5. *The previous silvicultural history of the stand. Unthinned stands will respond provided that they have not closed canopy. Therefore young stands may respond. N-deficient stands will respond because one of the characteristics of N deficiency is a thinning of the crown and a lack of needle retention. Thinned stands will generally respond well. Pruning leads to a similar magnitude of response. The combination of thinning and pruning usually reduces the response over that which would be expected from thinning alone or pruning alone.*

Session 3: How long will the response last?

1. *Most of the FRI/Industry trials were established between 1975 and 1980. They had an intensive measurement period of four years and then were measured infrequently and irregularly afterwards.*
   Some trials were lost due to windthrow, clearfelling, further thinning. Thus there is a small number of N fertiliser trials that have a response period of 10 plus years.

2. *We have re-measured as many of these as possible.*

3. *The conclusions are as follows:*

   a - most of the trials have given a small volume response to N i.e. less than 20 m°/ha. A few trials have given large responses.

   b - although the basal area growth ratio curves show that some trials appear to lose part of the fertiliser response after time, the volume data does not show the same trend. Response tends to be maintained with time.

Session 4: Do the trees change shape when fertilised?

1. *As part of the FRI/Industry series of trials, 1300 trees were sectionally measured after fertilising with either N or P fertiliser.*

2. *Phosphorus fertilising seems to lead to thinner bark and a slight improvement in form.*

3. *Nitrogen fertilising alone leads to a slight deterioration in form.*

4. *The response to fertiliser has to be large, i.e. bigger than 35% ,before there is a measurable improvement in tree form. At 35% this is equivalent to an underprediction of 2.5% in tree volume , rising to 10% at 150% response.*

Session 5: What next?

: What do we know?

1. Volume growth of radiata pine is proportional to the amount of N in the tree

2. The areas where N in the soil is insufficient for optimal growth are known

3. The N in the soil is important because N cycles only slowly through the litter

4. When radiata pine is fertilised:

4a. About 20% of the applied N is taken up by the trees

4b. The magnitude of the response depends on site. Strongly responsive sites can be predicted

4c. The magnitude of the response depends on the weight of canopy left after tending

4d. Tree growth is accelerated for approximately 5 years after fertilising

4e. From evidence to date it seems reasonable to assume that the cumulative response will be carried through to rotation.

4f. The average response to N fertiliser is 20 m°/ha

4g. Tree shape is changed slightly and volume thereby slightly reduced

: What do we not know?

1. *Why is the internal cycling of N less on poor sites than on good ones?*

2. *Why are ex pasture sites more productive than bush or forest sites?*

3. *How is N allocated above and below ground?*

4. *What is the effect of pruning and of disease on internal cycling?.*

5. *Can we increase the amount of N taken up?*

6. *How do weeds affect uptake by trees?*

7. *Does the response to operationally applied N differ from the experimental response? How do we ascertain and verify?*

8. *Why do responses to higher rates appear to be variable?*

9. *Is there a tool to assess canopy weight?*

OVERHEADS FROM SESSION 1

CONTENT OF NUTRIENTS IN 29 YEAR OLD RADIATA PINE AS A % OF THE N CONTENT

NUTRIENT	AS % OF NITROGEN
PHOSPHORUS	15
POTASSIUM	107
CALCIUM	77
MAGNESIUM	24
ZINC	1
IRON	2
MANGANESE	7
SULPHUR	12

PERCENTAGE OF A NUTRIENT IN BRANCHES AND FOLIAGE

Based on 29 year old radiata pine

NITROGEN	41%
PHOSPHORUS	41
POTASSIUM	35
CALCIUM	25
MAGNESIUM	26
MANGANESE	25
SULPHUR	38

INTERNAL CYCLING OF NITROGEN

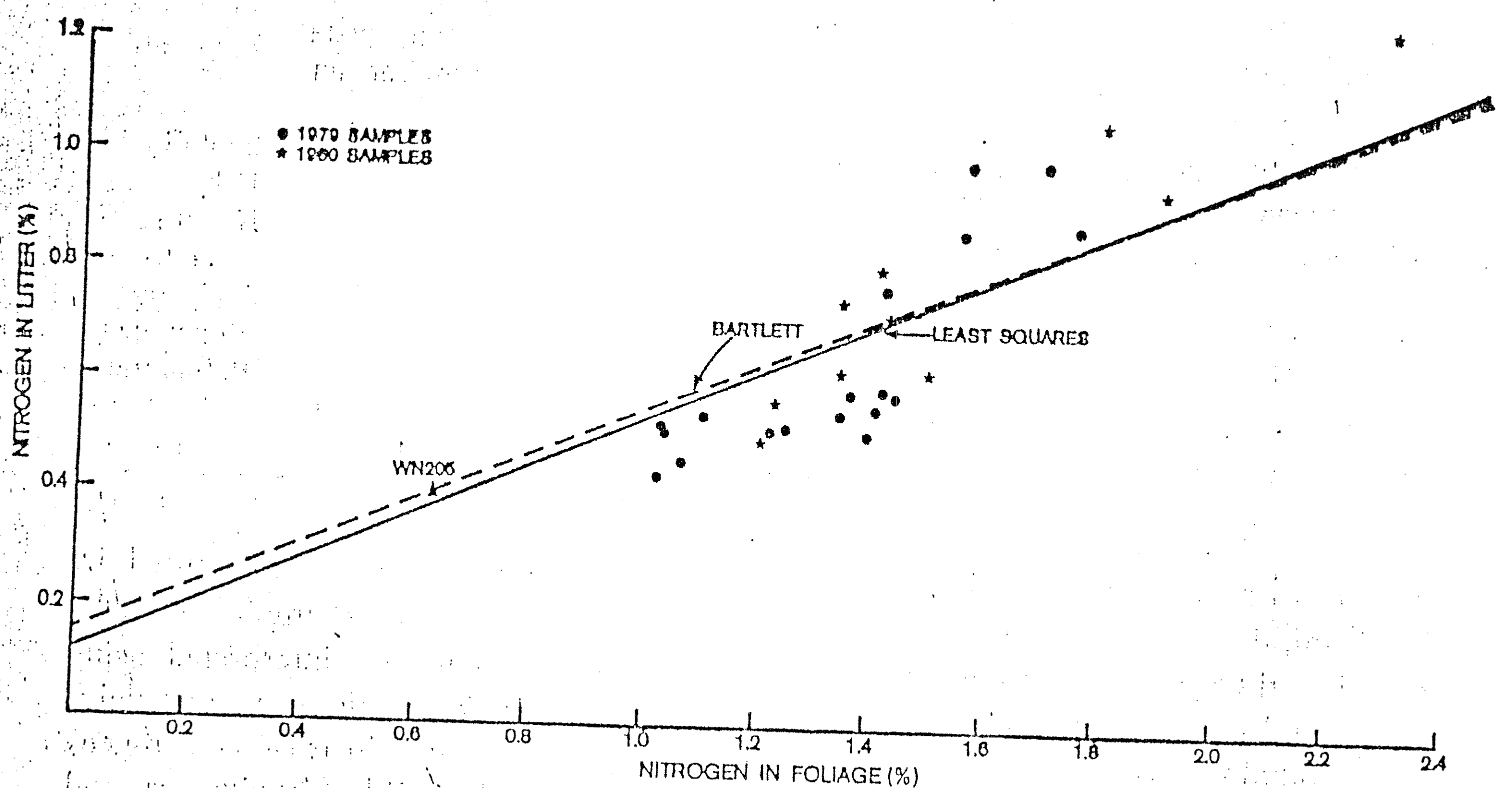


FIG. 1—Independent verification of relationship between foliage and recent litter nitrogen. Regressions from text. Verification data from fertiliser trials described by Hunter & Graham (1982) and from the severely chlorotic site (WN205) referred to by Hunter & Hoy (1983).

RELEASE OF NITROGEN FROM NATURALLY SHED PINE NEEDLES

1. Three types of needles; high medium and low in N
2. Exposed on a wide range of sites for 2 years

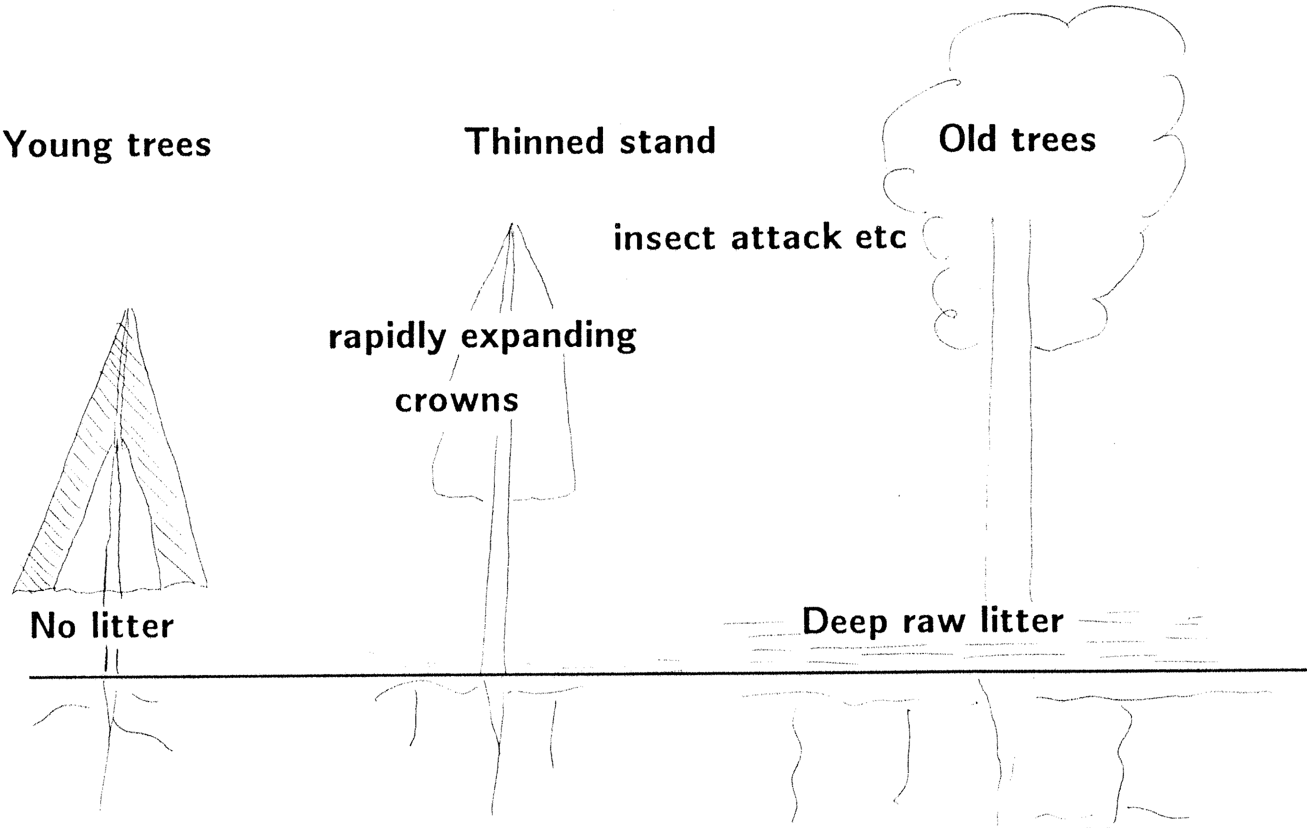
	Percent Organic matter remaining	Percent N remaining
High N	56	85
Med N	60	134
Low N	62	172

RELEASE OF NITROGEN FROM GREEN NEEDLES

1. Green needles placed in two ways; suspended and on forest floor
2. Experiment ran for 1 year

	Percent Organic matter remaining	Percent N remaining
Suspended .	61	86
Forest floor	56	83

CONDITIONS THAT PREDISPOSE TO N DEFICIENCY



Insufficient N in soil (generally a topsoil N concentration of less than 0.1% has a fair probability of being associated with N deficiency in the trees)

EFFECT OF NITROGEN AND OTHER FERTILISERS ON NEEDLE WEIGHT AND GROWTH

	TREATMENT		
	No fertiliser	N alone	N plus
Fascicle weight	3.06	3.46	3.80
Foliar N %	1.4	1.5	1.5
Foliar P %	0.12	0.10	0.12
Volume growth (5 yr)	49	43	52

EFFECT OF NITROGEN FERTILISER ON NEEDLE WEIGHT AND LENGTH

In a nitrogen fertiliser trial in Kaingaroa

SIX MONTHS AFTER FERTILISING:

FIRST YEAR NEEDLES IN THE FERTILISED PLOTS ARE:

1. **Longer**
2. **Heavier**
3. **Have a higher N concentration**
4. **Have 50% more N content**

SECOND YEAR NEEDLES IN THE FERTILISED PLOTS ARE:

1. **Unaltered in weight or length**
2. **Have a higher N concentration**
3. **Have a proportionately higher N content**

THUS, NOT SUPRISINGLY , THE CHANGES IN NEEDLE DIMENSIONS ARE RESTRICTED TO YOUNG NEEDLES, BUT OLDER NEEDLES CAN BENEFIT FROM INCREASED CHLOROPHYLL ACTIVITY AND THEY ARE A RESERVOIR OF N FOR FURTHER CROWN EXPANSION

CANOPY DEVELOPMENT IN EYREWELL N-FERTILISER TRIAL

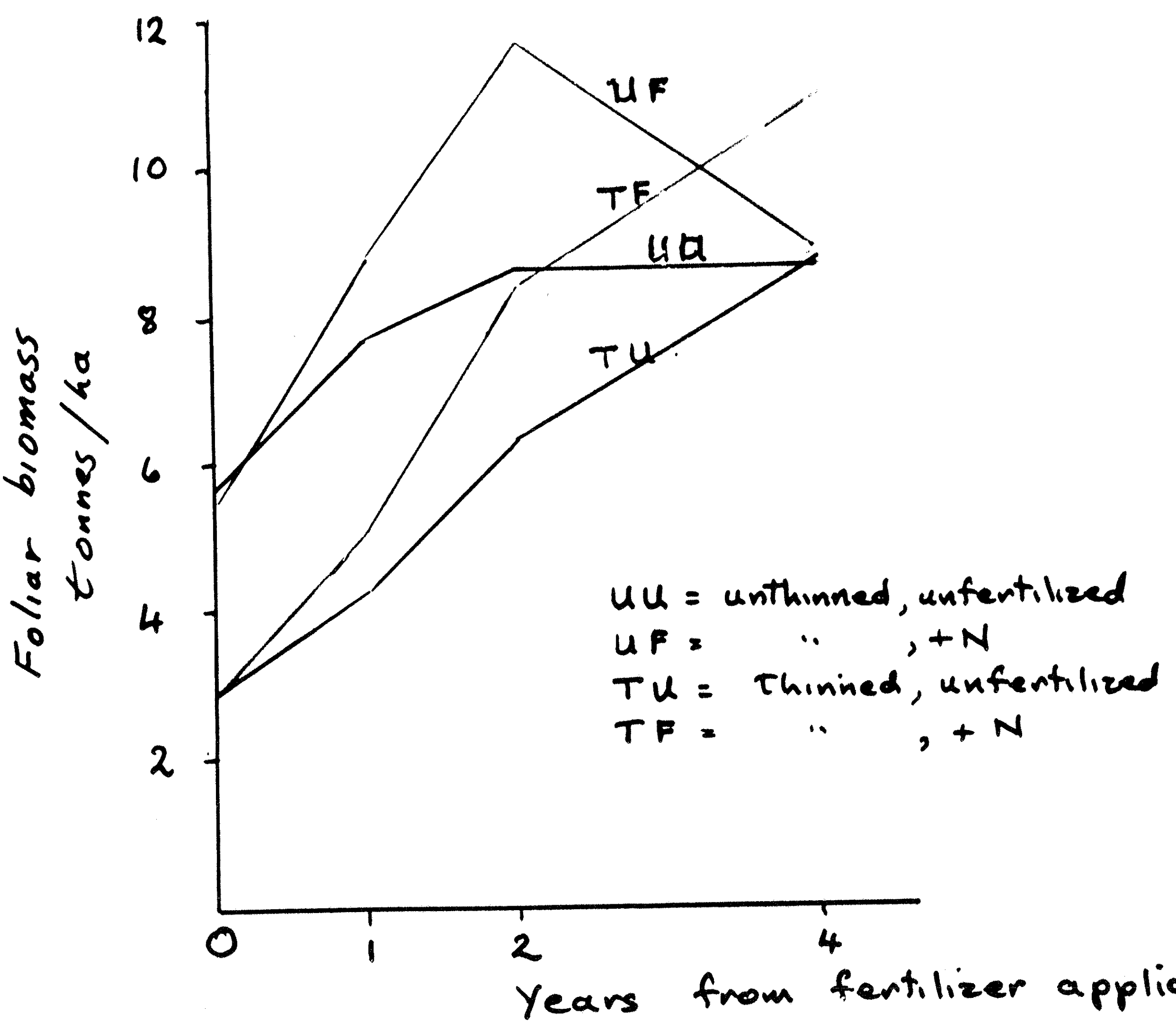
The trial is a 2*2 factorial in thinning and fertiliser

MAIN POINTS:

* Response to fertiliser largely due to increased foliar biomass

* Some indication of increased foliar efficiency from fertiliser, particularly in first 2 years

* Changes in branch growth are related to increased foliage



FERTILISER N UPTAKE BY TREES

* Ranges from 2 to 66% but is usually low and around 20%
* Where does the added N go?

VOLATILIZATION > 5% but < 30%

is favored by:

High application rates

Warm soil temperatures

High wind velocity

Low soil moisture

High soil pH

Low C.E.C

LEACHING is variable

occurs:

as urea (probably unlikely)

as NH_4 (in sandy soils)

as NO_3 (probably the most important)

DENITRIFICATION: probably unimportant

PLANT UPTAKE:

usually rapid and detectable within weeks

most uptake occurs within 6 months.

MICROBIAL IMMOBILISATION: an important sink for the remaind

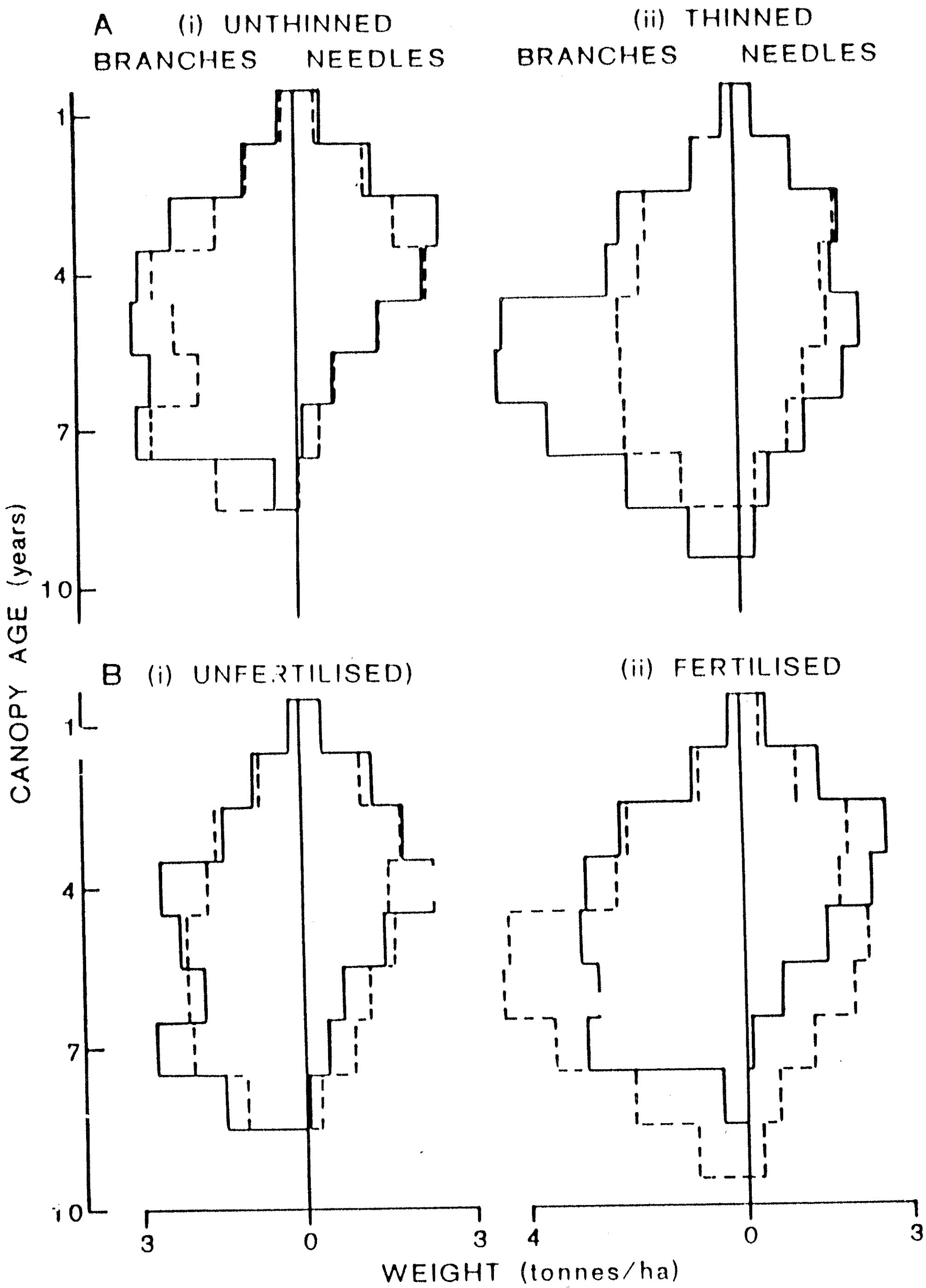


FIG. 4—Canopy structure 4 years after treatment. Canopy age refers to the year in which branches developed.

A = Comparison of fertilised (unbroken lines) and unfertilised (broken lines) canopy structure within thinning treatments.

B = Comparison of unthinned (unbroken lines) and thinned (broken lines) canopy structure within fertiliser treatments.

* Changes in Canopy structure after 4 yrs

* Changes in allocatión patterns of photosynthates.

N 15 STUDY AT BOTTLE LAKE

150 kg/ha of N applied once

split into three applications

split into nine applications

There was a good response to fetiliser (+ 25% above ground biomass)

* VOLATILISATION < 2%
* UPTAKE BY TREES - 21%

  regardless of treatment or season of application

  uptake detectable in 2 weeks , complete by 6 months
* IMMOBILISED IN SOIL

  For the single dressing this was 40%

  Fir the 9 split it was 70%
* LEACHING was greatest in the single dressing
* DENITRIFICATION probably not important

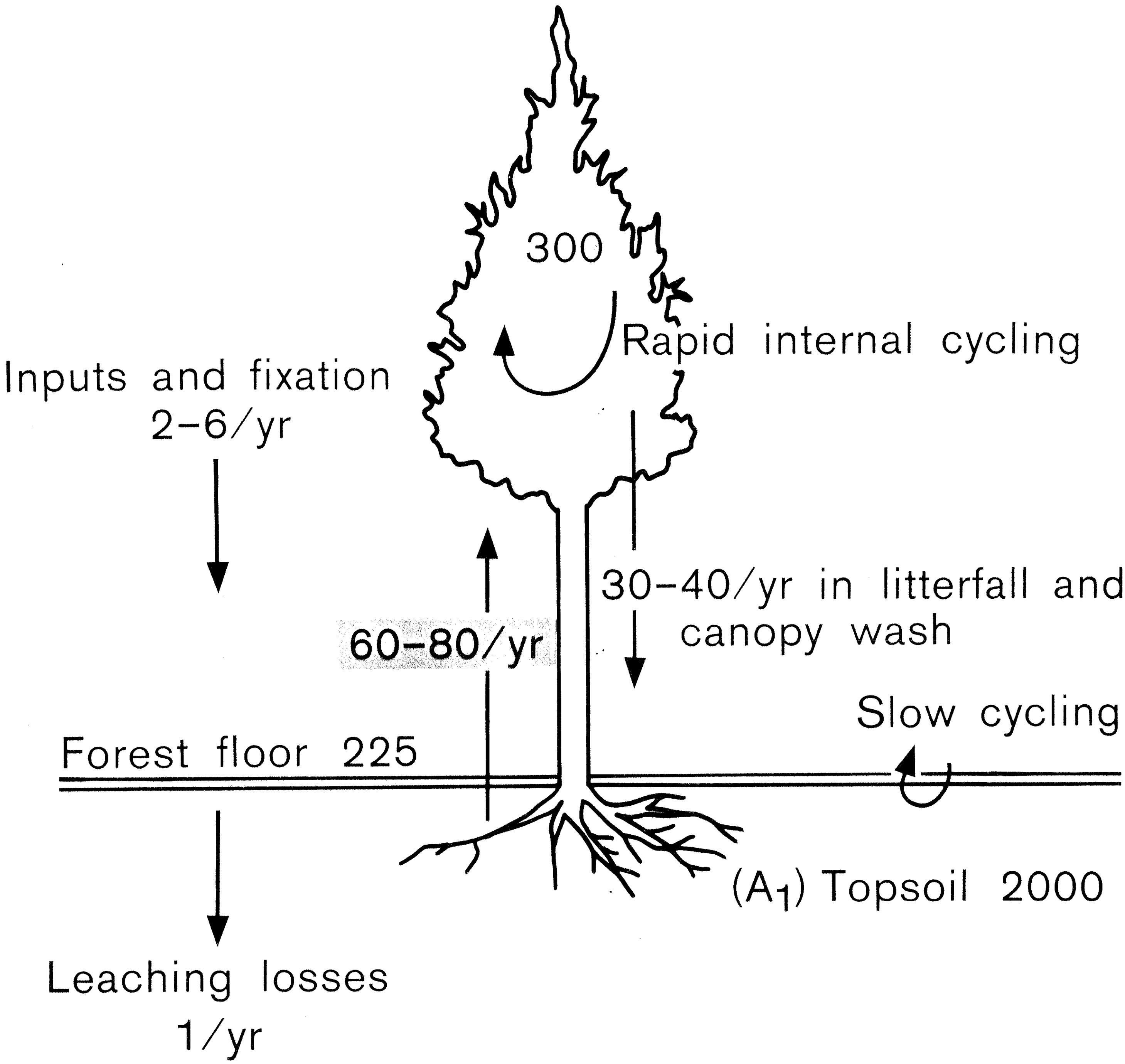
CONCLUSIONS

Split dressings do not lead to greater uptake, at least in short term

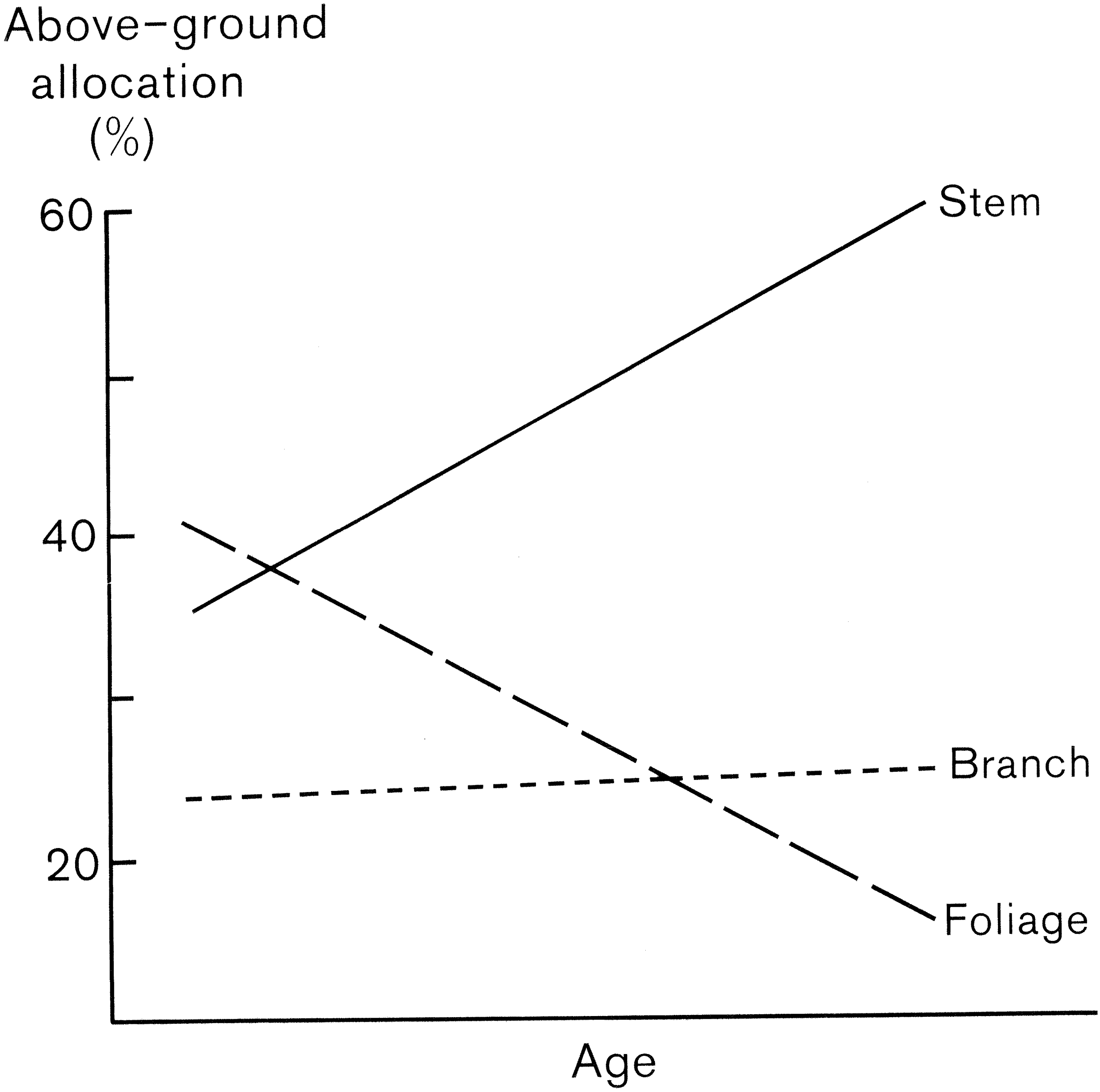
However split dressings will reduce leaching and soil water contamination

FOREST FERTILISATION MANAGEMENT SYSTEM

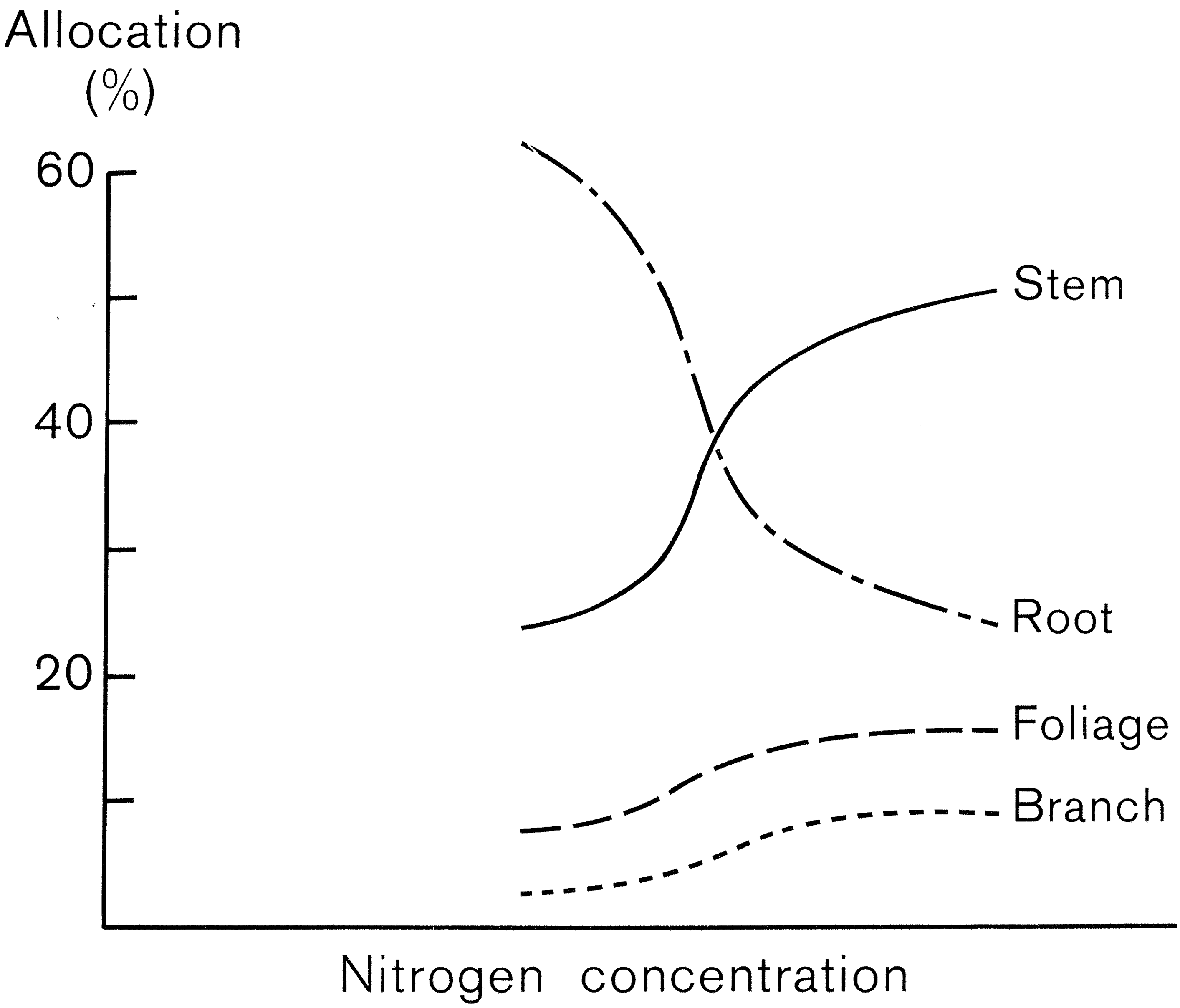
Nitrogen pools and annual cycling of nitrogen in 16-year-old radiata pine (kg/ha)



Allocation depends on age

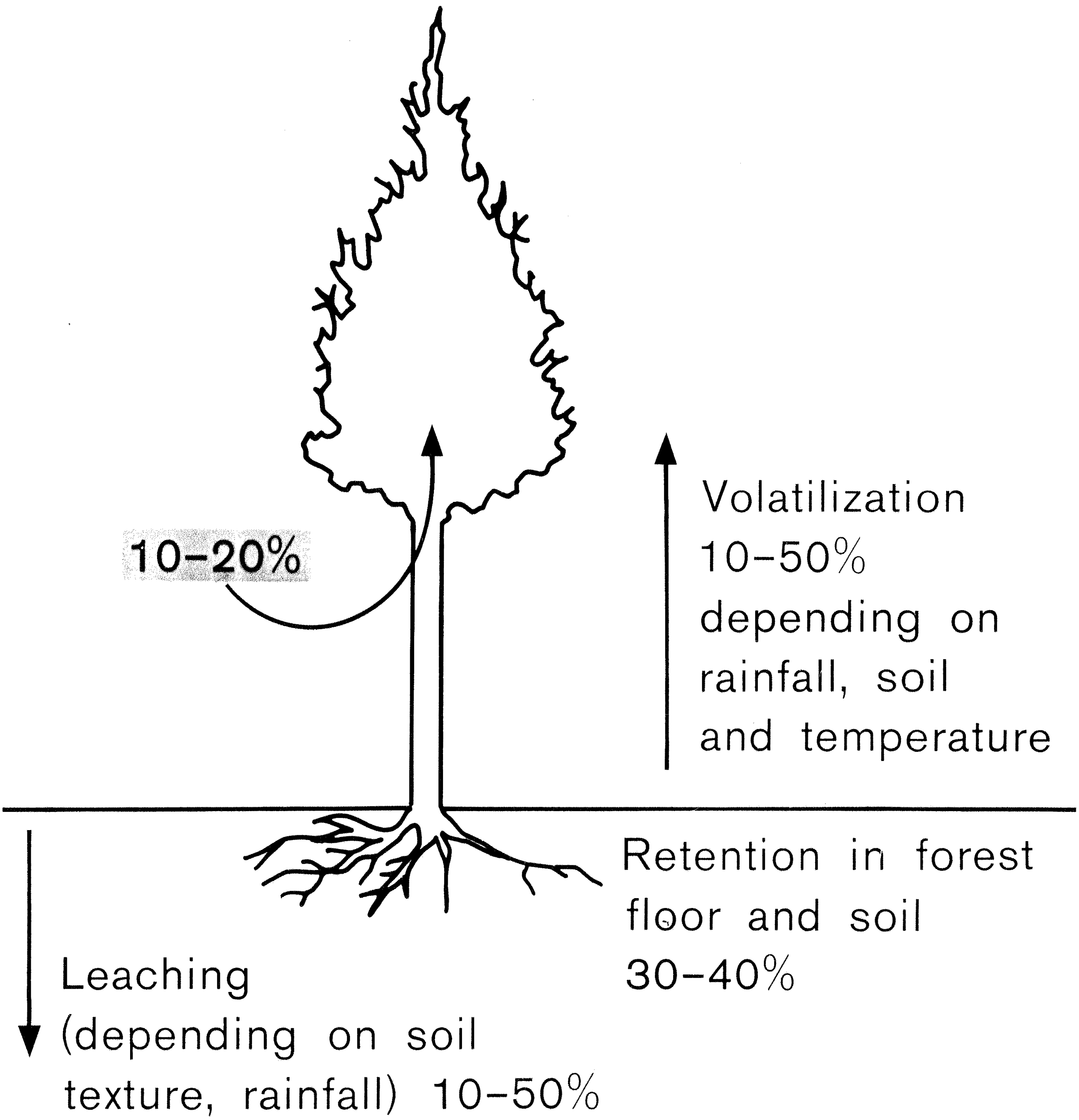


Allocation depends on nutrition



FOREST FERTILISATION MANAGEMENT SYSTEM

Probable fate of applied fertiliser (200kg N/ha)



OVERHEADS FROM SESSION 2

THE TRIAL DATABASE ON WHICH THE N RESPONSE MODEL IS BASED

1. 32 trial sites from North Cape to the Bluff (almost)

2. 44 individual comparisons of fertilised against unfertilised

3. Age at fertilising ranging from 4 to 20

4. Topsoil N ranging from 0.01 (grossly deficient) to 0.47% (luxury)

5. Topsoil available phosphorus ranging from 3 ppm (deficient) to 86 ppm

6. % clay ranging from 1 (sand) to 33 %

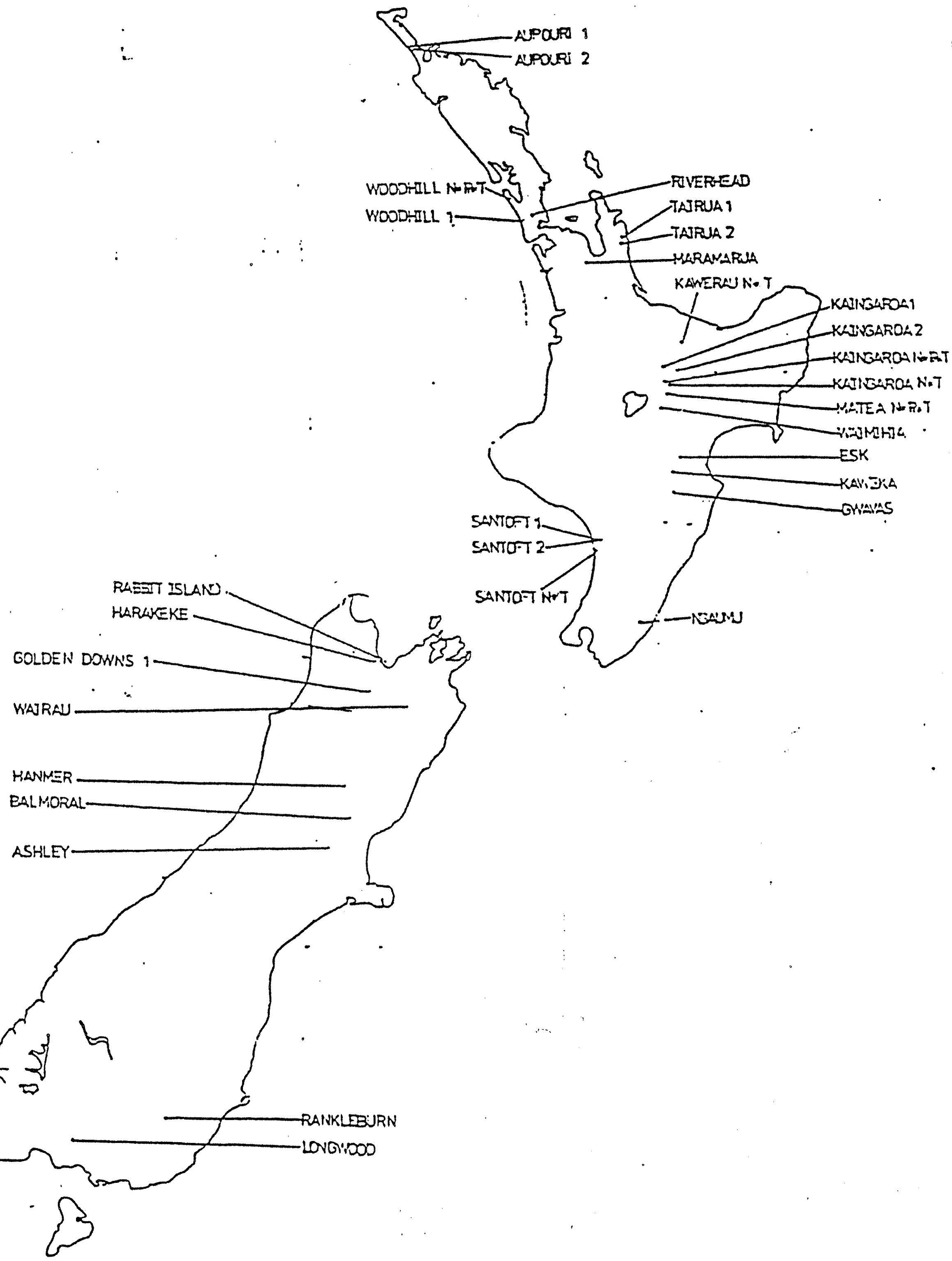
7. 54% of the stands recently pruned

8. 78% of the stands recently thinned

2/1

FIGURE 1: Trial locations

TRIALS USED IN N RESPONSE DATABASE.



FACTORS THAT DETERMINE THE SIZE OF AN N FERTILISER RESPONSE

1. the amount of N in the soil

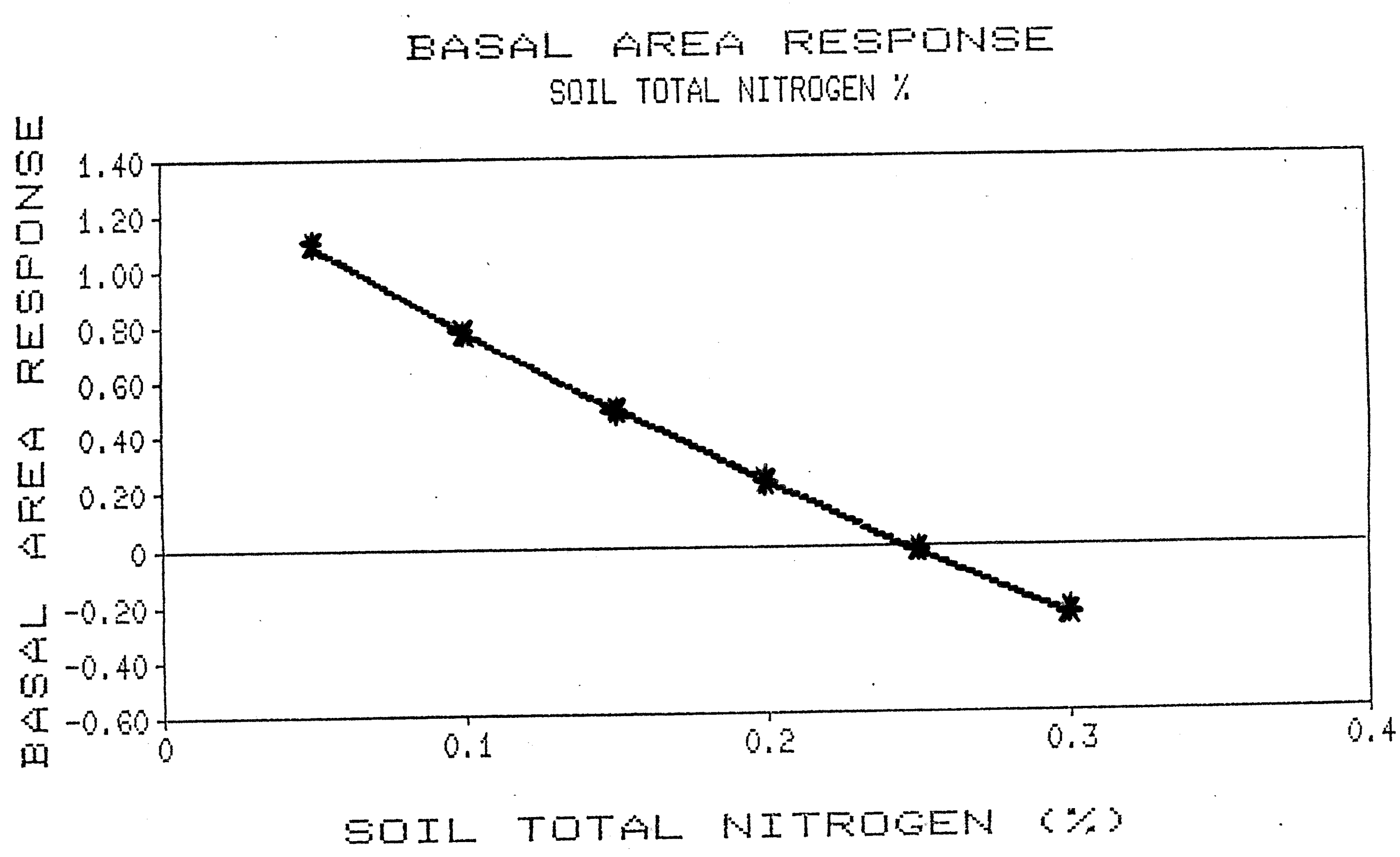
2. the amount of phosphorus in the soil

3. the amount of clay in the soil

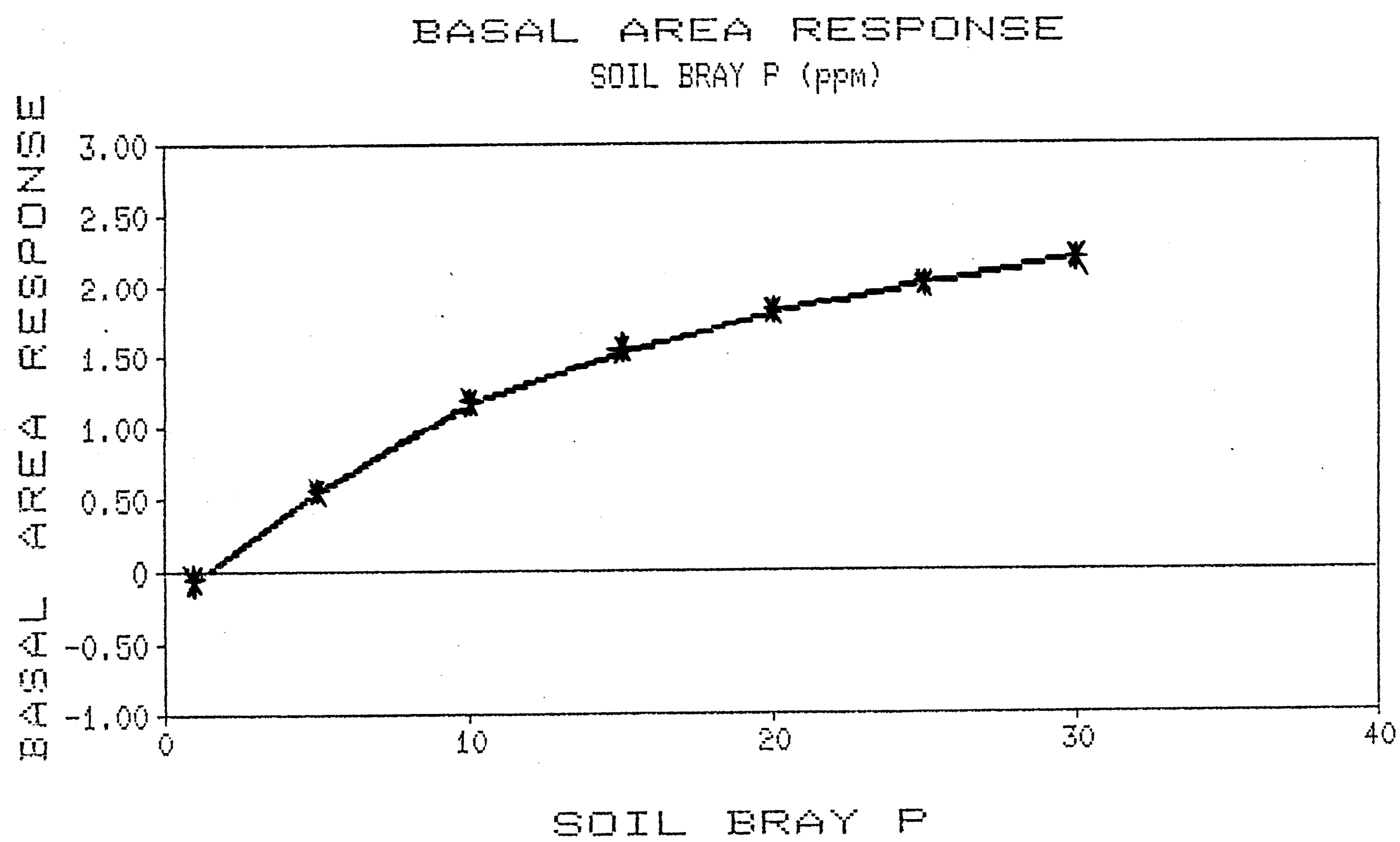
4. age at the time of fertilising

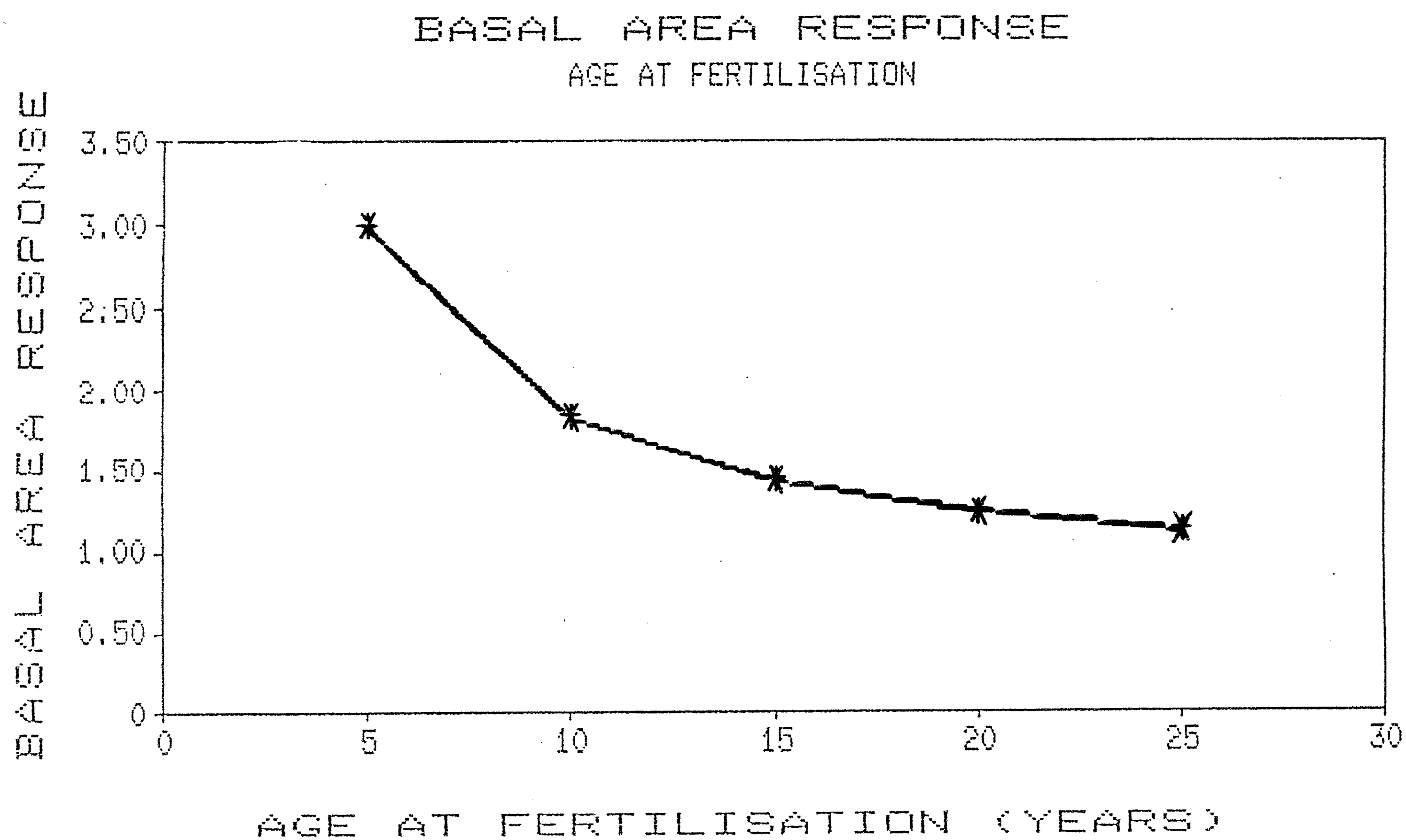
5. recent silvicultural history

2/2


BASAL AREA RESPONSE
SOIL TOTAL NITROGEN %
BASAL AREA RESPONSE
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
-0.20
-0.40
-0.60
0
0.1
0.2
0.3
0.4
SOIL TOTAL NITROGEN (%)

2/2


BASAL AREA RESPONSE
SOIL BRAY P (ppm)
BASAL AREA RESPONSE
3.00
2.50
2.00
1.50
1.00
0.50
0
-0.50
-1.00
0
10
20
30
40
SOIL BRAY P


BASAL AREA RESPONSE
AGE AT FERTILISATION
BASAL AREA RESPONSE
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0
0
5
10
15
20
25
30
AGE AT FERTILISATION (YEARS)

HOW THE NITROGEN FERTILISER RESPONSE VARIES WITH THE AMOUNT OF FOLIAGE LEFT AFTER TENDING

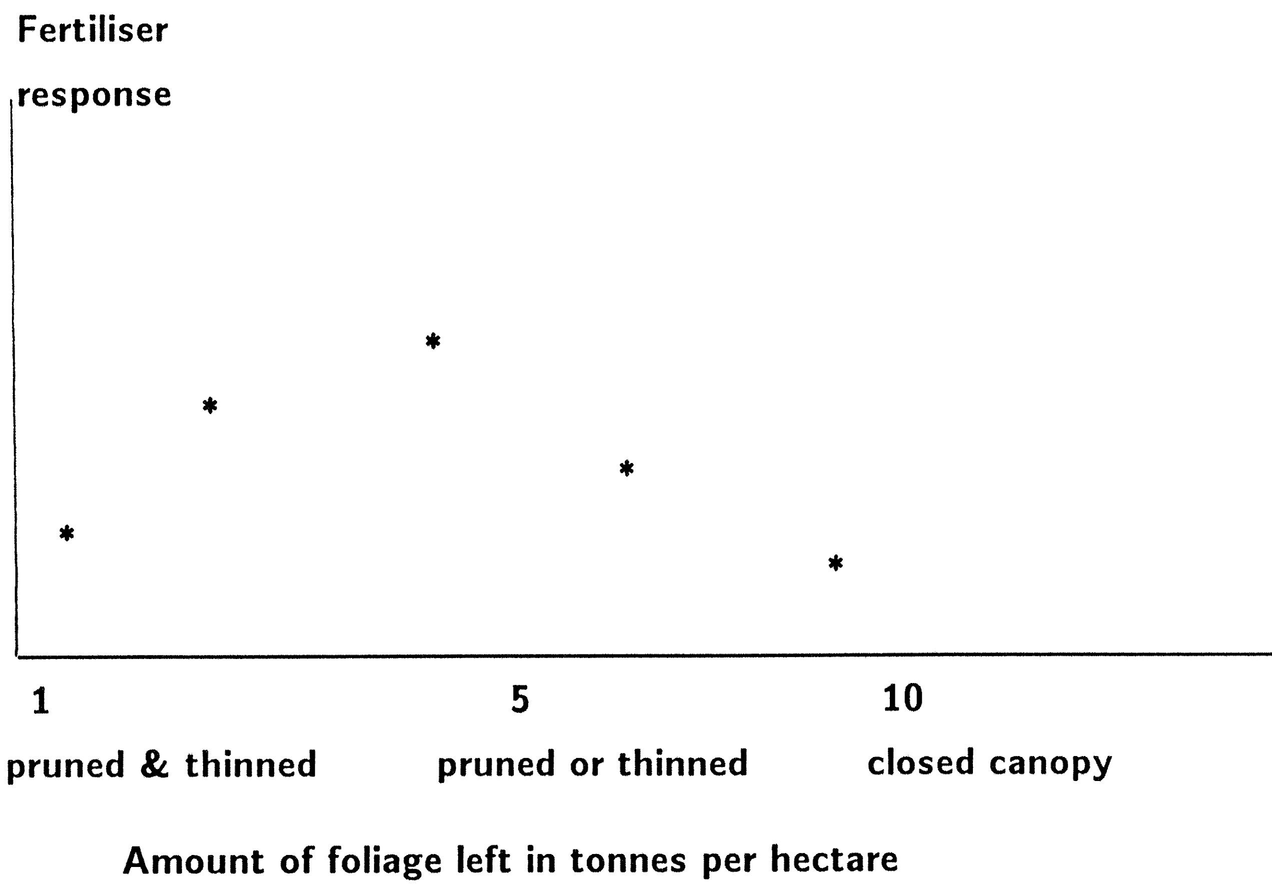


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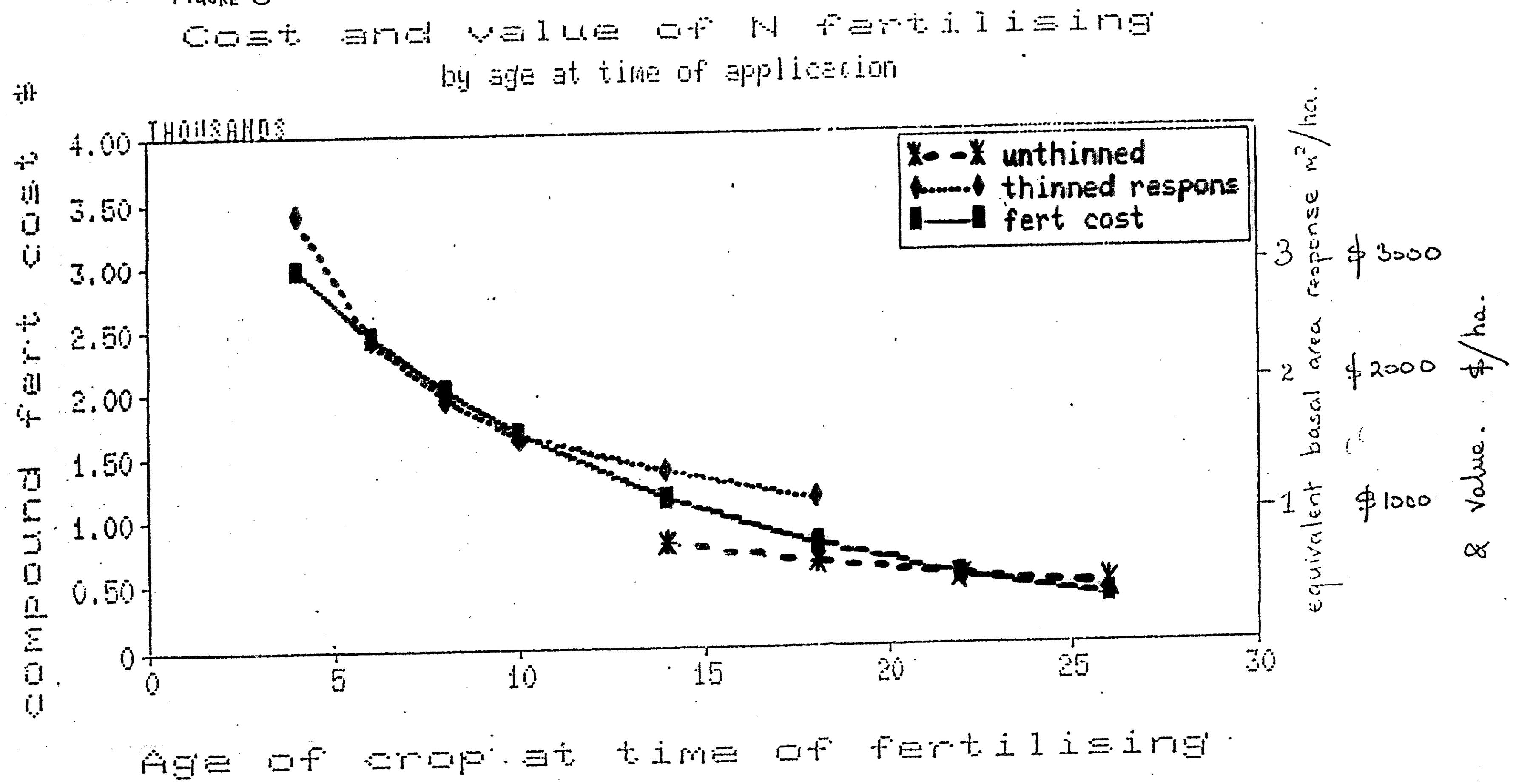
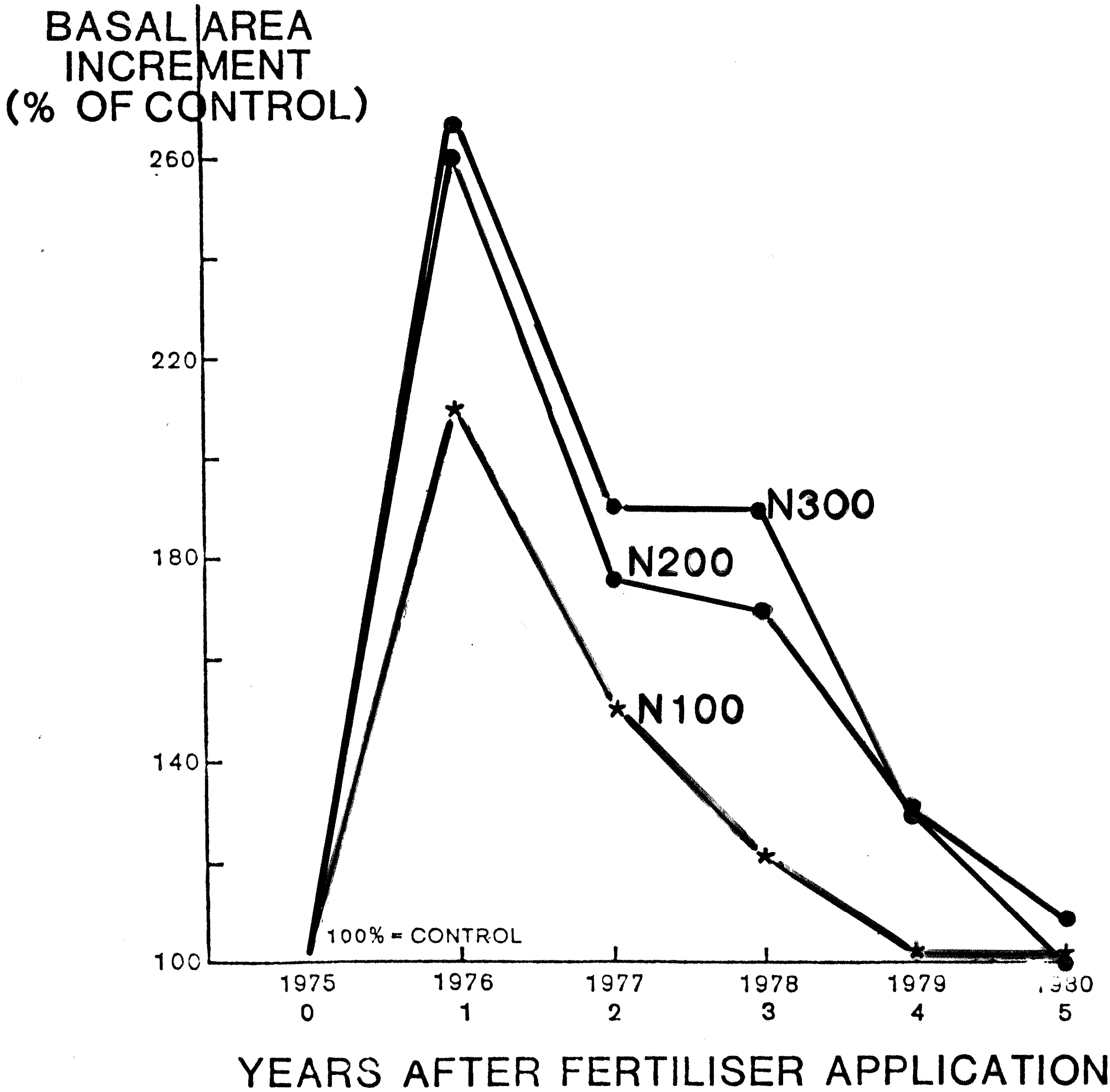
Figure 3


Cost and value of N fertilising
by age at time of application
compound fert cost $
THOUSANDS
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0
0
5
10
15
20
25
30
unthinned
thinned respons
fert cost
equivalent basal area response m²/ha.
& value. $/ha.
3
2
1
$3000
$2000
$1000
Age of crop at time of fertilising



DECREASING RATE OF RESPONSE WITH INCREASING RATE OF FERTILISER.

R WOOLLONS.

NITROGEN ON RADIATA PINE ON THE PUMICE PLATEAU

Between 1968 and 1975 NZFP established 9 trials looking at mid rotation Pinus radiata fertilization

These showed:

1. N was the essential active element
   [P singly or in interaction never showed a response]
2. THINNING was required [unthinned stands older than 10 did not respond]
3. 500 kg/ha of UREA was required. Lesser rates did not respond beyond 1 or 2 years.
   Higher rates gave inconsistent responses
4. Dothistroma lessened response
5. Form/shape changes through fertilisation are small (usually 3-4 years and of 2-3% magnitude)
6. No height response

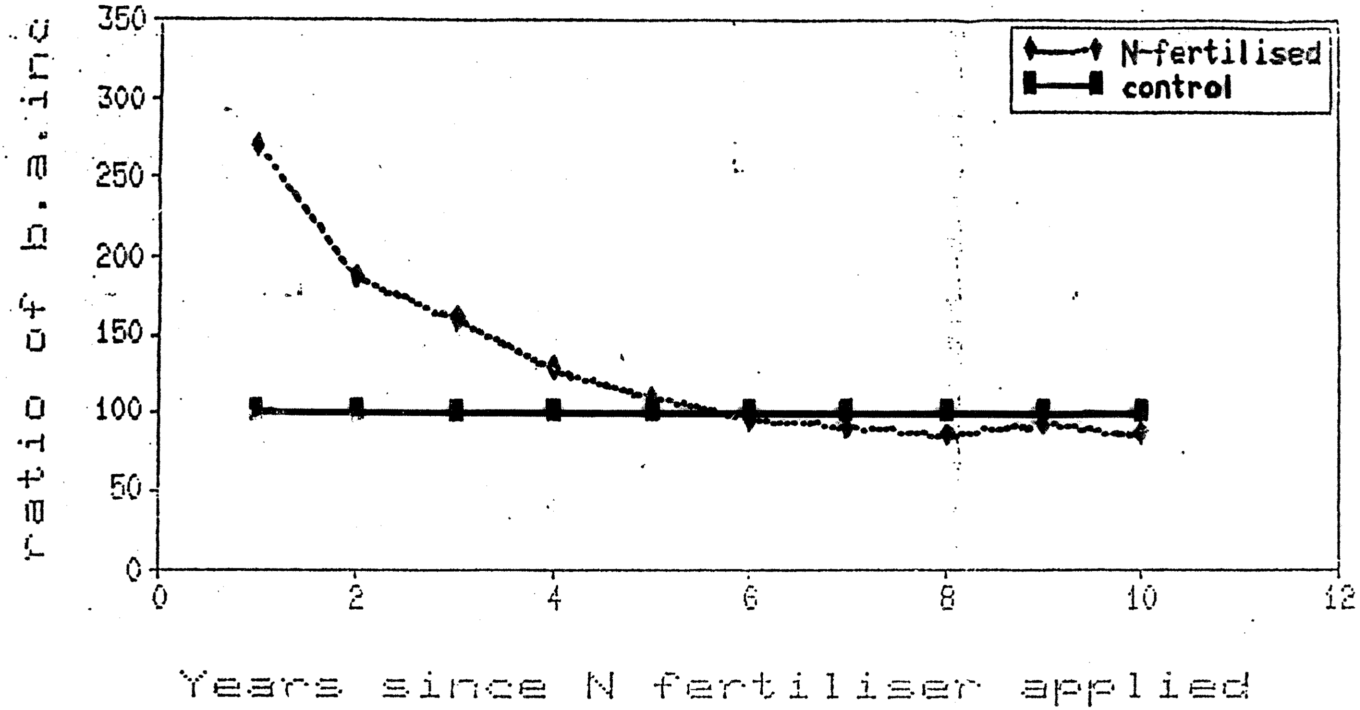
OVERHEADS FROM SESSION 3

9/2

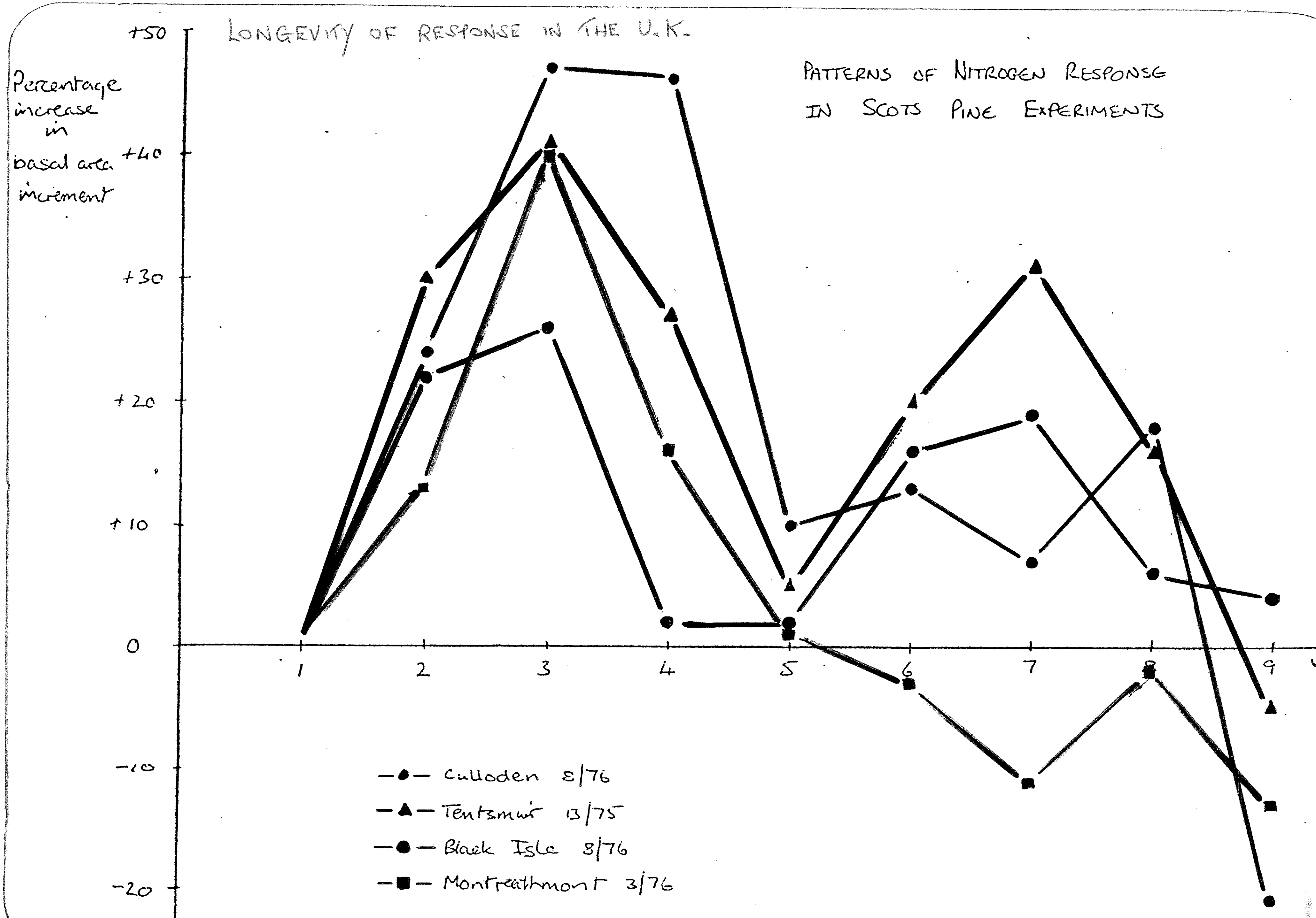
LONGEVITY OF RESPONSE IN ONE NZ TRIAL.

FIGURE 2

Ratio of basal area growth in N fert plots to unfert plots over time



NOTES


LONGEVITY OF RESPONSE IN THE U.K.
PATTERNS OF NITROGEN RESPONSE IN SCOTS PINE EXPERIMENTS
Percentage increase in basal area increment
+50
+40
+30
+20
+10
0
-10
-20
1
2
3
4
5
6
7
8
9
Culloden 8/76
Tentsmuir 13/75
Black Isle 8/76
Montreathmont 3/76

MODEL FOR NITROGEN FERTILISER RESPONSE

Assumptions:
1. Fertilised stands put on 160% of pre-existing foliage; unfert 40%
2. The site can carry a maximum of 12 tonnes of foliage.
3. The site can supply 40 kg/yr of N

	Unfertilised				Fertilised			
Year	canopy weight	%N	Total N	Volinc	canopy weight	%N	Total N	Voli
0	4.5	1.3	58		4.5	1.7	78	
1	6.3	1.4	88	20	7.2	1.5	106	28
2	8.8	1.3	113	26	11.3	1.2	128	31
3	12.0	1.1	134	33	12.0	1.2	146	37
4	12.0	1.3	152	38	12.0	1.3	162	41

Ratio of volinc fertilised:volinc unfertilised

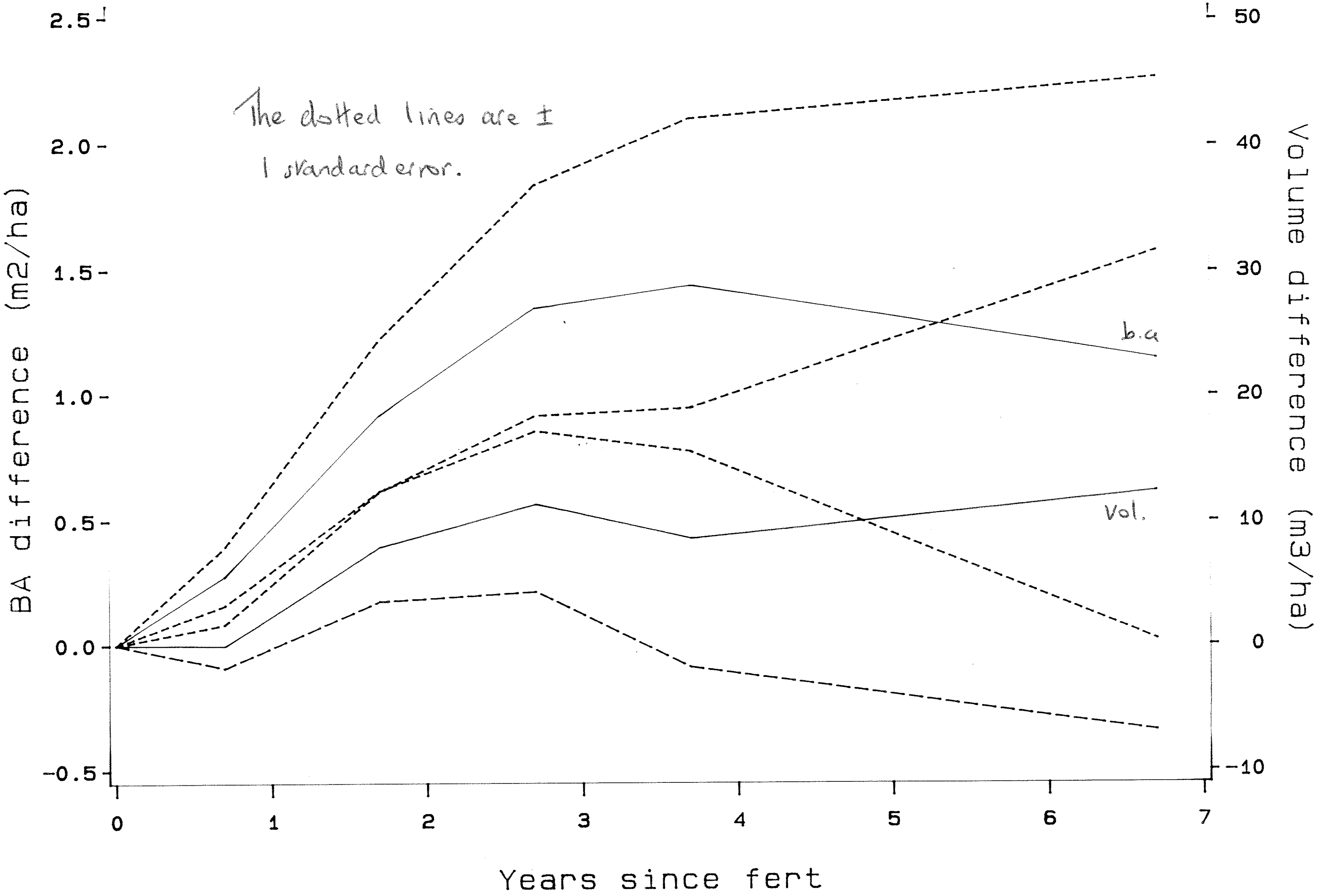
Year	1	2	3	4
Ratio	1.4	1.2	1.1	1.1

TRIALS STUDIED FOR LONGEVITY OF RESPONSE TO NITROGEN

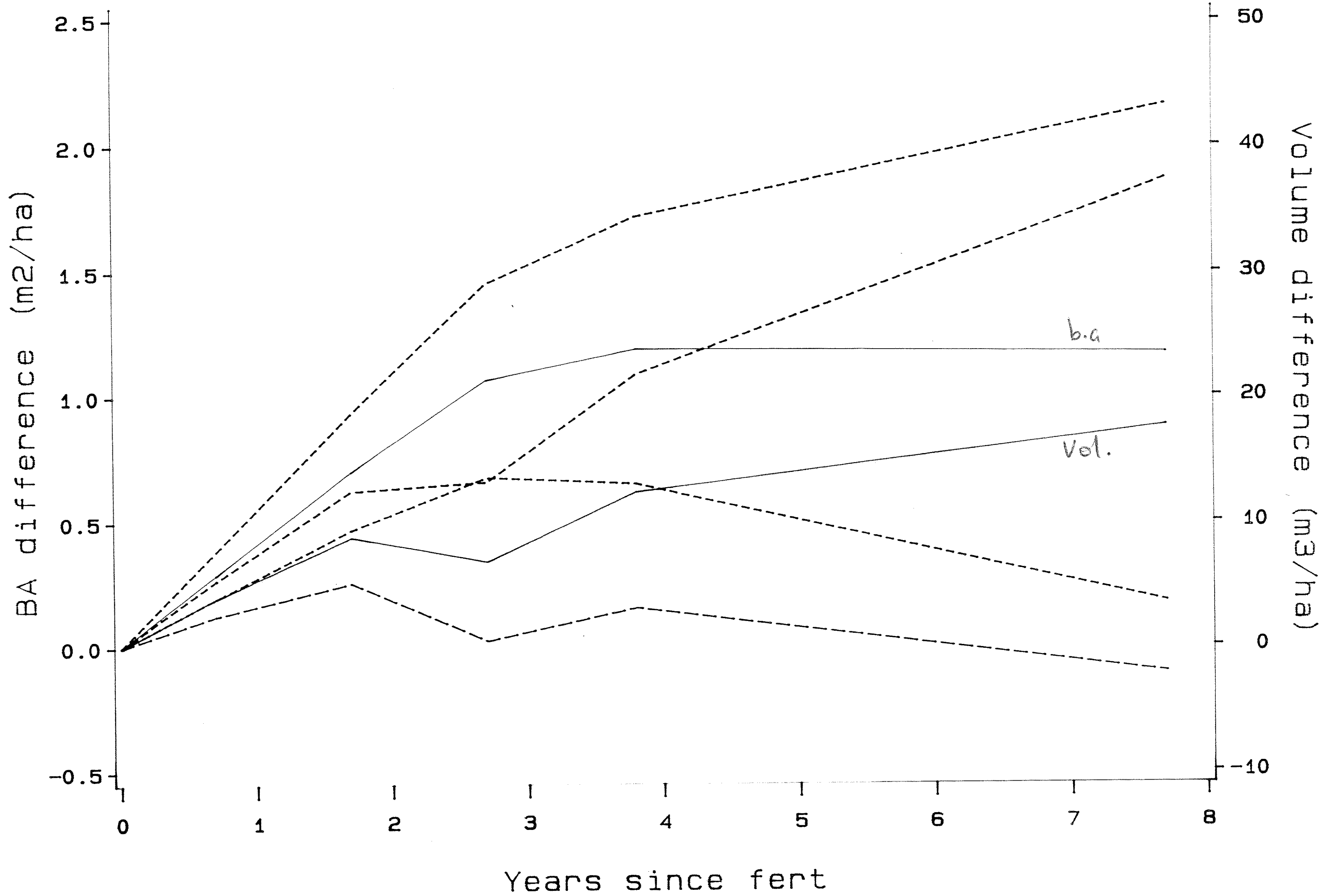
M KIMBERLEY.

TRIAL	FOREST	SOIL	AGE AT ESTAB.	MEASUREMENT PERIOD (YRS)	STEMS/HA	REPS	LATEST MEAS. BY
AK670	AUPOURI	SAND	8	12	330	3	TIMBERLANDS
AK693	WOODHILL	SAND	12	12	380	4	TIMBERLANDS
AK748	RIVERHEAD	CLAY	12	11	390	4	TIMBERLANDS
AK755/1	MARAMARUA	CLAY	11	11	100–420	4	FRI
AK830/1	AUPOURI	SAND	6	7	840	2	TIMBERLANDS
AK911	WOODHILL	SAND	5	6	750	3	FRI
RO1818	KAINGAROA	PUMICE	16	8	220	6	FRI
RO1843	KAINGAROA	PUMICE	15	7	230	4	FRI
RO1844	TARAWERA	PUMICE	19	7	250	4	FRI/TASMAN
WN201	SANTOFT	SAND	11	12	510	2–3	FRI/MOF
WN205	SANTOFT	SAND	13	11	2300	2–3	FRI/MOF
WN278	SANTOFT	SAND	6	5	660	4	FRI/MOF

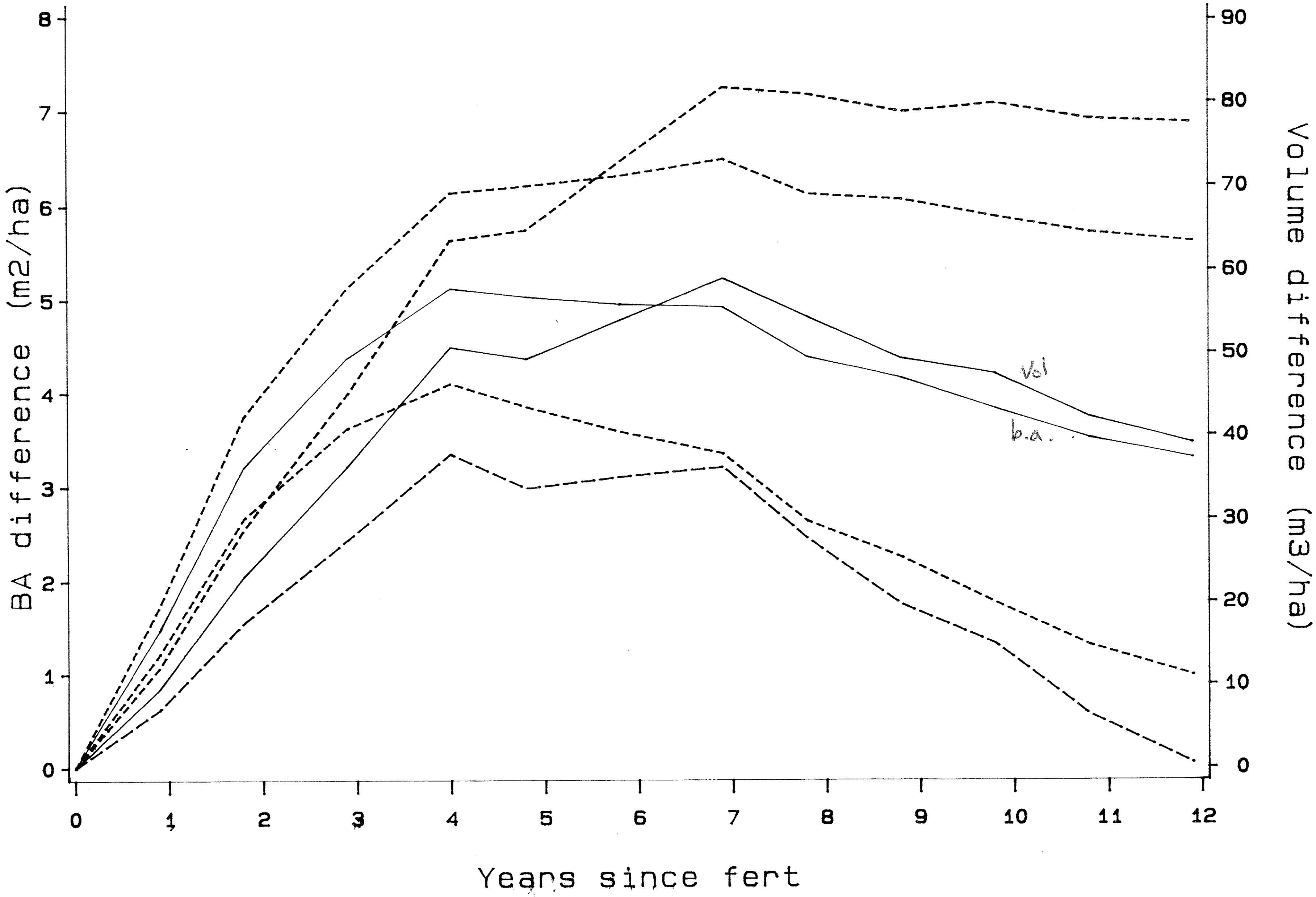
RO1843: Basal area & volume increase differences (fert – unfert)



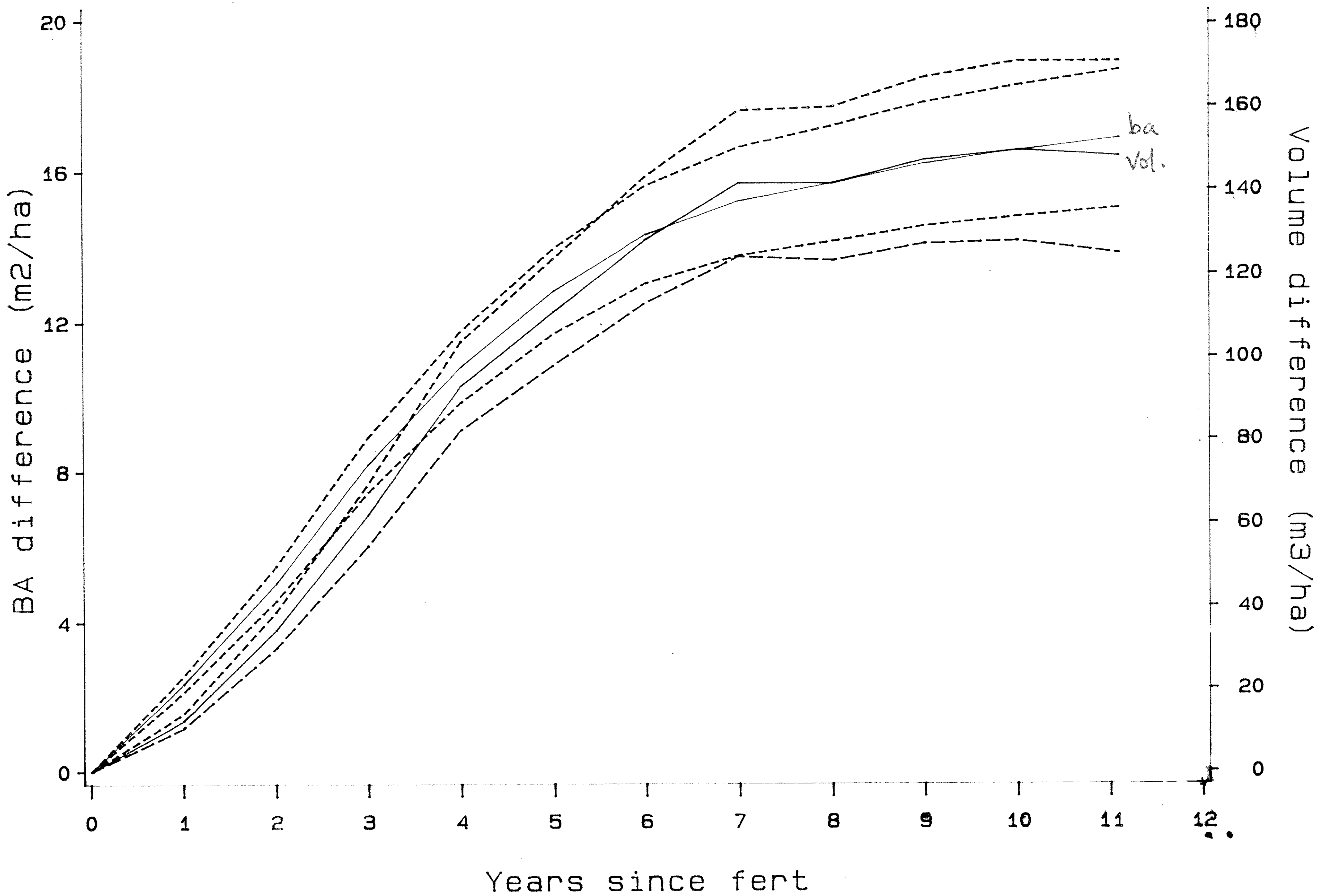
RO1818: Basal area & volume increase differences (fert – unfert)



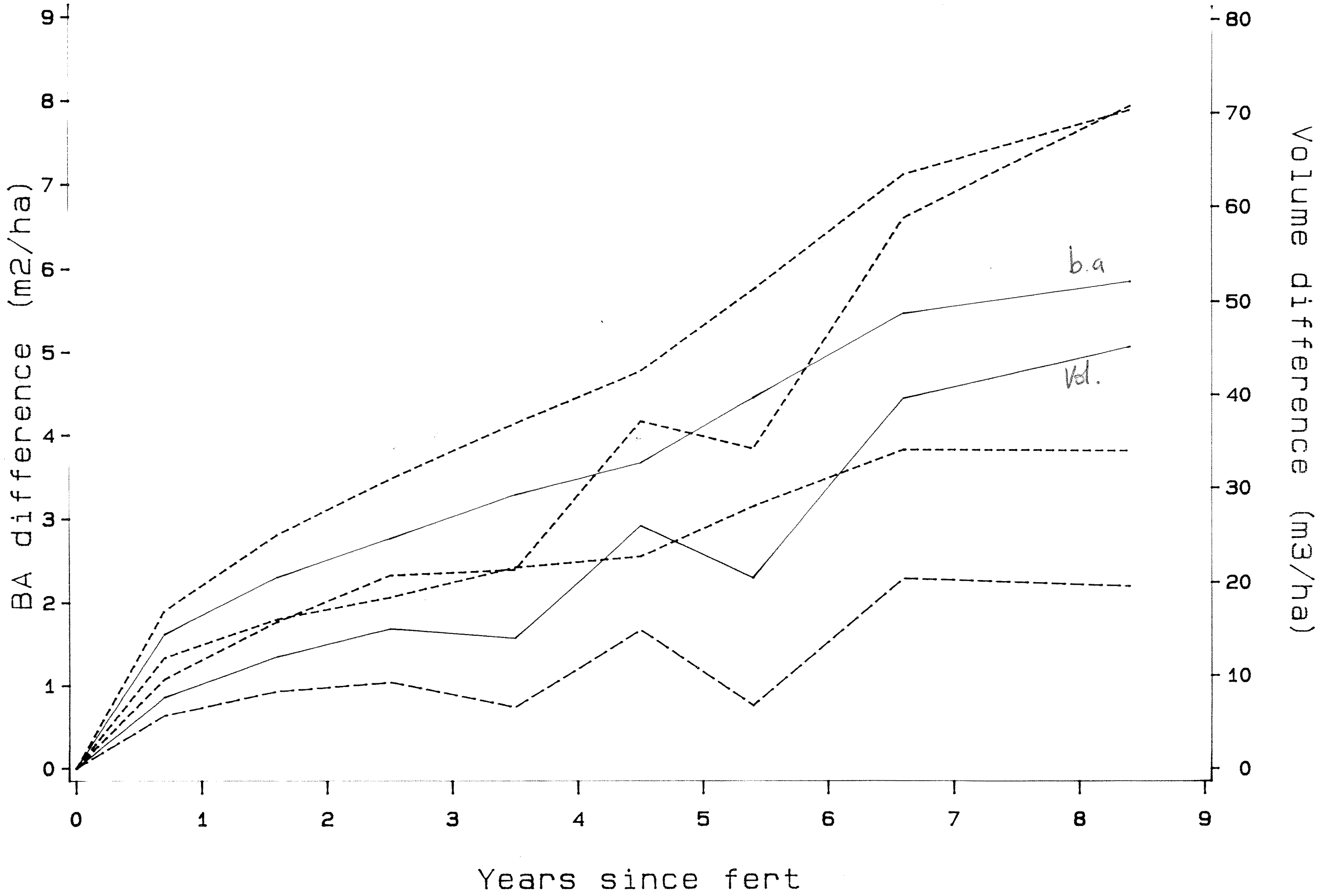
WN201: Basal area & volume increase differences (fert – unfert)



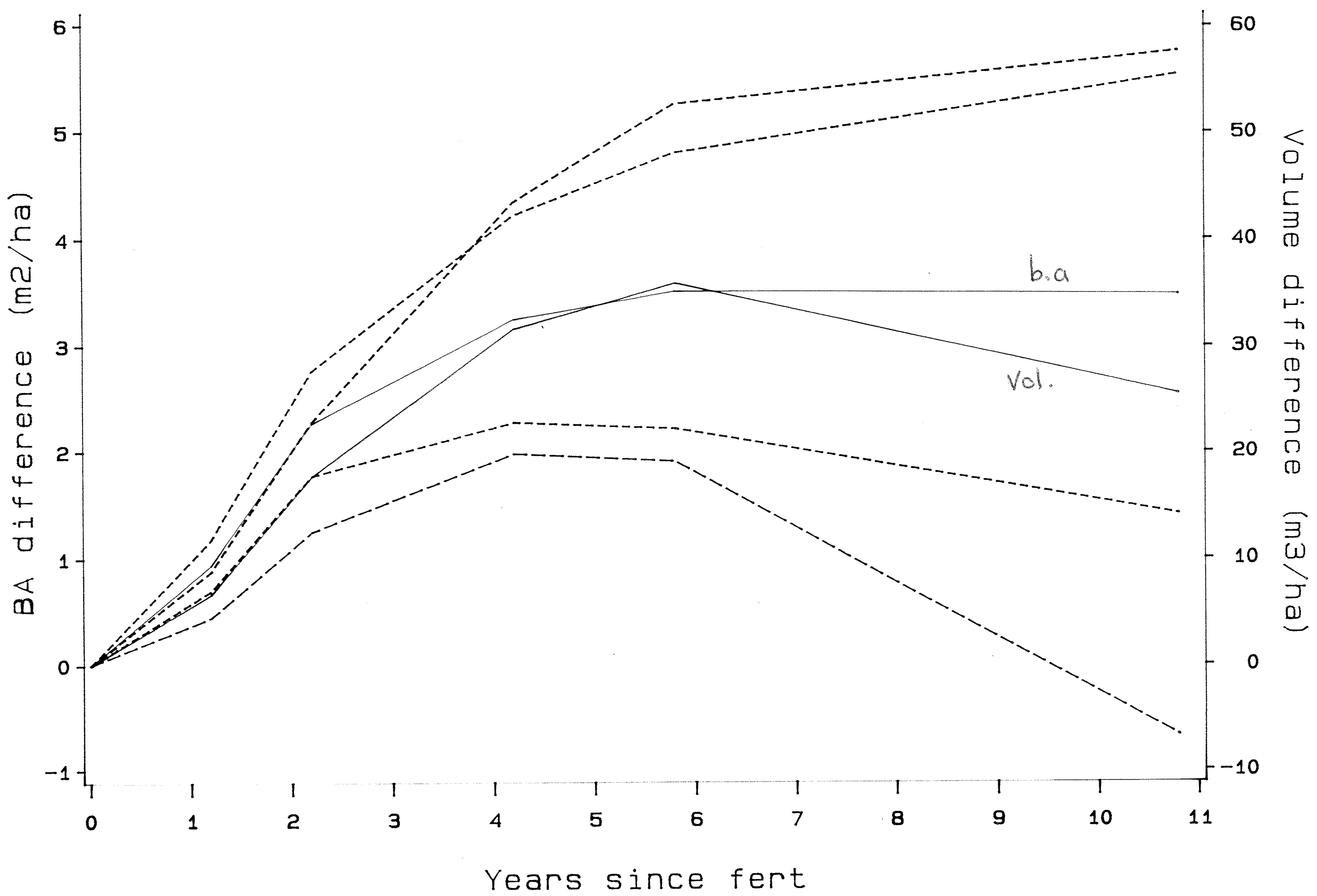
WN205: Basal area & volume increase differences (fert – unfert)



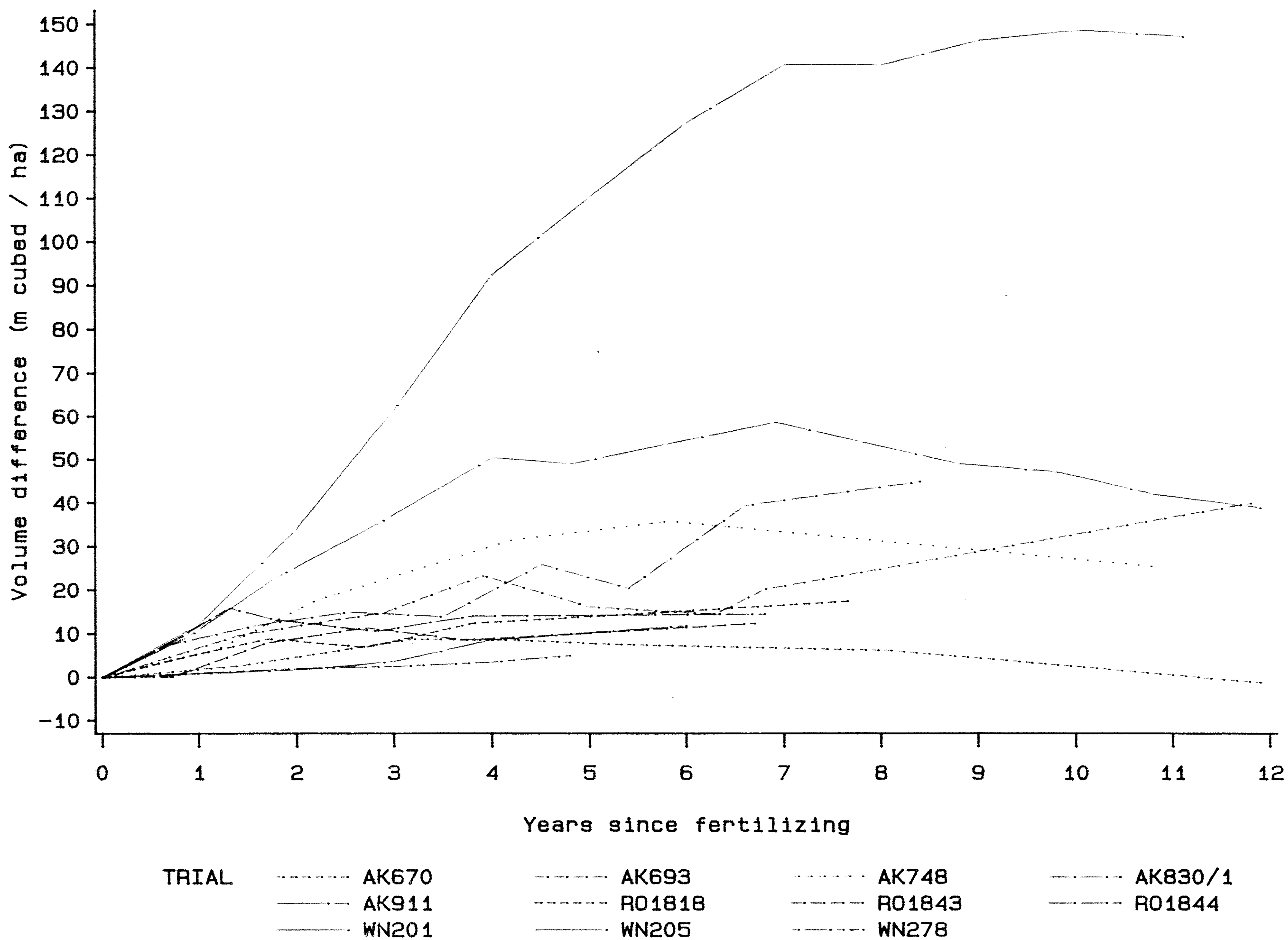
AK830/1: Basal area & volume increase differences (fert – unfert)



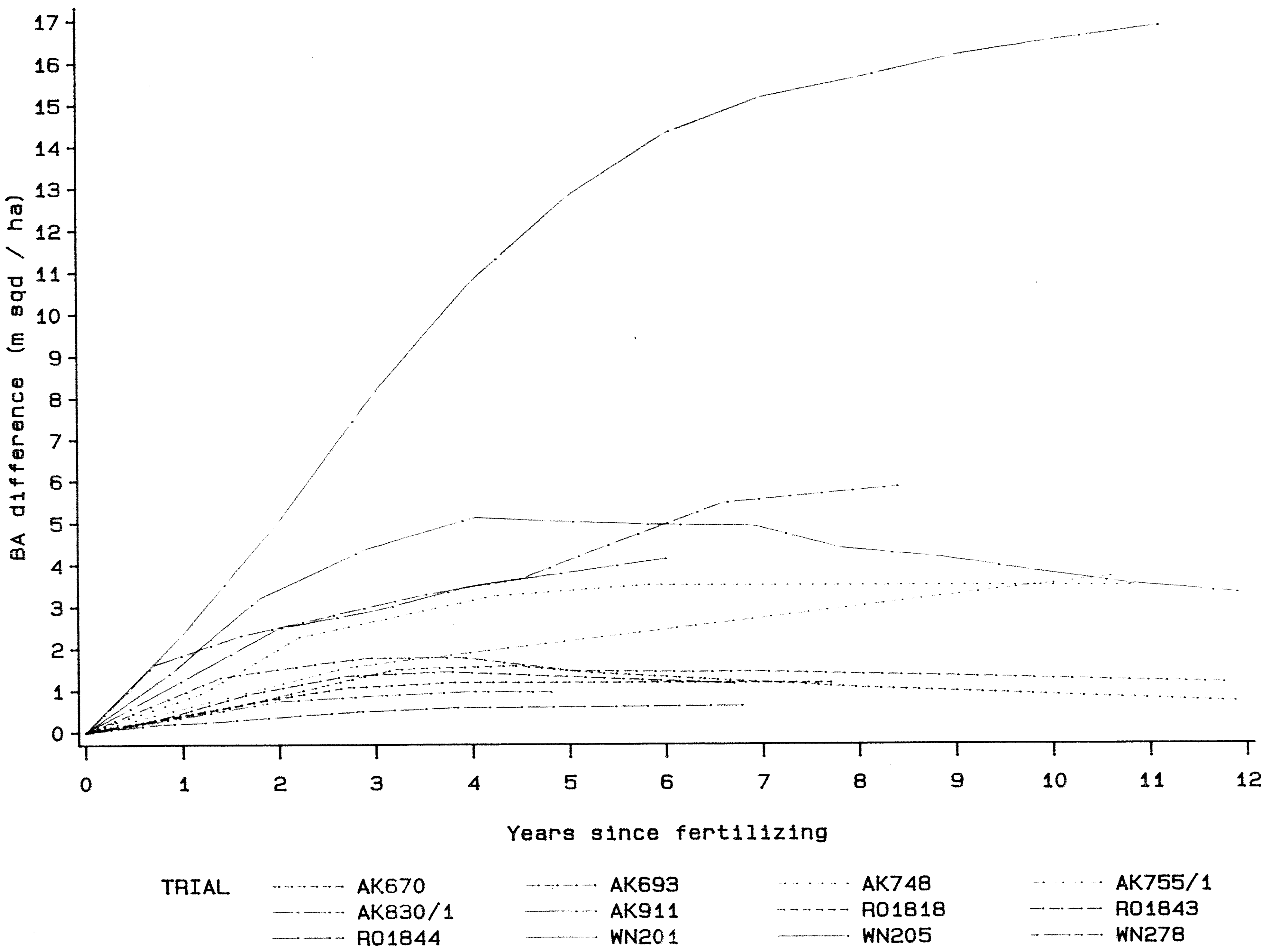
AK748: Basal area & volume increase differences (fert – unfert)



Difference (fert–unfert) in volume increase since fertilizing



Difference (fert–unfert) in basal area increase since fertilizing



N : RADIATA PINE

Position/statement on basic results

R C Woollons/A G D Whyte

NZFP Forests Ltd has four experiments initiated at age 13, following thinning, measured between 6 - 19 years.

Trial	Period	Stocking (stems/ha)	Urea applied	Responses G (m^2/ha)	Responses V (m^3/ha)	Form change
1(a)	9	571	500	6.2(9%)	66(11%)	0.008
1(b)	19	357	500	5.6(8%)	39(8%)*	0.006
2	6	463	250	1.5(3%)	21(4%)	-
3	6	437	500	0.9(2%)	18(3%)	-
4	11	398	500	3.8(7%)	40(8%)+	0.007

* = 7 year response
\+ = 6 year response

1. Basal-area and volume responses compound (albeit slowly).
2. Form changes, generally proportional to response: small, can be transient (2-3%).
3. Responses proportional to base growth rate.
4. Responses retarded by <u>Dothistroma pini</u>
5. 500 kg/ha urea required for sustained response
6. No height response
7. Unthinned stands (past age 10) will not respond.

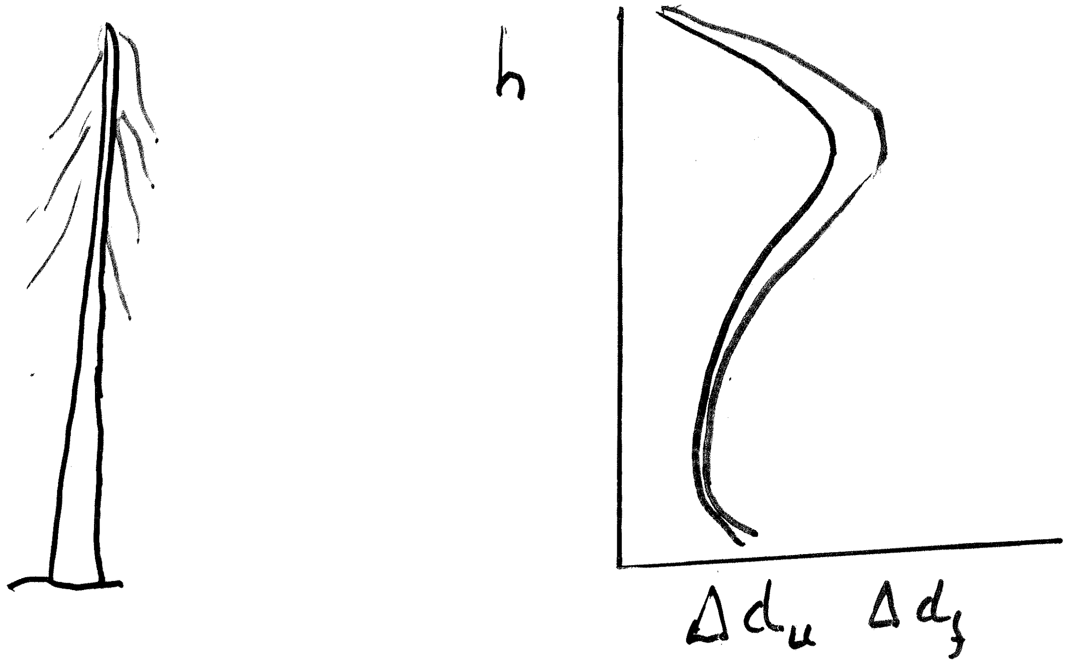
EYREWELL FOREST

D. MEAD'S 2^2 FACTORIAL

	RESPONSES (m^2/ha)	
	THINNED	UNTHINNED
1978	0.72	0.59
1979	1.90	2.34
1980	3.95	4.65
1981	4.51	4.94
1982	4.32	5.66
1983	4.40	6.21
1986	2.66	6.34
1987	1.98	6.13

NZFP (UNPUBLISHED EXPT)

	1st year after thinning & fertilising	2nd year	3rd year
		m^2/ha/annum	
Control	1.8 n.s	3.0	2.3
Fert.	1.82	3.6	2.7



- NO HEIGHT RESPONSE TO N
- SOME BASAL AREA RESPONSE (TRANSITORY)
- GREATEST STEM DIAMETER RESPONSE AROUND BASE OF GREEN CROWN
- VOLUME RESPONSE LONGER LASTING THAN BASAL AREA
- MOST USEFUL RESPONSES (ALSO REL<u>ATIV</u>ELY GREATER) IN YOUNGER TREES

RESPONSE/TREE NOT LARGE.
THUS NEED VERY SENSITIVE MEASUREMENT TECHNIQUES.

OVERHEADS FROM SESSION 4

A GORDON.

Information on Trials

trial	Age	Mean DBH	Mean Height	Period	Meas./tree
Hanmer	8	13.0	-	4	9-20
Ashley	11	21.3	-	4	9-22
Longwood	9	9.4	-	4	5-12
Esk	9	22.6	-	4	6-10
Kaweka	9	15.8	-	4	5-9
Balmoral 1	7	8.3	6.3	4	8-14
Balmoral 2	12	17.0	10.5	4	7-18
Gdn.Downs1	7	12.5	9.0	4	5-11
Gdn.Downs2	8	10.4	6.8	4	5-9
Sth Pigeon	10	19.1	-	4	5-8
Rabbit Isld	8	13.8	15.6	4	6-10
Santoft	11	16.2	12.6	5	7-12
Mariri	40	42.9	36.0	5	12-22
Tawhai	24	38.9	-	5	6-11
Harakeke	20	29.5	27.4	5	6-10
Kaingaroa	16	32.7	24.1	2	6-9
Rankleburn	8	10.3	-	4	4-8
Riverhead	6	4.2	3.3	6	4-9

Tree age and size are at time of fertilization

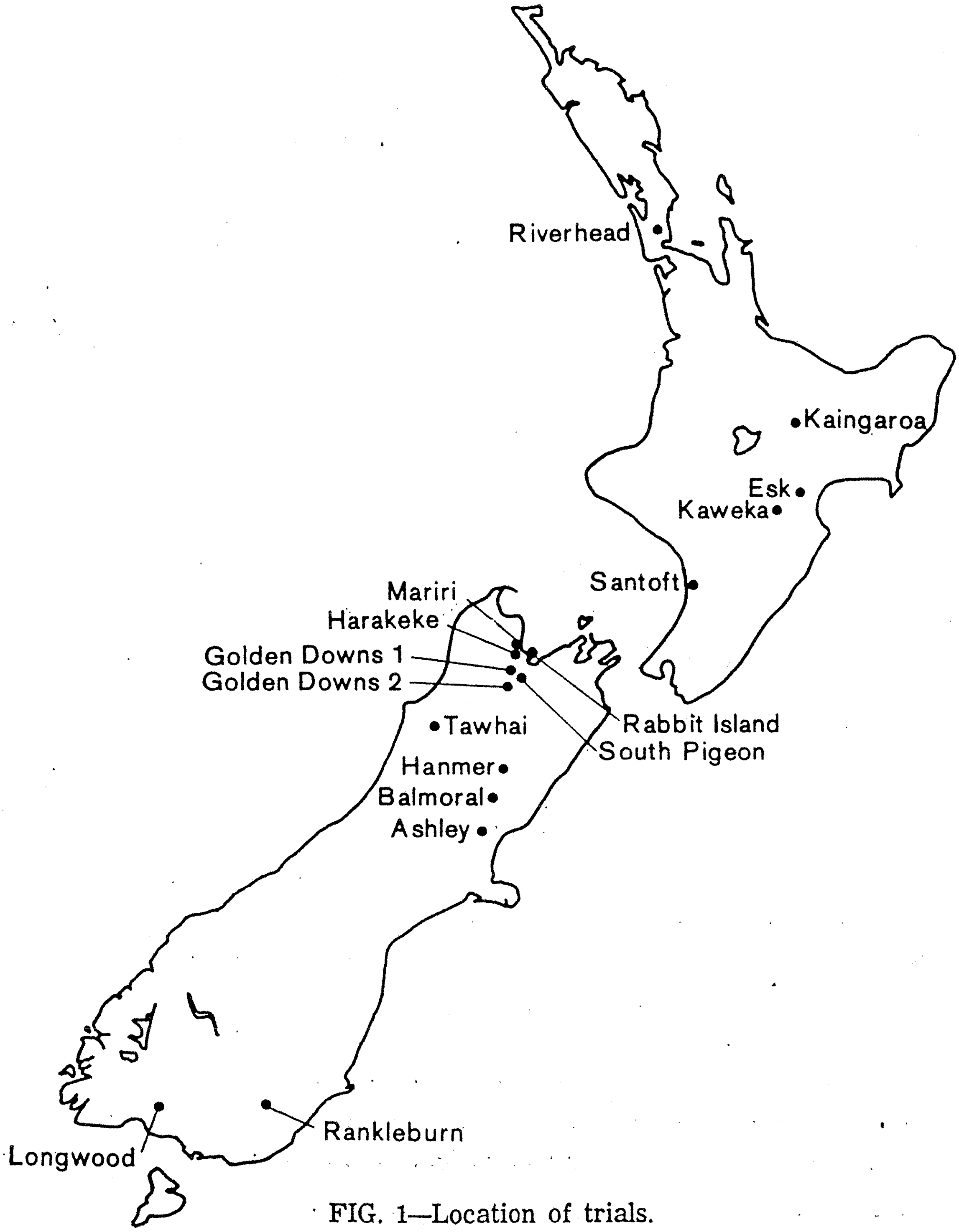
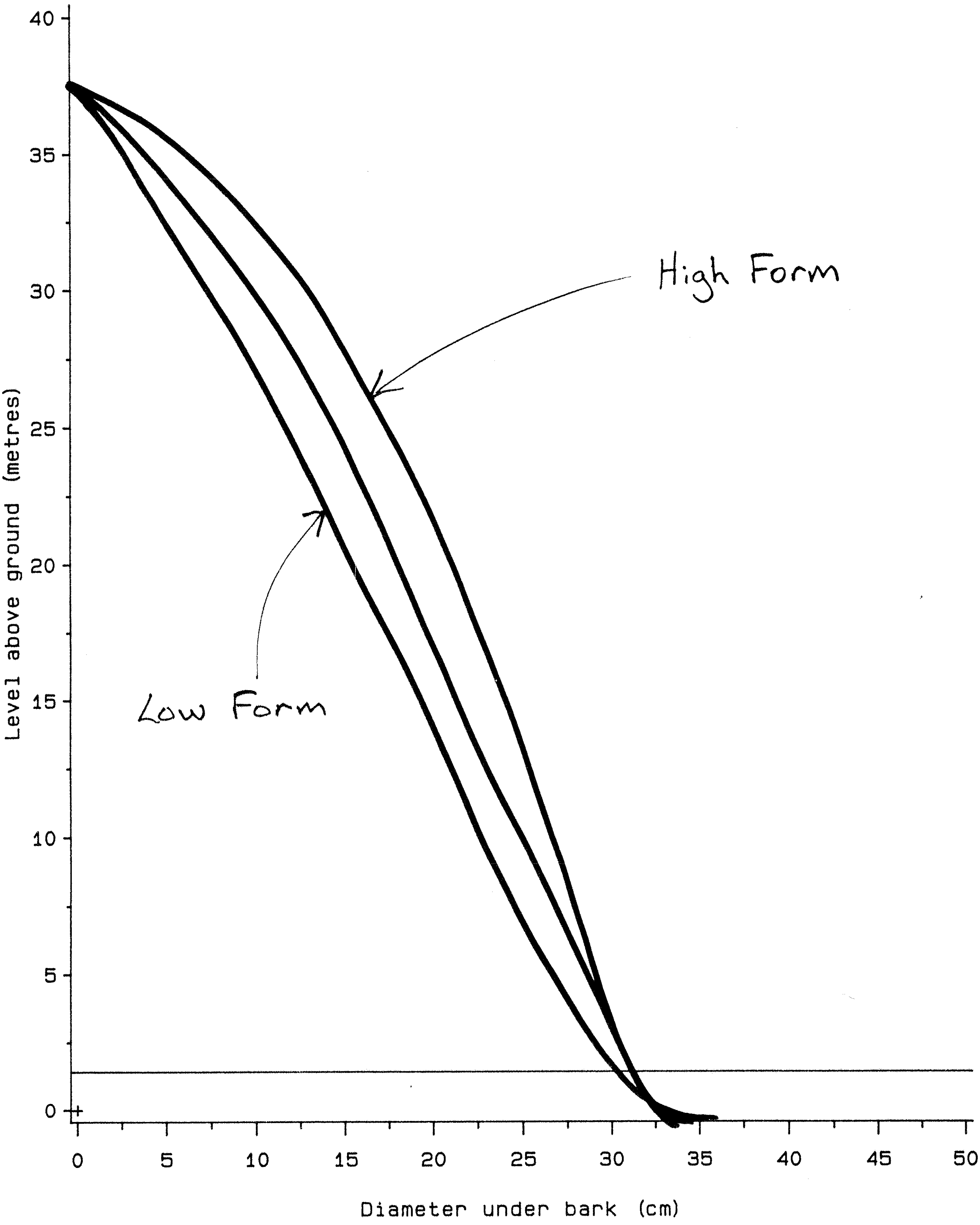
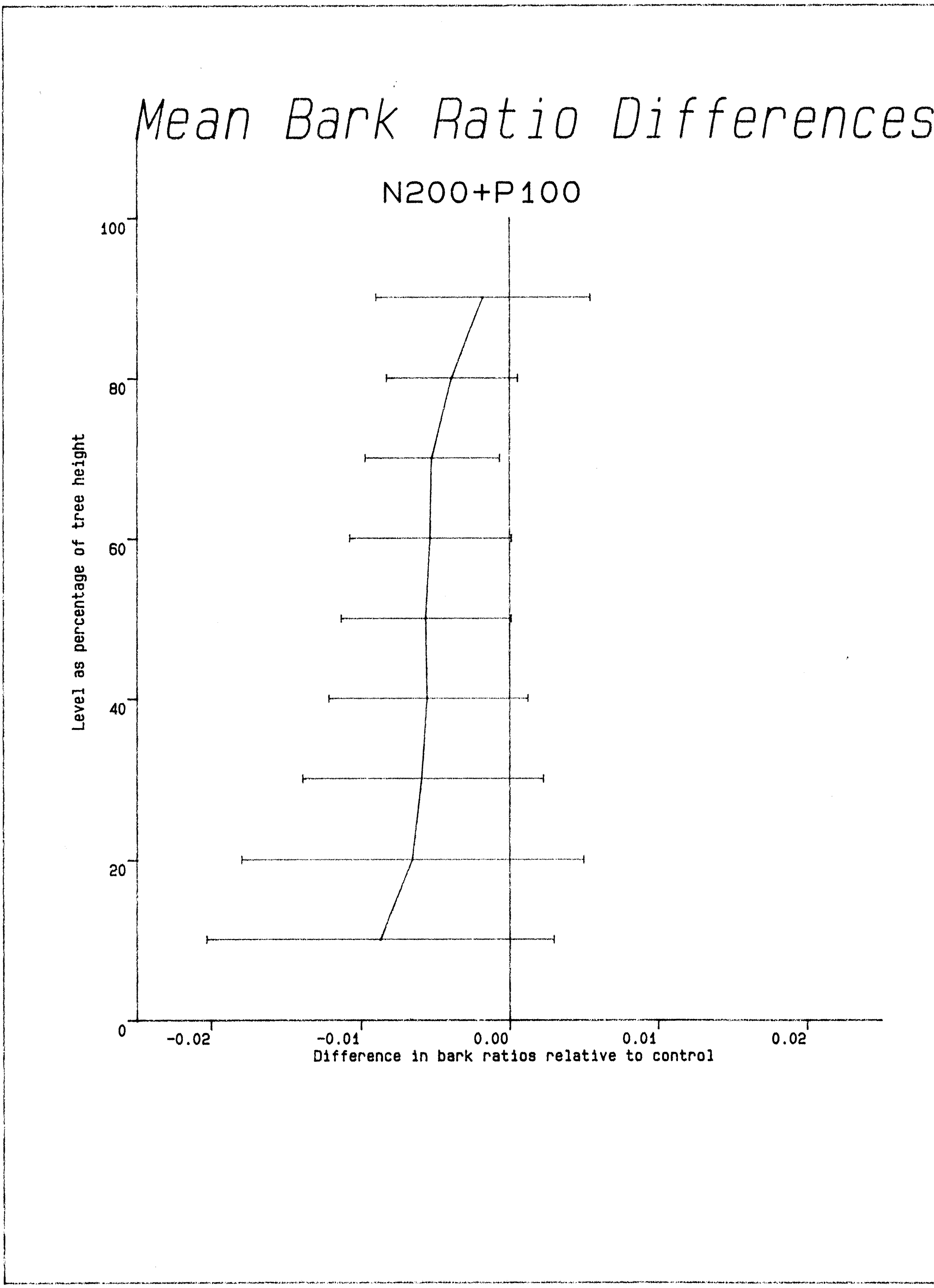


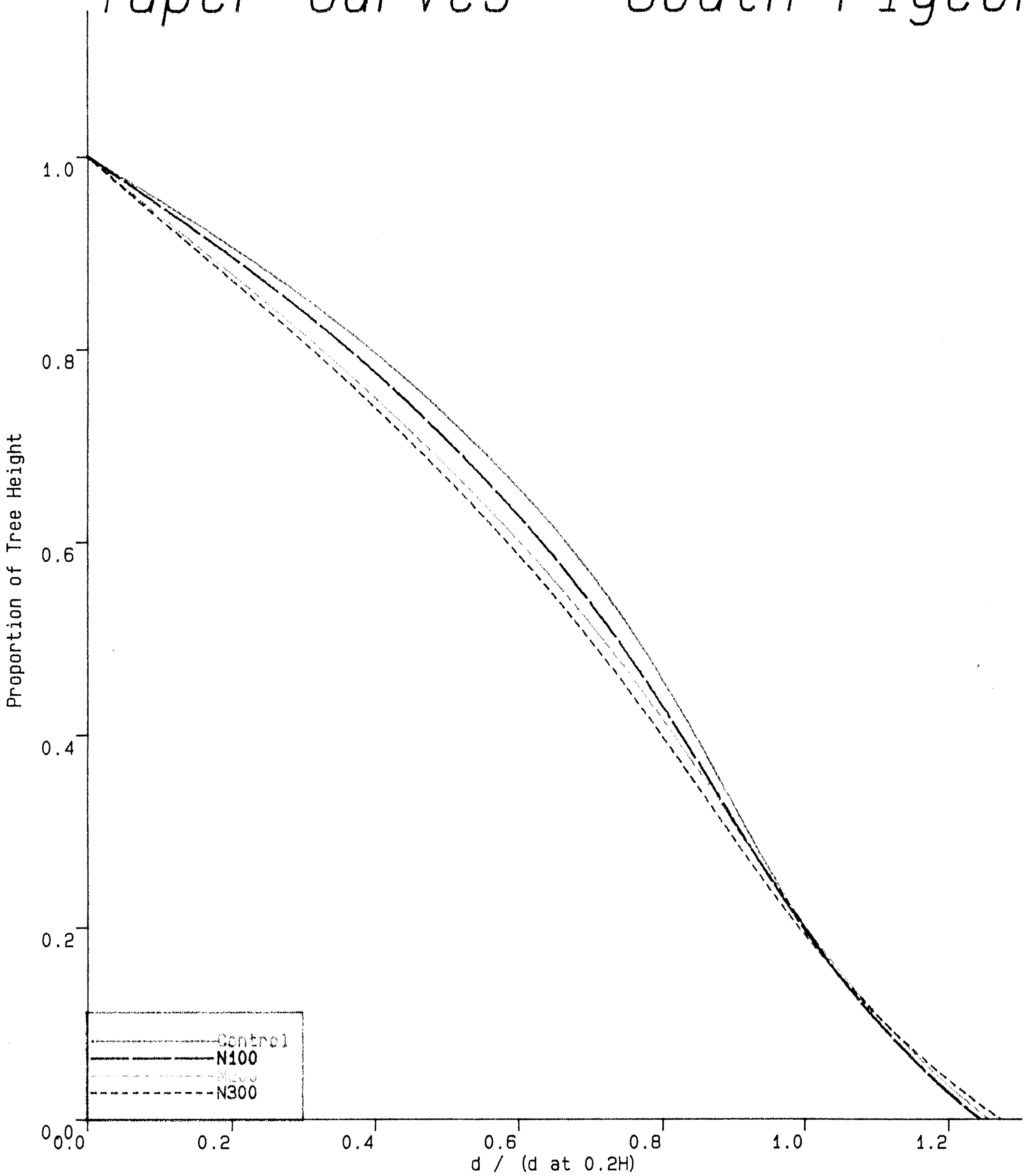
FIG. 1—Location of trials.

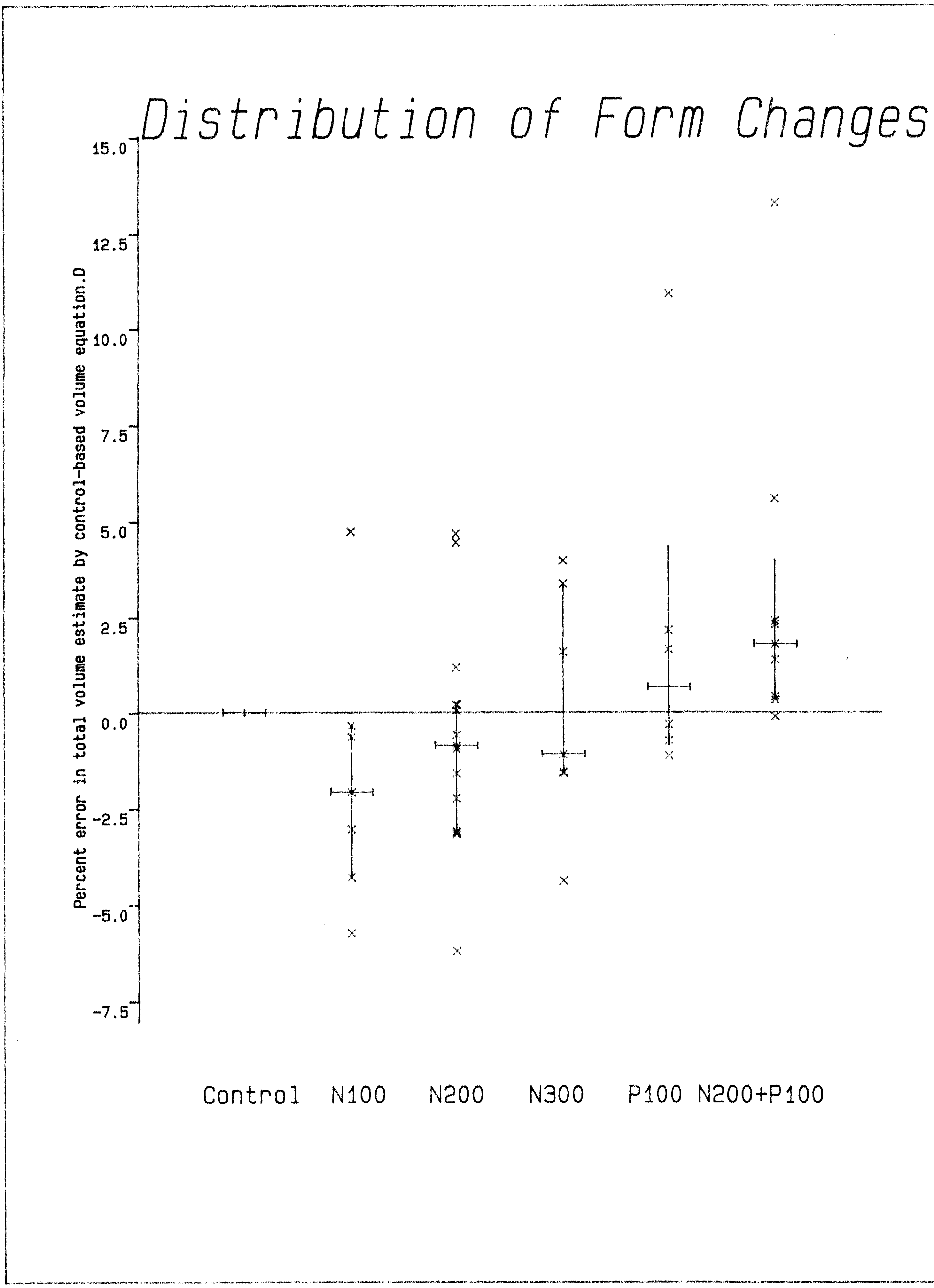
Tree Stem Shape



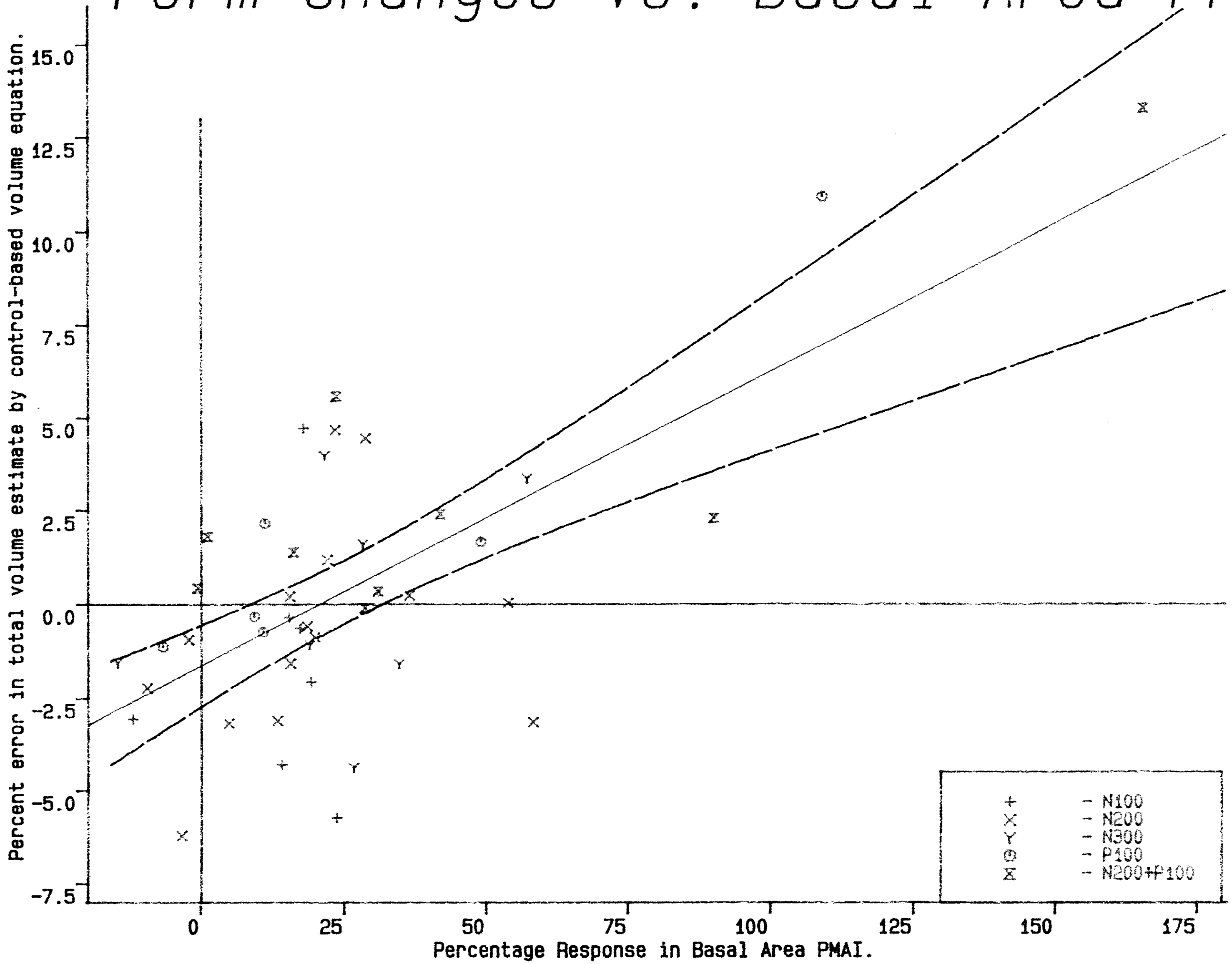

Mean Bark Ratio Differences
N200+P100
Level as percentage of tree height
100
80
60
40
20
0
-0.02
-0.01
0.00
0.01
0.02
Difference in bark ratios relative to control

Taper Curves - South Pigeon




Distribution of Form Changes
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
Percent error in total volume estimate by control-based volume equation.D
Control
N100
N200
N300
P100
N200+P100

Form Changes vs. Basal Area PMAI



Do trees change shape when fertilised?

Dr A.G.D. Whyte

Published articles referred to:

1. "Measuring responses to fertiliser in the growth of radiata pine" WHYTE 1973

2. "Quantifying responses to fertiliser in the growth of radiata pine" WHYTE & MEAD 1976

3. "Production Forest fertiliser trials: Information they should provide and how to get it" WHYTE, MEAD & BALLARD 1978

4. "Long term growth responses in radiata pine fertiliser experiments " WOOLLONS, WHYTE AND MEAD 1988

Whyte and Mead NZ Jour. For. Sc. 6(3) 431-42, 1976

TABLE 1—Estimates of unadjusted plot volumes in 1968 and 1973 and their increments for treatments N_0P_0 and N_3P_1 +

Treatment	Plot	Plot Volumes (m^3/ha) in 1968, by method: 1	2	3	4	1973, by method: 1	2	3	4	Plot Volume Increments (m^3/ha) 1968-73 by method 1	2	3	4
N_0P_0	7	957.3	850.5	842.1	855.6	1097.7	1005.1	964.5	962.6	140.4	154.6	122.4	107.0
	14	1104.7	924.7	915.4	956.4	1312.8	1131.9	1085.7	1133.0	208.1	207.2	170.3	176.6
	19	605.4	543.7	540.9	501.2	684.4	627.2	604.7	565.3	79.0	83.5	63.8	64.1
	21	758.2	631.0	625.7	654.4	893.1	758.9	729.3	758.0	134.9	127.9	103.6	103.6
	29	657.8	631.3	625.7	584.3	752.2	743.9	714.5	671.5	94.4	112.6	88.8	87.2
	45	756.8	654.1	651.0	639.7	851.2	744.5	726.6	718.9	94.4	90.4	75.6	79.2
	Mean	806.7	705.9	700.1	698.6	931.9	835.2	804.2	801.6	125.2	129.4	104.1	103.0
N_3P_1 +	6	745.5	701.6	685.4	736.0	920.7	890.7	856.6	923.4	175.2	189.1	171.2	187.4
	13	626.1	627.7	612.4	527.4	781.6	786.9	753.8	657.4	155.5	159.2	141.4	130.0
	15	803.2	718.4	701.8	714.6	950.1	871.3	837.1	848.8	146.9	152.9	135.3	134.2
	16	618.0	553.9	539.4	532.1	764.5	721.0	687.5	668.4	146.5	167.1	148.1	136.3
	18	852.7	778.4	760.9	766.1	1025.7	967.5	931.7	943.3	173.0	189.1	170.8	177.2
	44	877.5	744.7	727.6	780.6	1036.3	920.0	884.7	937.8	158.8	175.3	157.1	157.2
	Mean	753.8	687.4	671.2	676.1	913.1	859.6	825.2	829.8	159.3	172.1	154.0	153.7

Plot volumes estimated by following methods:

1. Stand volume equation based on 2 dimensional volume tables and estimates of basal area and predominant mean height.
2. Volume $/d^2$ regressions made on independent samples sectionally measured in 1968 and 1973.
3. Volume $/d^2$ regressions on the same 20 trees per treatment as 2 above but derived from stem analysis.
4. Volume $/d^2$ regressions on an individual plot basis using 5 stem-analysed trees per plot.

RESPONSE TO NP FERTILISER IN 40 YEAR OLD RADIATA PINE

Method	change in volume		response (by difference)
	unfert	NP fert	m**3/ha
1	121	164.2	43.2 +- 42.0
2	127.5	174.0	46.5 +- 50.2
3	100.6	155.5	54.9 +- 47.3
4	98.1	158.6	59.5 +- 23.3
5	94.6	155.4	60.8 +- 27.6
6	102.1	145.8	43.7 +- 28.7

Methods explained

1. general volume equations
2. independent v/d**2 from sectional measurements
3. stem analysis v/d**2 by treatments
4. stem analysis v/d**2 by plots
5. stem analysis v2/v1 by plots
6. stem analysis change in v/d**2 by plots

For methods 1,2,3 the covariate was v1968

For methods 4,5,6 the covariate was (v1968 - v1963)

NORWAY SPRUCE STUDY IN SWEDEN Mead and Tamm 1988

Trial is a LARGE N*P factorial with 15 year responses to different fertility levels

* Response to N   LARGE
* Response to P   LOWER
* Difference between fertilisers less marked

* N increased average taper
* with P there was no change
* N therefore decreased form (by 10%)
* P brought about small changes in form (2%)

How important are these changes?

Comparison of general basal area/volume regressions to individual ones showed:

Differences could be as much as +- 9%.

25% of treatments have differences greater than +- 5%

SHAPE CHANGE IN NORWAY SPRUCE.

D MEAD

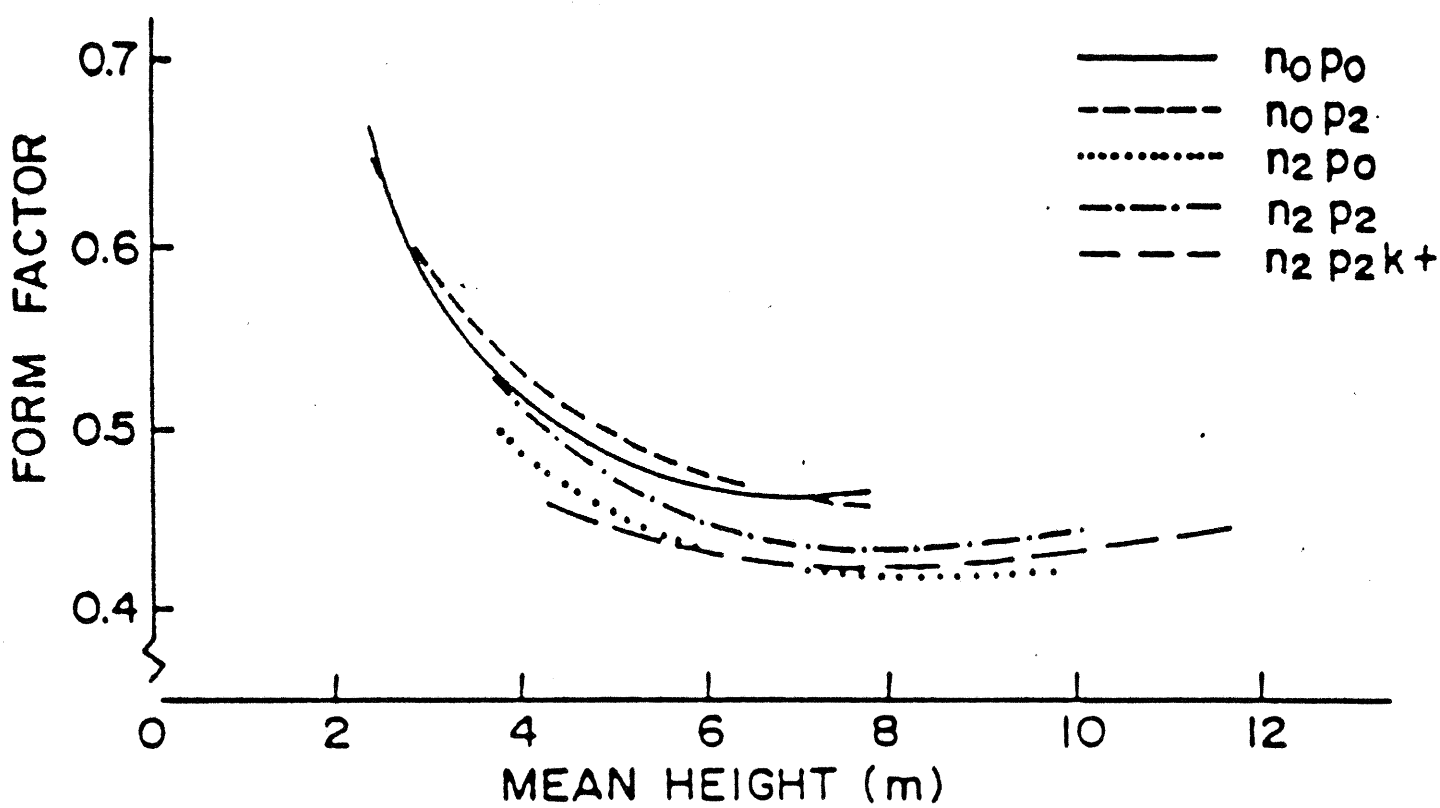


Fig. 2. The effect of fertilizer treatment and tree size on form factor based on the sectional area (underbark) at 0.65 m.

SHAPE CHANGE IN NORWAY SPRUCE

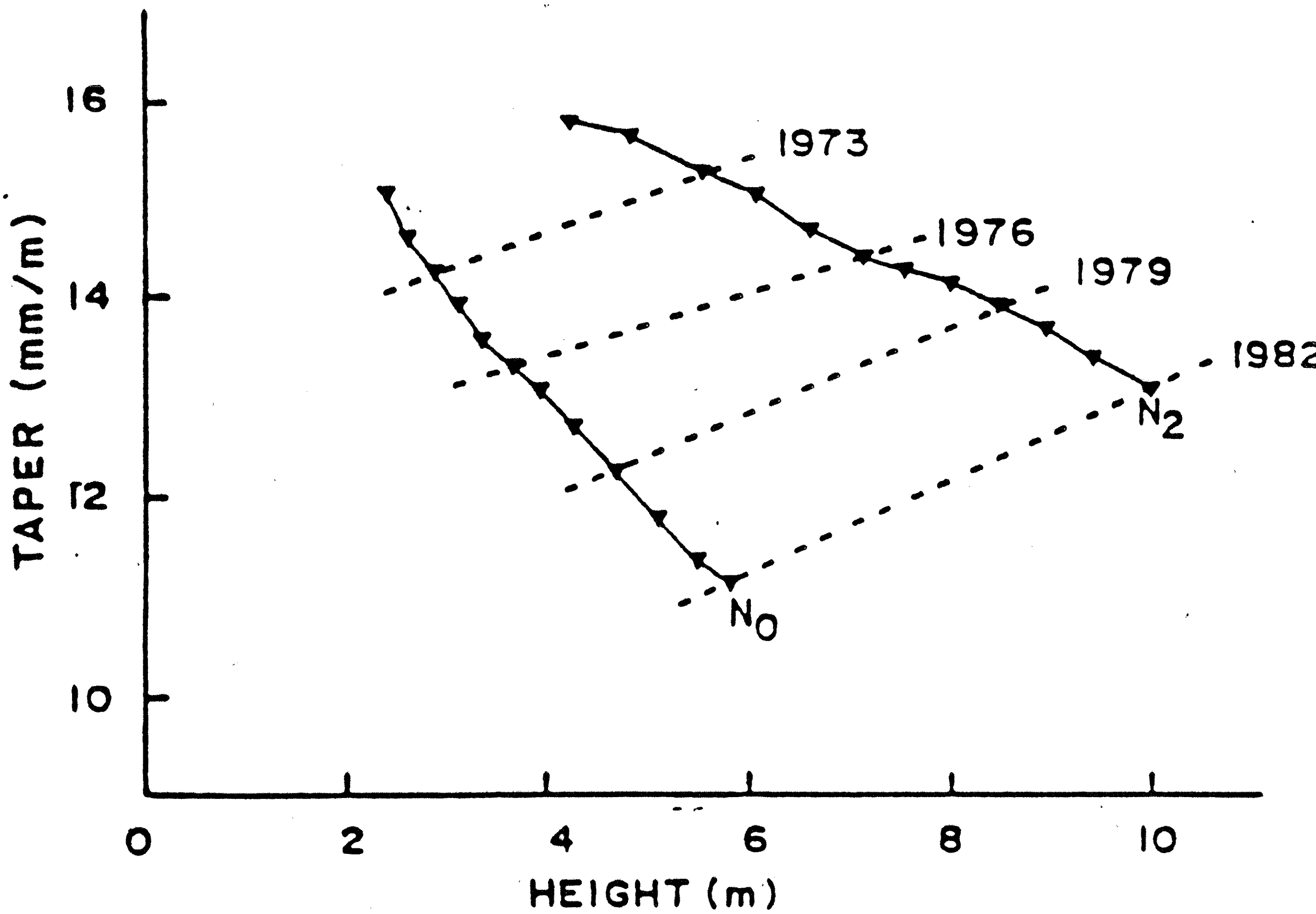


Fig. 1. The effects of nitrogen supply, tree size and age on average tree taper (underbark) above 0.65 m.