Heather McKenzie

FRI/INDUSTRY RESEARCH COOPERATIVES

MANAGEMENT OF EUCALYPTS COOPERATIVE

FOREST RESEARCH INSTITUTE
PRIVATE BAG
ROTORUA

THE NZFP FORESTS LTD *EUCALYPTUS REGNANS* GROWTH MODEL

W. HAYWARD
NZFP FORESTS LTD

REPORT NO. 4 NOVEMBER 1988

Confidential to Participants of the Management of Eucalypts Cooperative

MANAGEMENT OF EUCALYPTS COOPERATIVE

IN KIND CONTRIBUTION

THE NZFP FORESTS LTD

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This material is unpublished and must not be cited as a literature reference.

FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

IN KIND CONTRIBUTION — THE NZFP FORESTS LIMITED

***E. REGNANS* GROWTH MODEL**

Growth data from Permanent Sample Plots established within the Kinleith Forest has been used to develop a growth model for *E. regnans*. The age, stocking and volume per hectare limits for the contributory plots are displayed graphically within this report, indicating the range of model applicability.

Functions describing Basal Area per hectare, Mean Top Height and Volume per hectare development are presented along with an explanation of the function derivation.

Precision, as evaluated by a percentage bias table, is acceptable, indicating that the overall model is more than an adequate estimator of the growth of *E. regnans* growing on the Volcanic Plateau.

Cost & Increase of E regnans plots

Since 1986

Ave cost = $270 / plot.

70 plots existing before 1986.
(includes 67 in E regnans Regime & Nelder trial)

∴ 75 new plots established.

145 plots = 820 measurements.
= $221,400 over 7 years.

ERRATUM

Management of Eucalypts Cooperative
Report No. 4

The NZFP Forests Ltd. *Eucalyptus regnans* Growth Model

It has been found that the function reported on page 3 for stand volume is in error, and should be replaced by

$$V = 0.355786\ G.H - 1.469$$

Steve,

Paul Lane wrote a program for our group to use the above growth model.
NZFP Forests have found an error.
Could you please edit the programme and provide us with a new version to run? Oscar says it's o.k for you to do it
Thanks

Jonathan McKenzie
Special purpose species

Job number 36E/020

EARLY RESULTS FROM THE NELDER SPACING TRIALS

These results are from spacing trials in the Rotorua Conservancy. The species and locations are E. regnans (Murupara), E. nitens (Murupara), E. saligna (Kawerau).

Overhead No. 1 gives data for E. regnans established in 1978. The first column indicates the arc number for the Nelder trial and the second column the initial stocking equivalent in stems/ha which corresponds to the arc number. The next three columns give the mean dbh in cms, for 1980, 1983 and 1984 for each arc/stocking. These trends are illustrated in the succeeding overheads.

No. 2 illustrates the figures given in overhead No. 1. There was no detectable difference in mean dbh at age 2 across the range of stockings but by ages 5 and 6 there was a strong uniform effect of competition at stockings greater than 1500 stems/ha. For stockings less than this there was a progressive increase in mean diameter as stockings reduced.

No. 3 illustrates the same trends converted to basal area. Basal area increases as stocking increases but in a curvilinear fashion due to the larger trees at low stockings.

No. 4 shows the height/diameter relationships for the various stockings. As stocking level reduces trees become shorter for a given diameter.

No. 5 shows the frequency distribution of stem dbh; as it varies with initial stocking rate. The previously illustrated trend of increasing mean dbh with decreasing stocking is confirmed. There is a change in distribution about the mean. As stocking decreases the distribution becomes more dispersed.

The height and diameter data shown in the previous overheads were used with the standard NZFS volume table to calculate tree and then total volumes per hectare. These are shown in overhead No. 6 for E. regnans at age 7.

Similar values were calculated for E. nitens (No. 7) and E. saligna (No. 8). For both these two species stockings higher than 4444/ha were included because of the possibility of firewood/biomass yields.

For No.'s 6, 7 and 8 the volume is shown on the left hand histogram and mean annual increment on the right hand histogram. The most relevant stocking for high stand density pulpwood regimes is approximately 4400 stems/ha and for this stand density the MAI values for the 3 species are approximately:

E. regnans 25 m^3/ha/an

E. nitens 40 m^3/ha/an

E. saligna 30 m^3/ha/an

Note that in all cases the eucalypt establishment was very good and the site index of adjacent radiata pine was very high; 32 m at Murupara and 35 m at Kawerau.

JAL NO.
BJECT

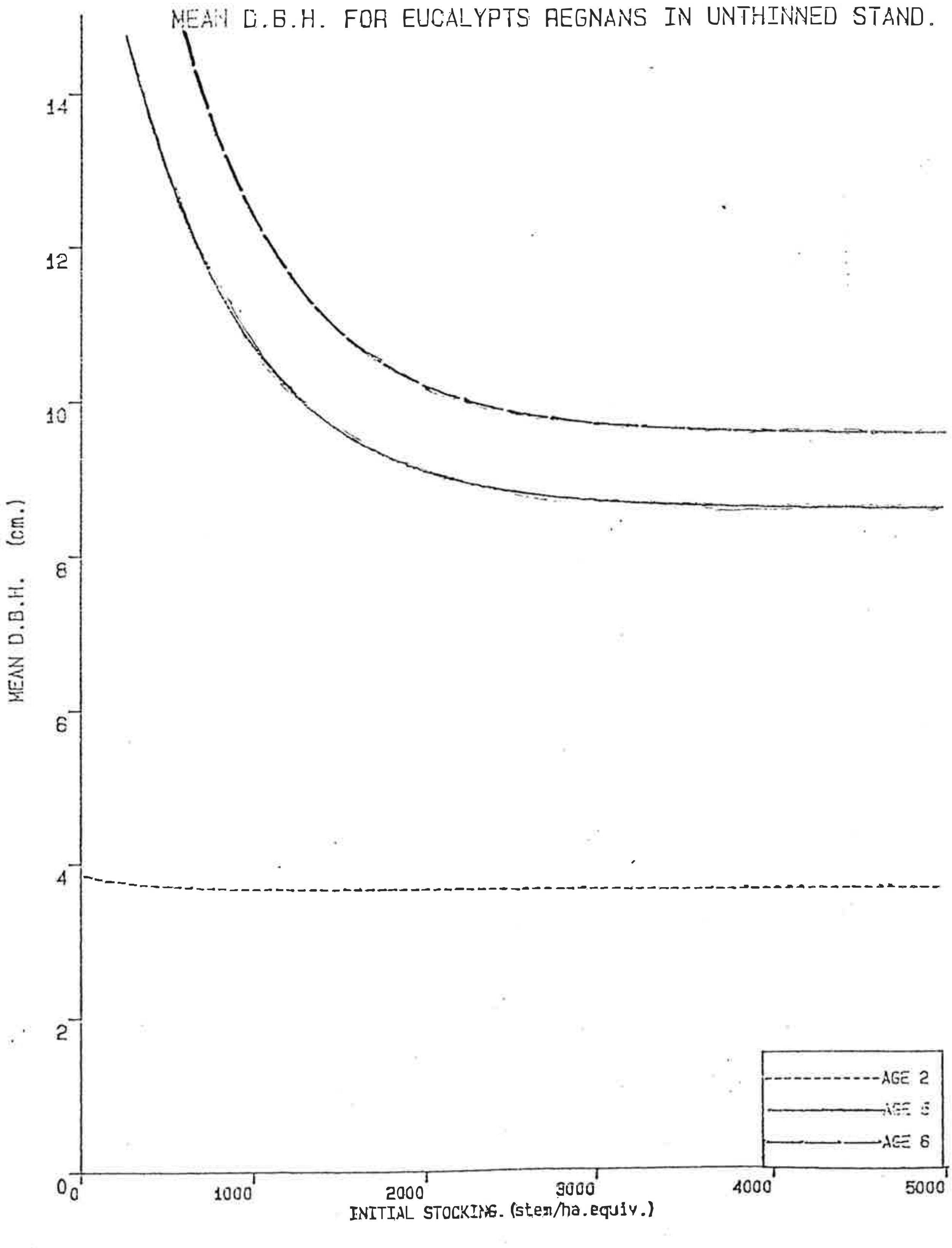
NEW ZEALAND LTD

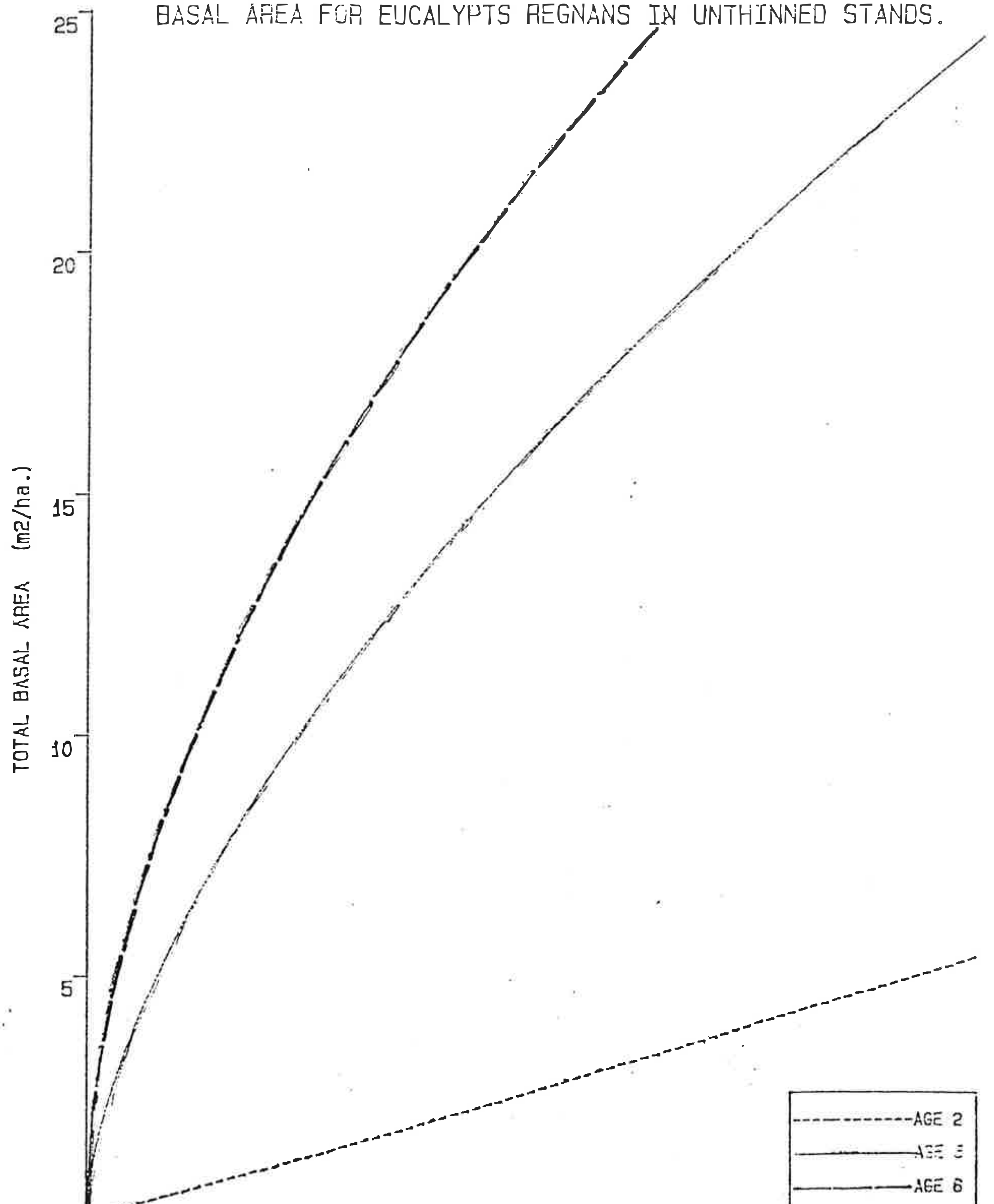
No 1.

ARC N	I.STOCKING (STEM/HA)	MEAN D.B.H.		
		1980	1983	[illegible]
1	4444	3.60	8.00	[illegible]
2	3380	3.99	8.99	9.90
3	2551	3.43	9.12	10.20
4	1924	3.22	8.89	10.15
5	1457	3.46	10.00	11.50
6	1111	3.47	10.58	12.40
7	835	3.65	11.24	13.05
8	634	3.69	11.82	14.05
9	480	3.47	11.91	14.60
10	364	3.68	14.04	16.90
11	275	4.15	15.33	18.15
12	209	3.92	16.21	[illegible]
13	158	3.83	15.77	[illegible]
14	120	4.33	16.80	[illegible]
15	91	3.69	15.11	19.55

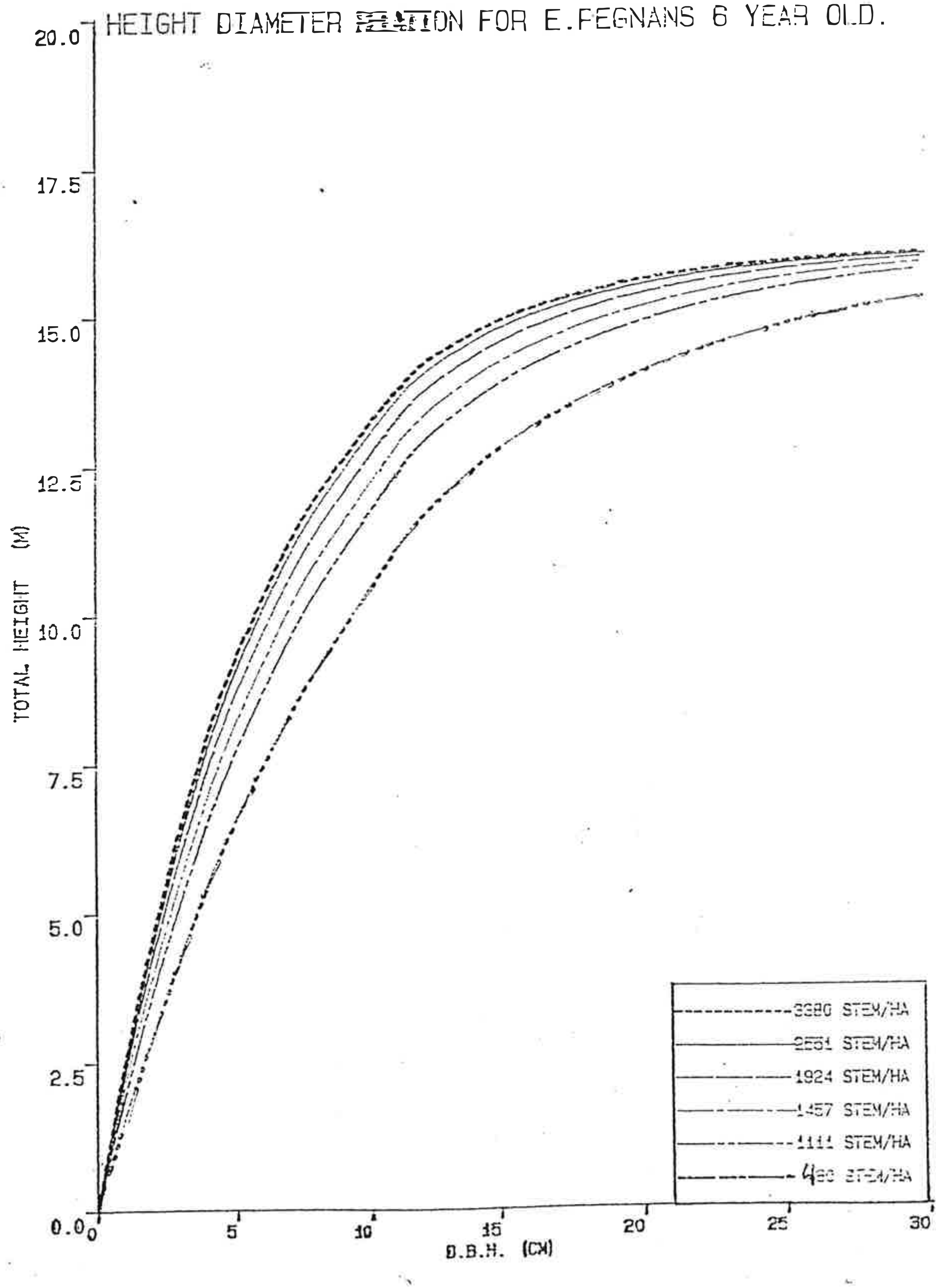
NOTES

No 2.

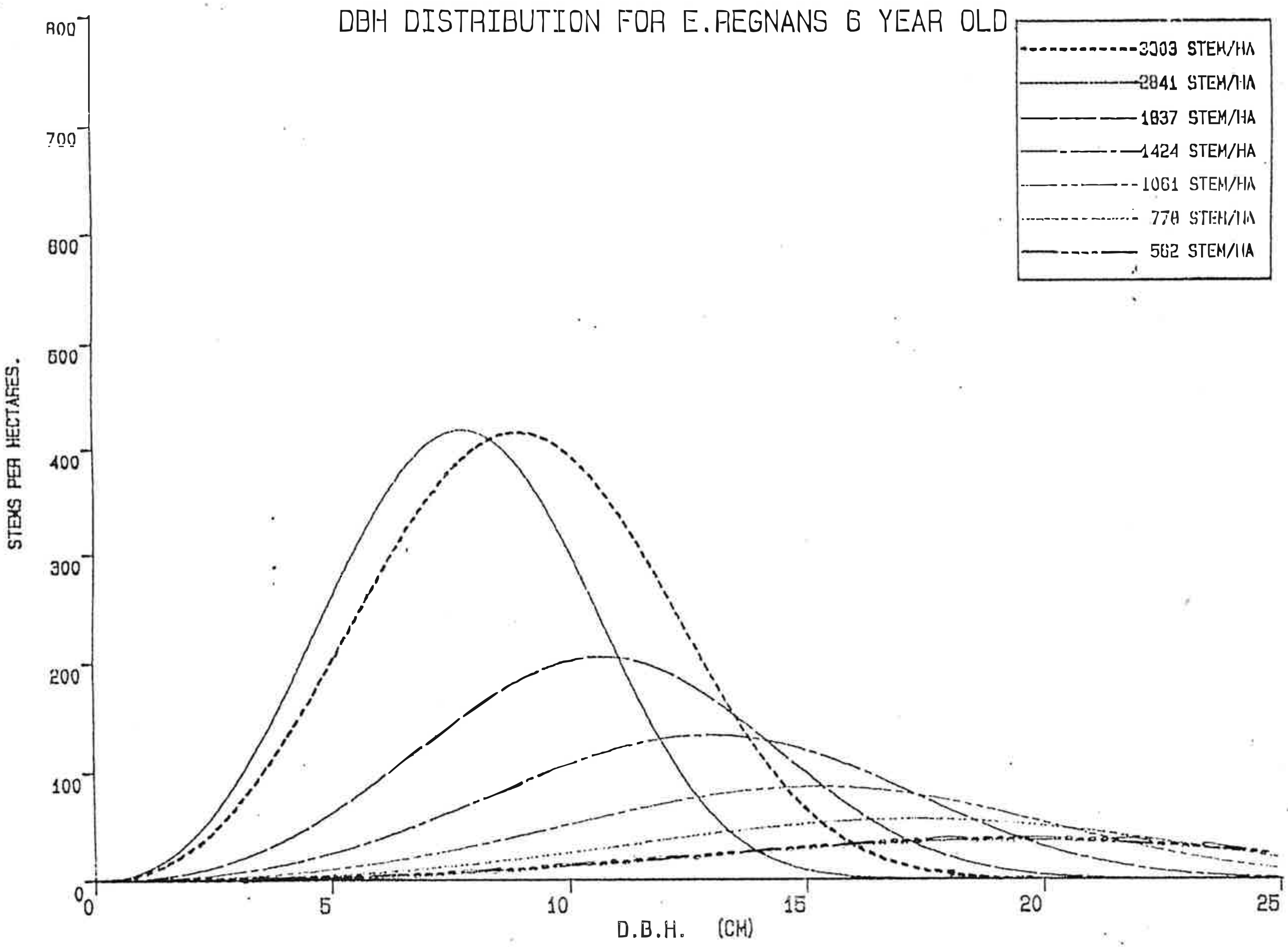

MEAN D.B.H. FOR EUCALYPTS REGNANS IN UNTHINNED STAND.
MEAN D.B.H. (cm.)
INITIAL STOCKING. (stem/ha.equiv.)
AGE 2
AGE 6
0
2
4
6
8
10
12
14
1000
2000
3000
4000
5000


BASAL AREA FOR EUCALYPTS REGNANS IN UNTHINNED STANDS.
TOTAL BASAL AREA (m2/ha.)
ACTUAL STOCKING (stems/ha.equiv.)
0
5
10
15
20
25
1000
2000
3000
4000
5000
AGE 2
AGE 6

No. 4

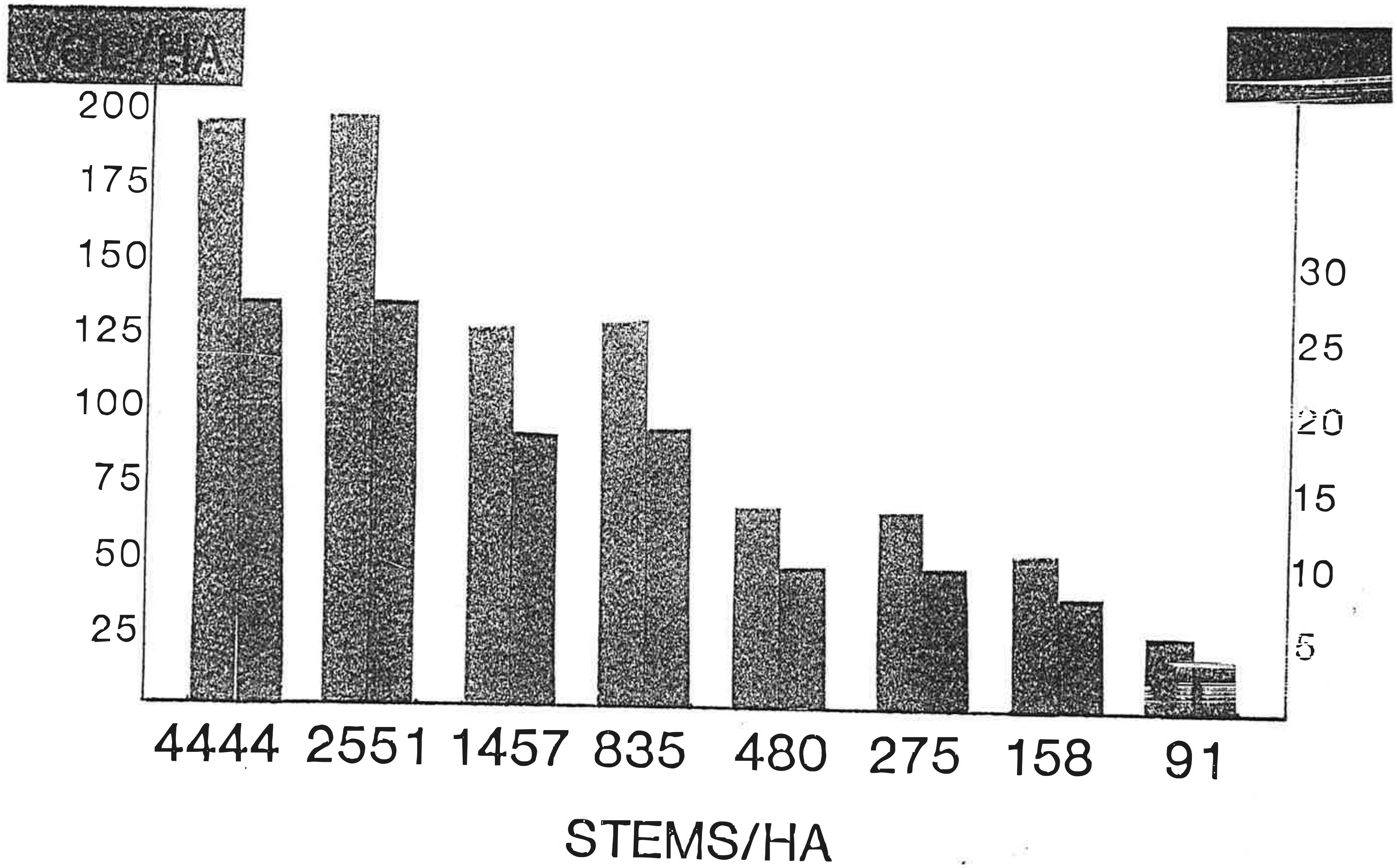

HEIGHT DIAMETER RELATION FOR E.REGNANS 6 YEAR OLD.
TOTAL HEIGHT (M)
D.B.H. (CM)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
0
5
10
15
20
25
30
3380 STEM/HA
2551 STEM/HA
1924 STEM/HA
1457 STEM/HA
1111 STEM/HA
480 STEM/HA

No 5

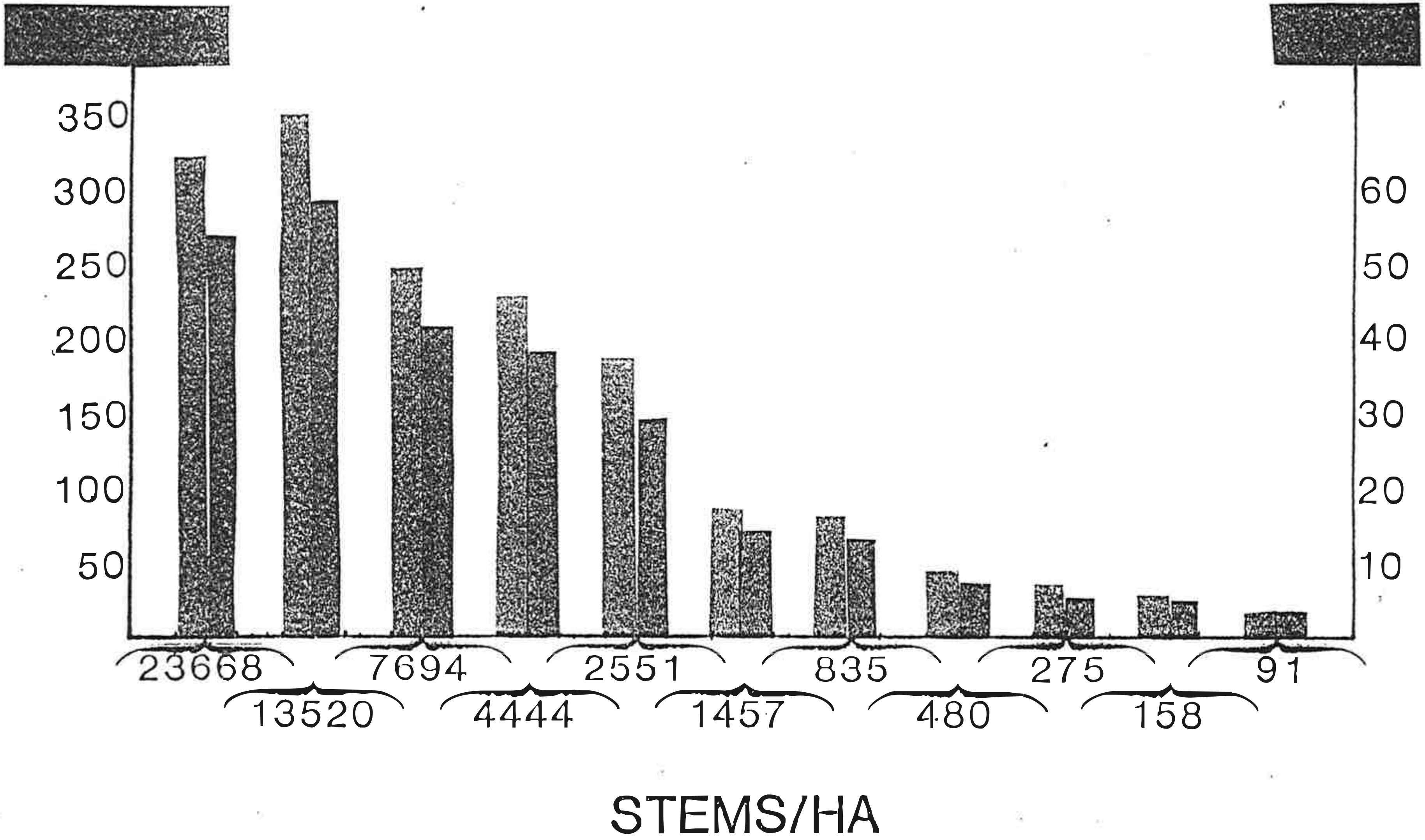

DBH DISTRIBUTION FOR E.REGNANS 6 YEAR OLD
3303 STEM/HA
2841 STEM/HA
1837 STEM/HA
1424 STEM/HA
1061 STEM/HA
778 STEM/HA
562 STEM/HA
STEMS PER HECTARES.
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
D.B.H. (CM)

N°6

E. REGNANS -AGE 7

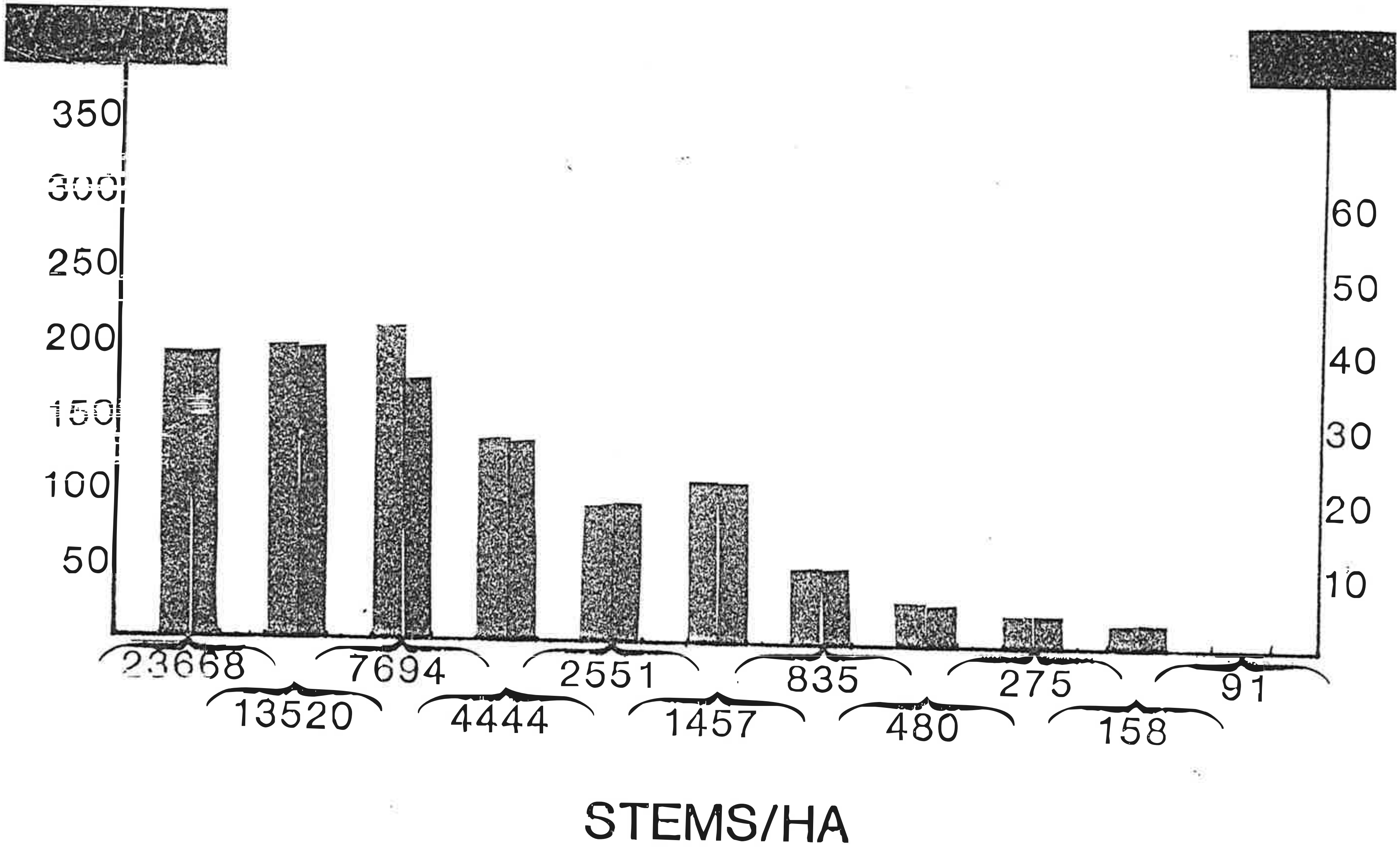


E. NITENS - AGE 6

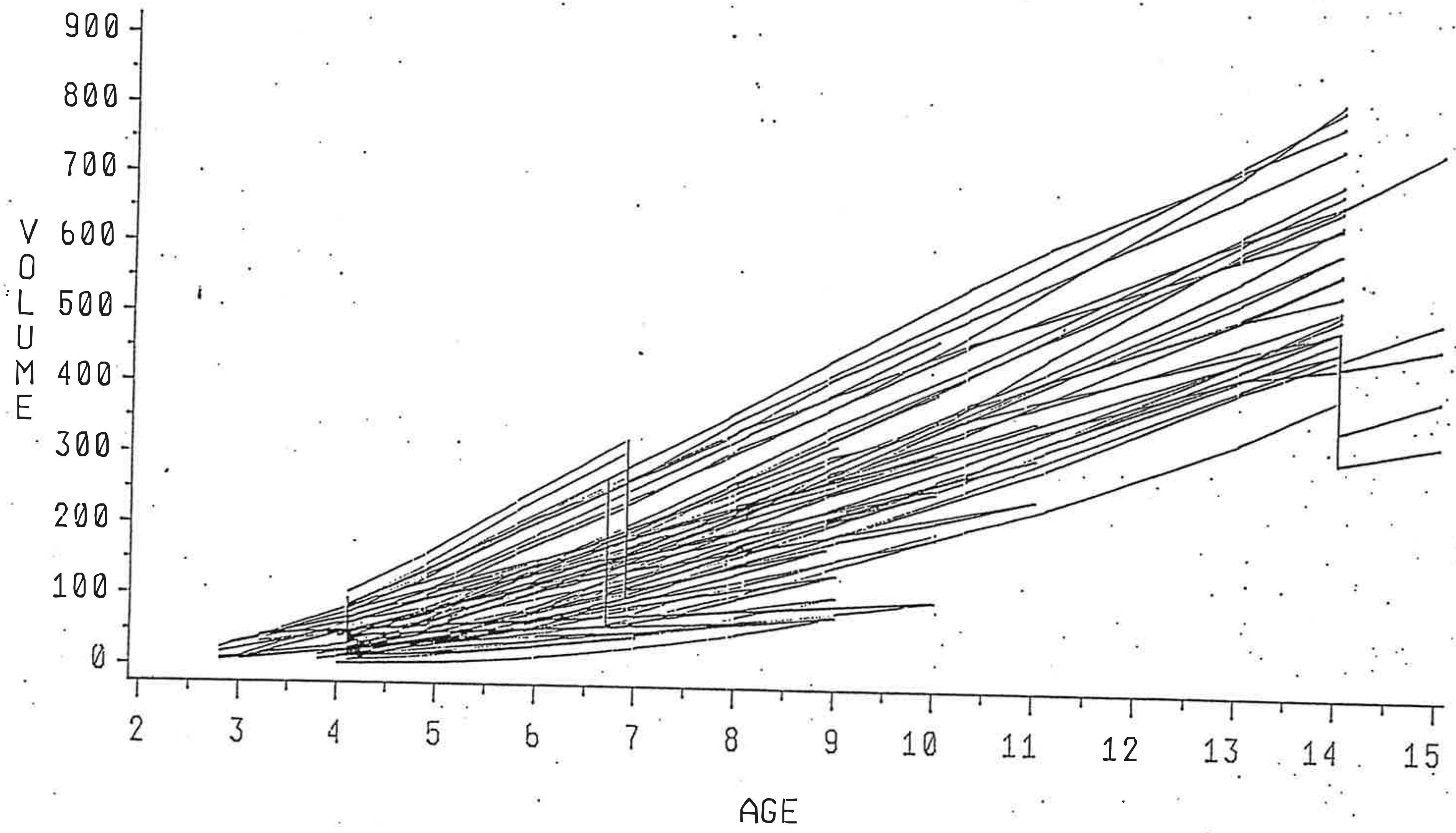


N° 8

E. SALIGNA - AGE 5



E.REGNANS DATABASE



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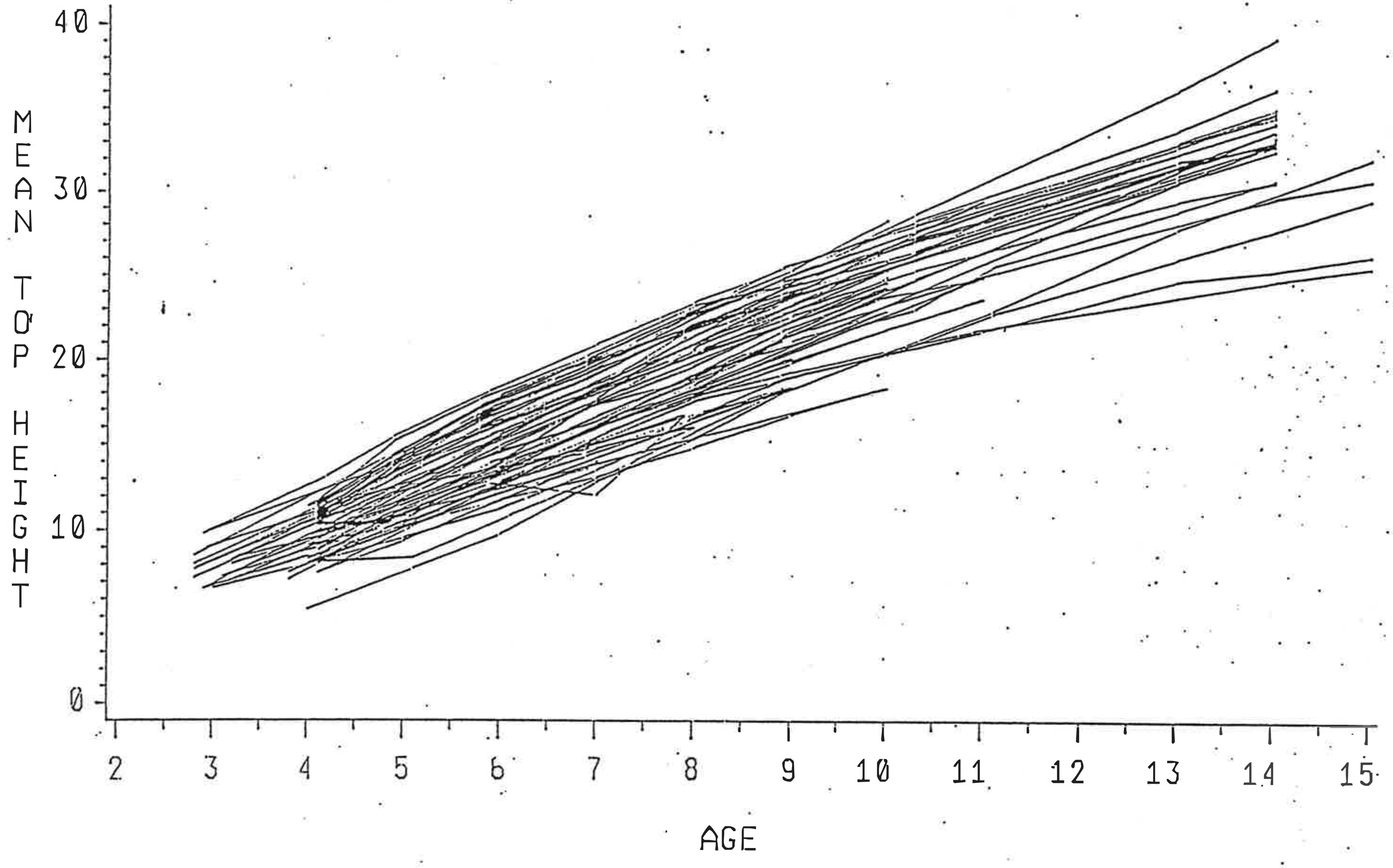
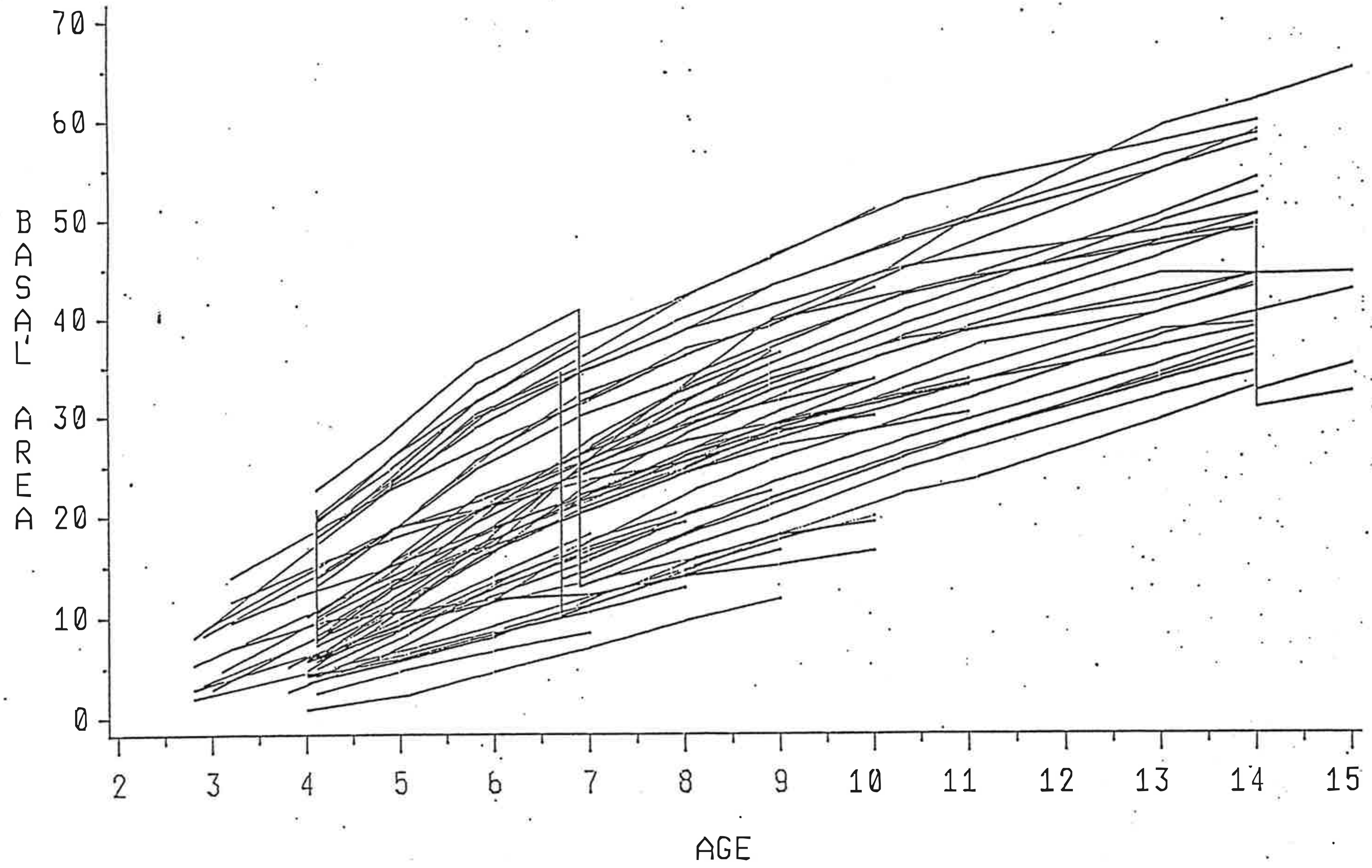
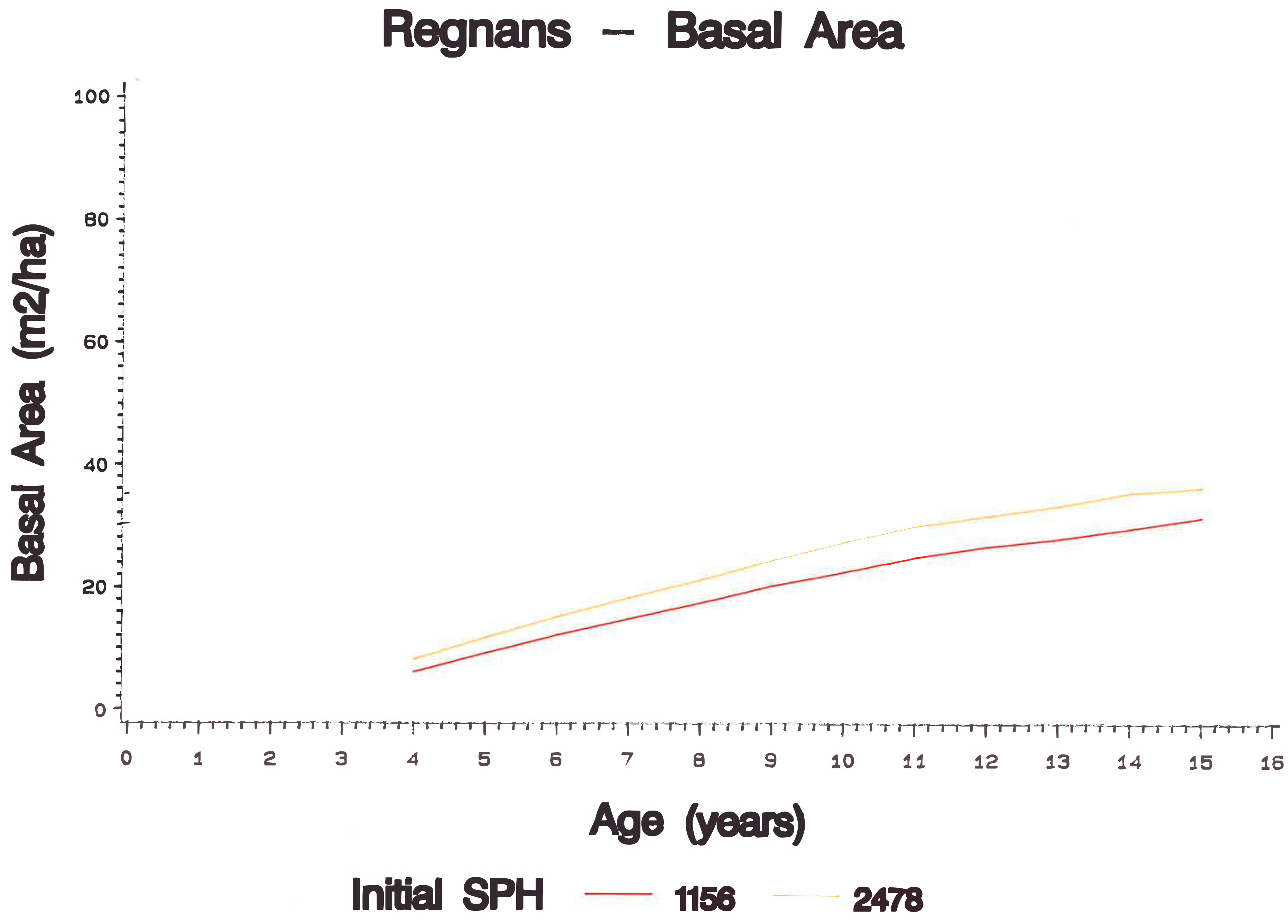
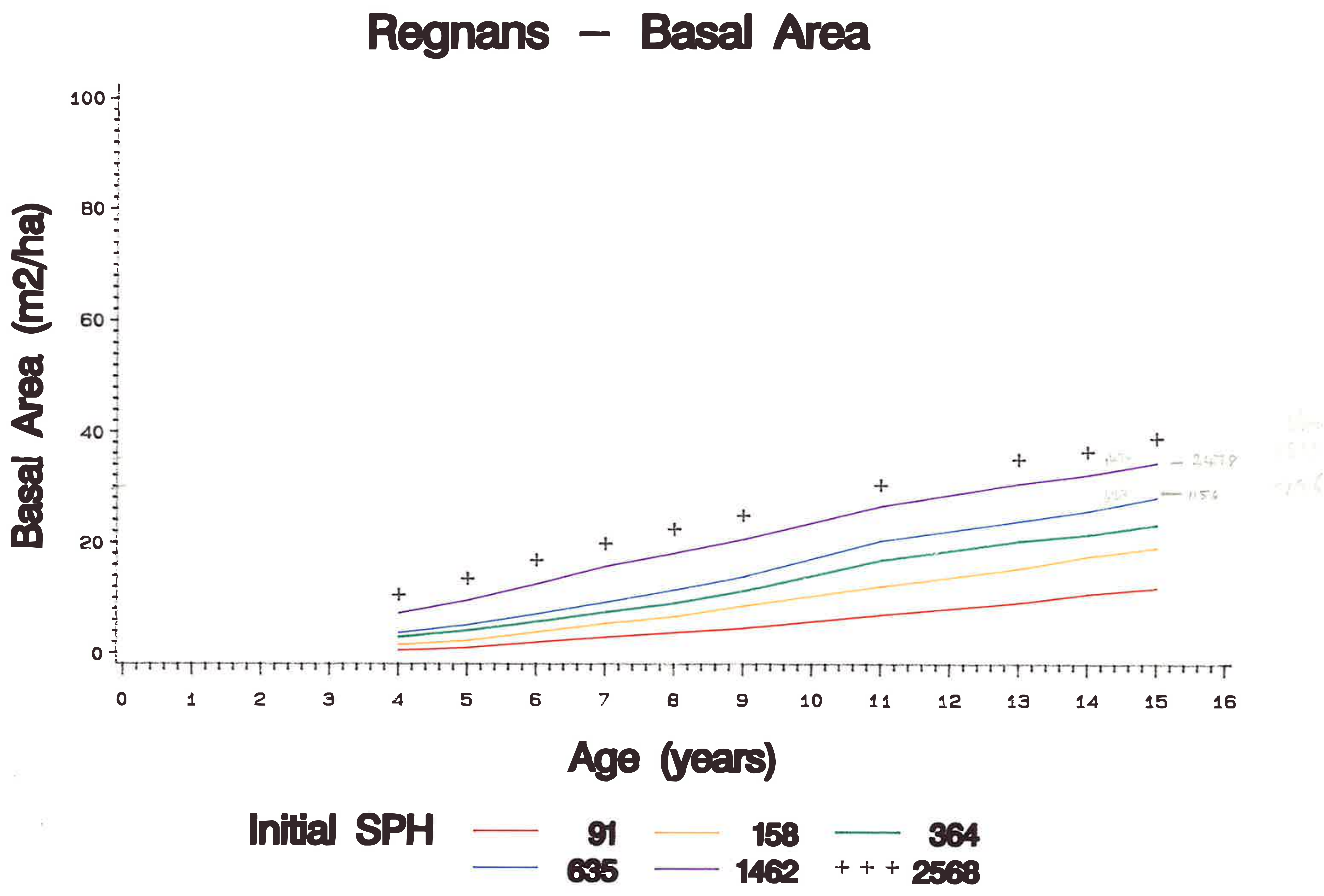


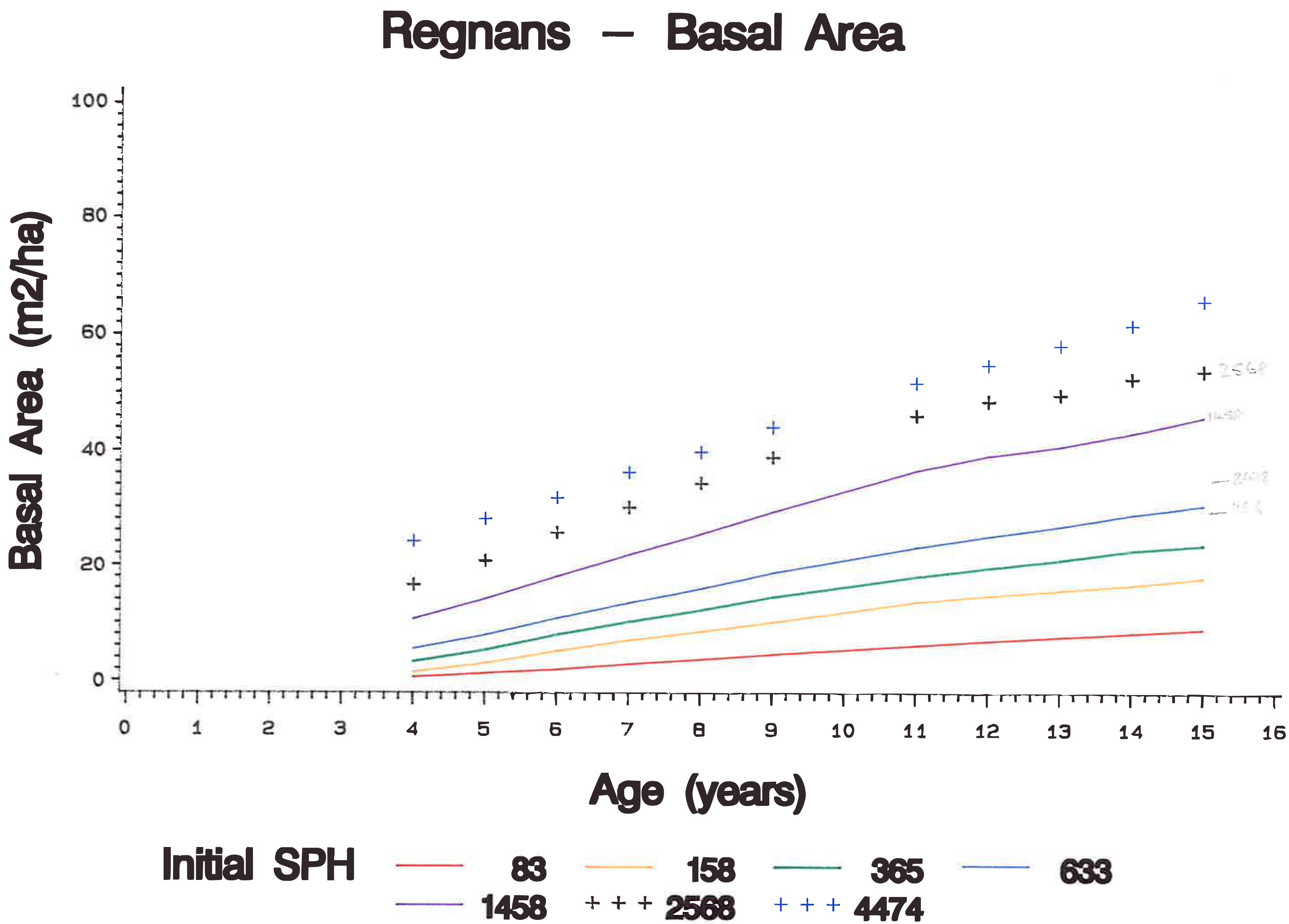
E.REGNANS DATABASE

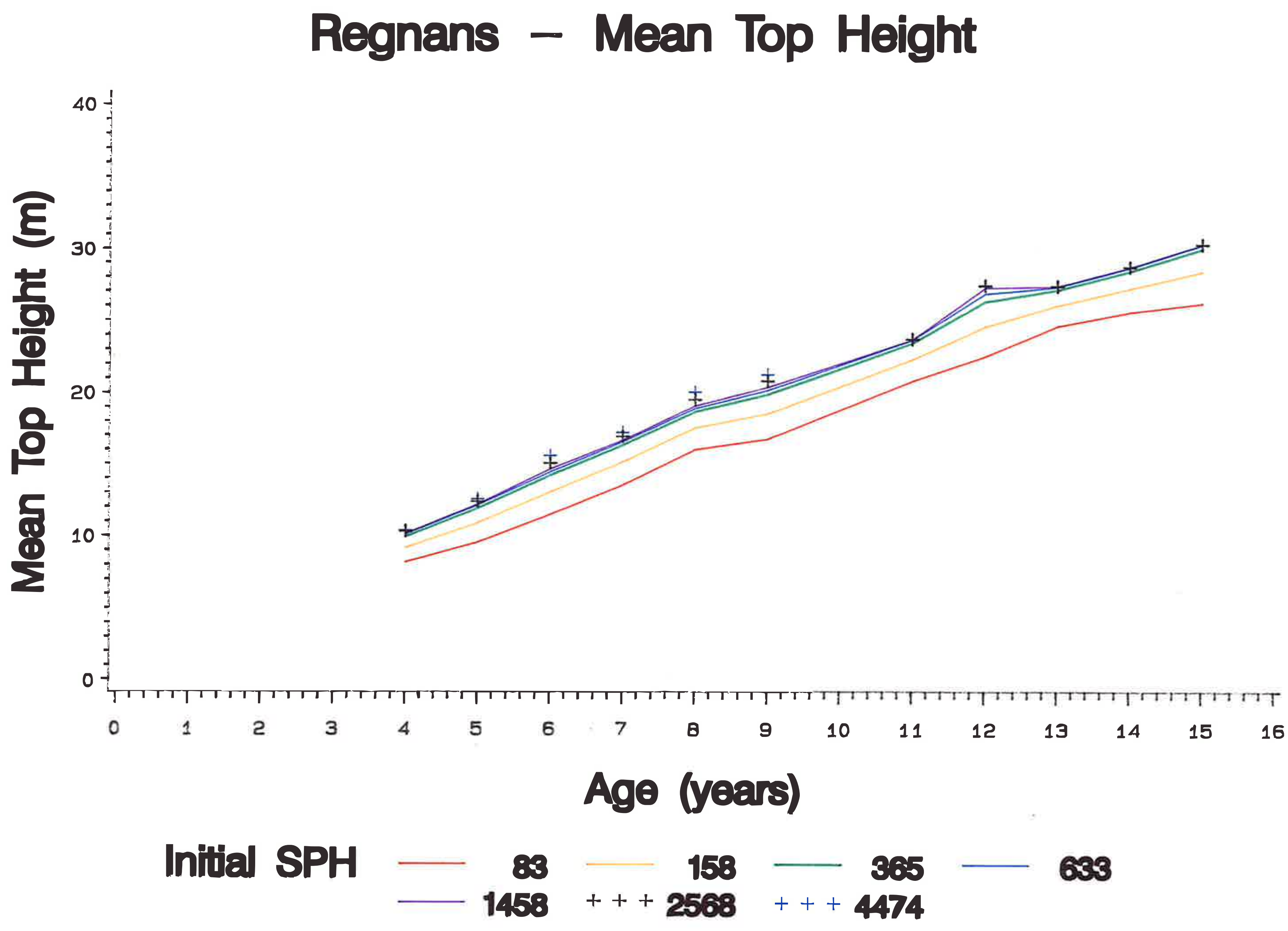



Regnans – Basal Area
Basal Area (m2/ha)
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Age (years)
Initial SPH
1156
2478

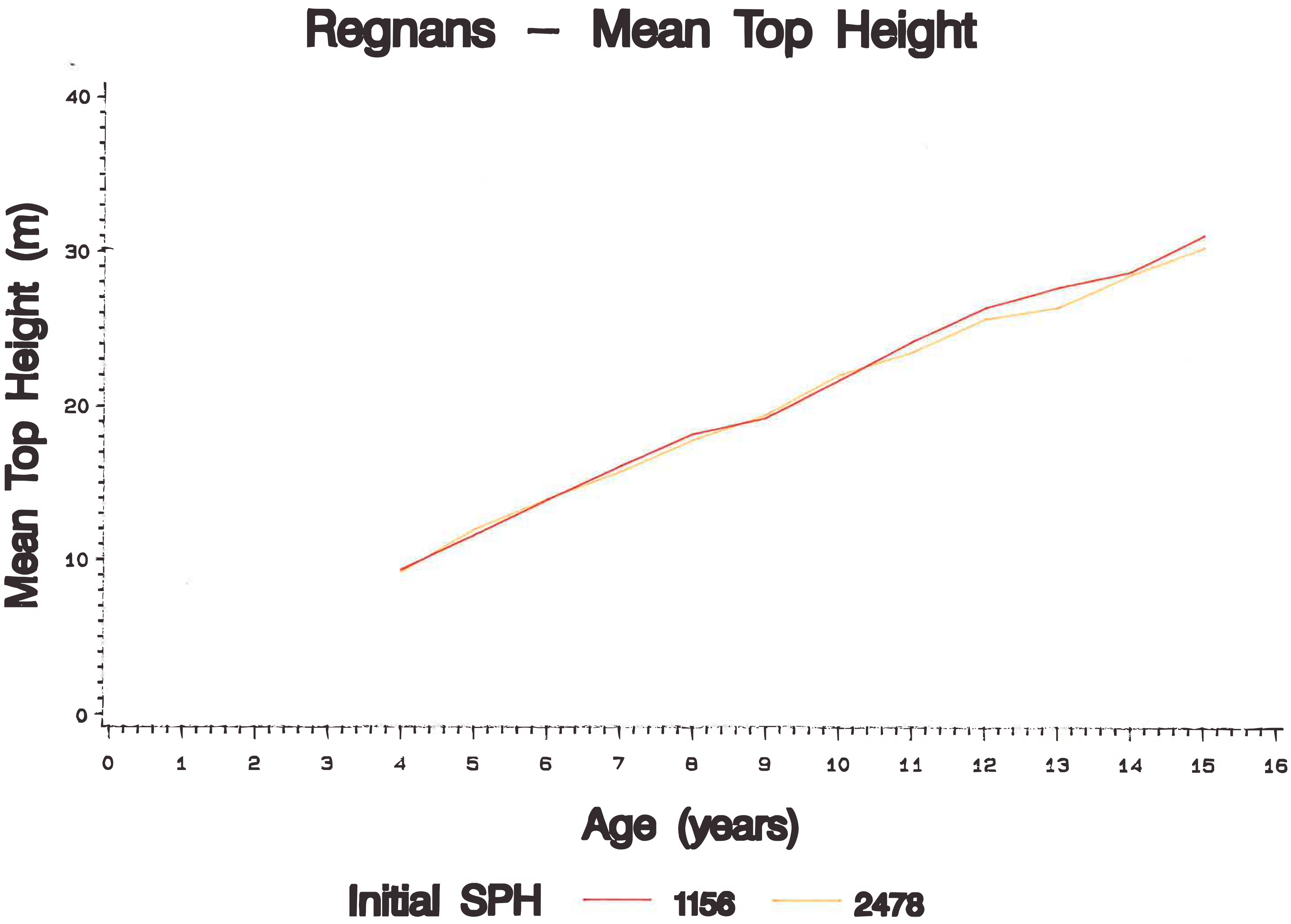


Regnans – Basal Area
Basal Area (m2/ha)
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age (years)
Initial SPH
91
158
364
635
1462
+ + + 2568

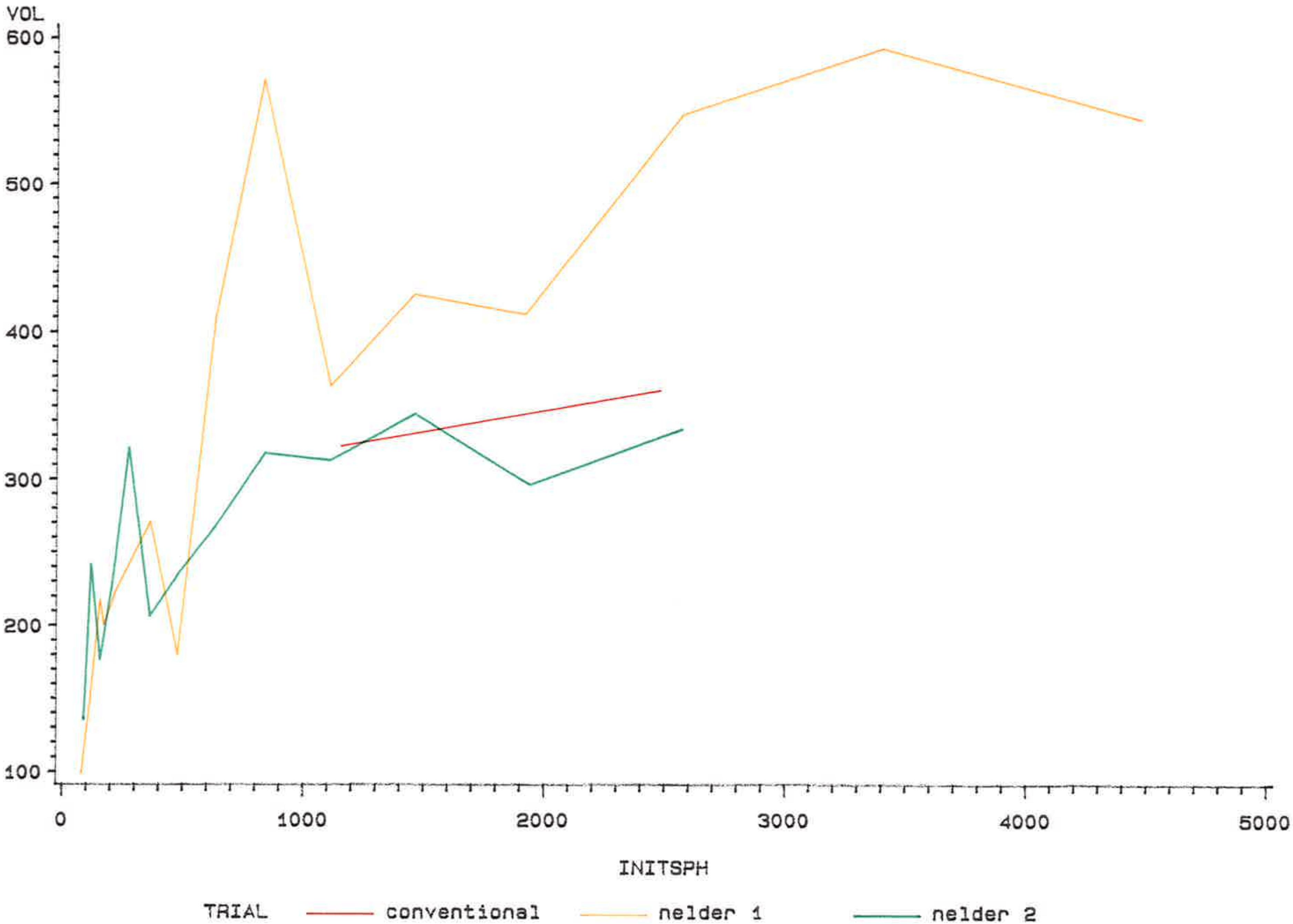

Regnans – Basal Area
Basal Area (m2/ha)
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age (years)
Initial SPH
83
158
365
633
1458
2568
4474



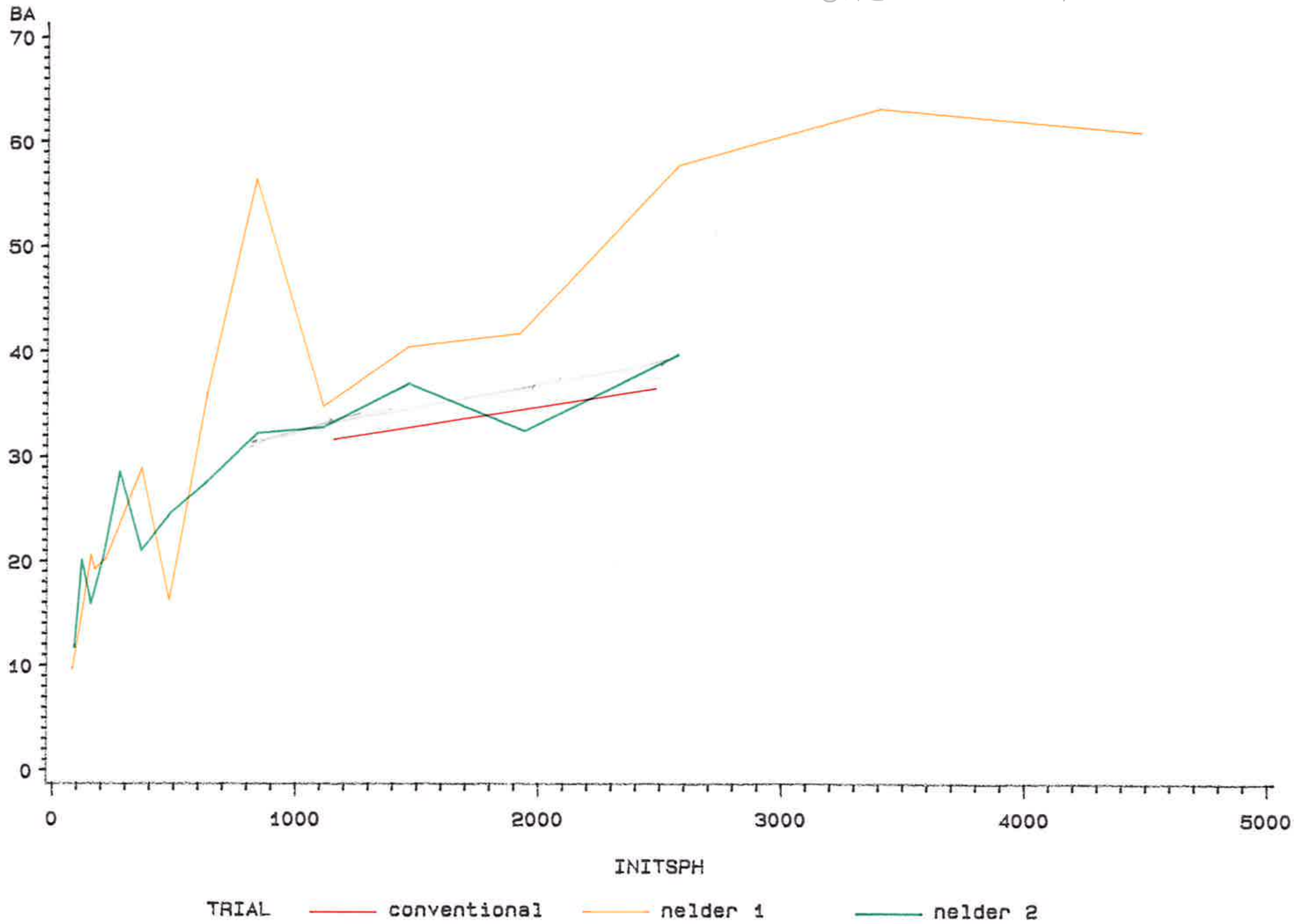
Regnans — Mean Top Height
Mean Top Height (m)
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age (years)
Initial SPH
83
158
365
633
1458
2568
4474

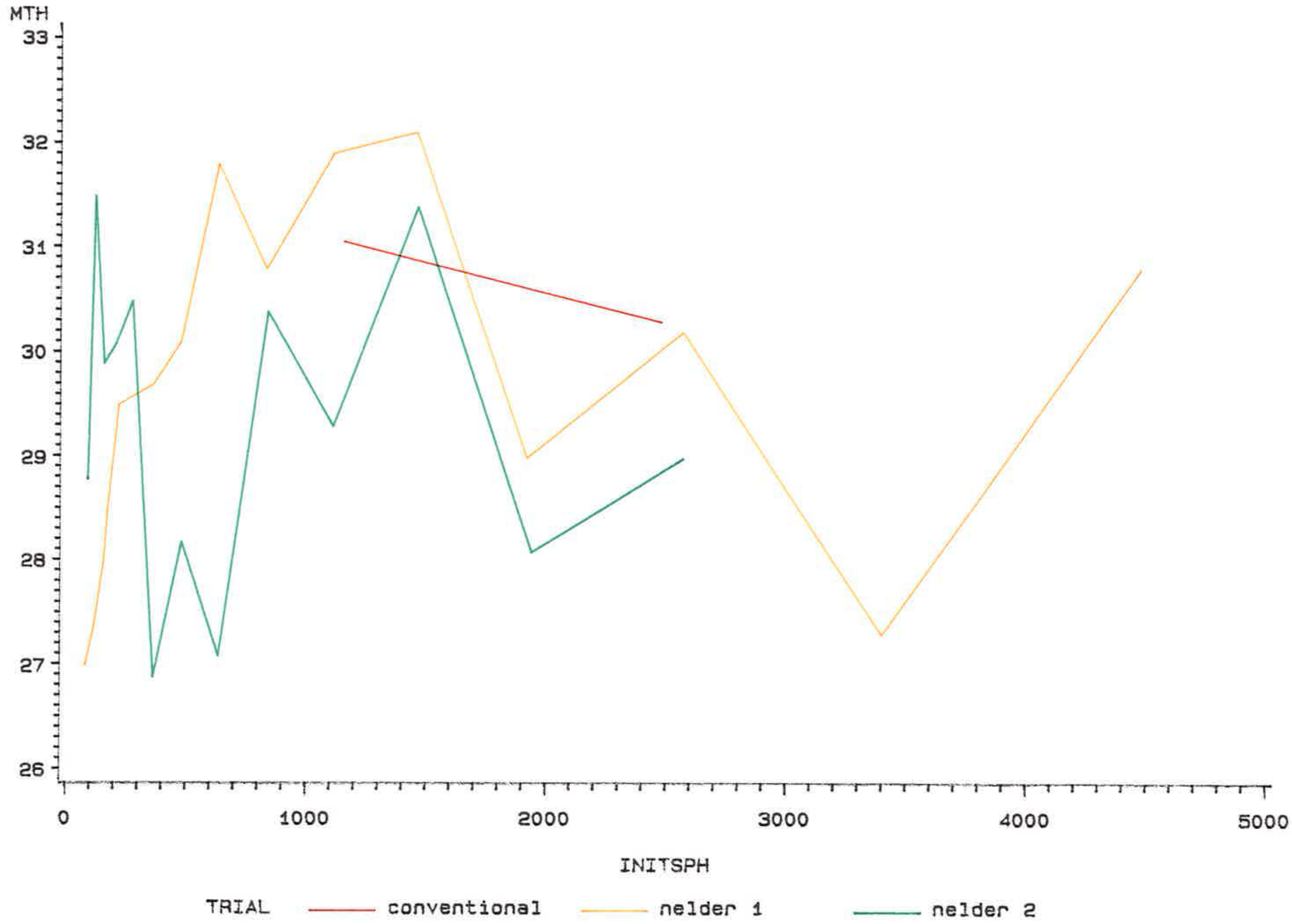


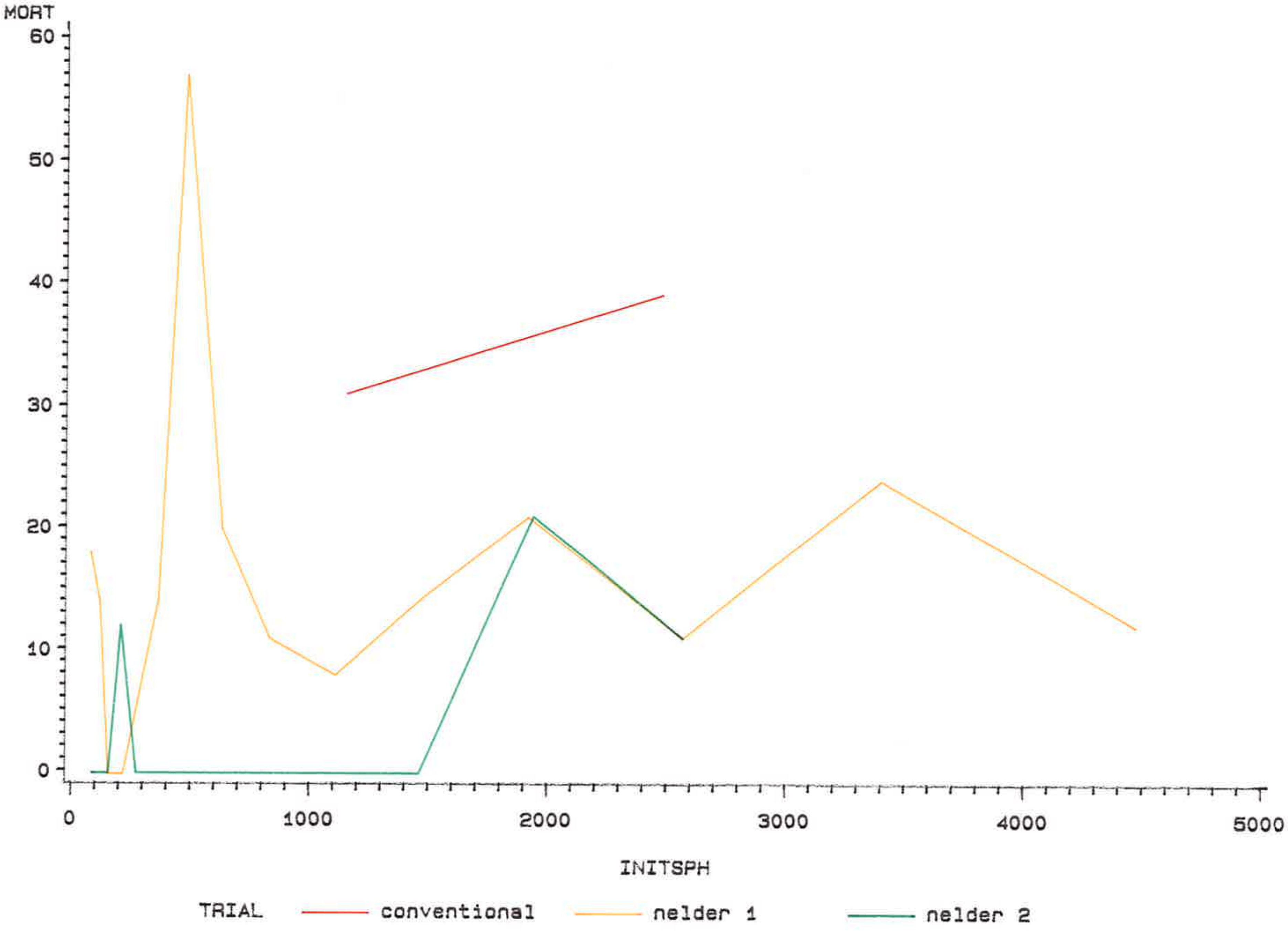
Regnans — Mean Top Height
Mean Top Height (m)
0
10
20
30
40
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age (years)
Initial SPH
1156
2478


VOL
600
500
400
300
200
100
0
1000
2000
3000
4000
5000
INITSPH
TRIAL
conventional
nelder 1
nelder 2

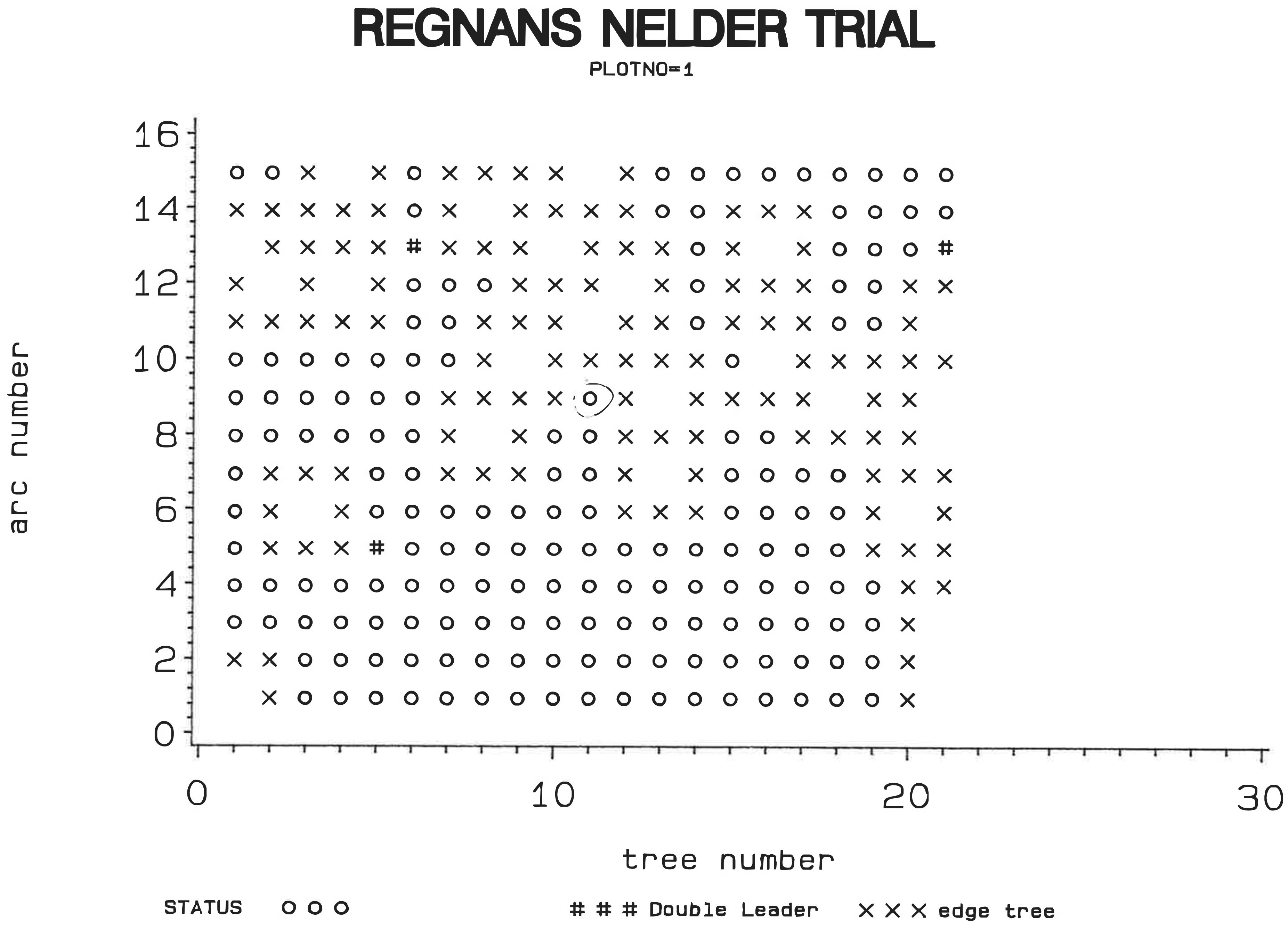
Use this in report.




MTH
33
32
31
30
29
28
27
26
0
1000
2000
3000
4000
5000
INITSPH
TRIAL
conventional
nelder 1
nelder 2

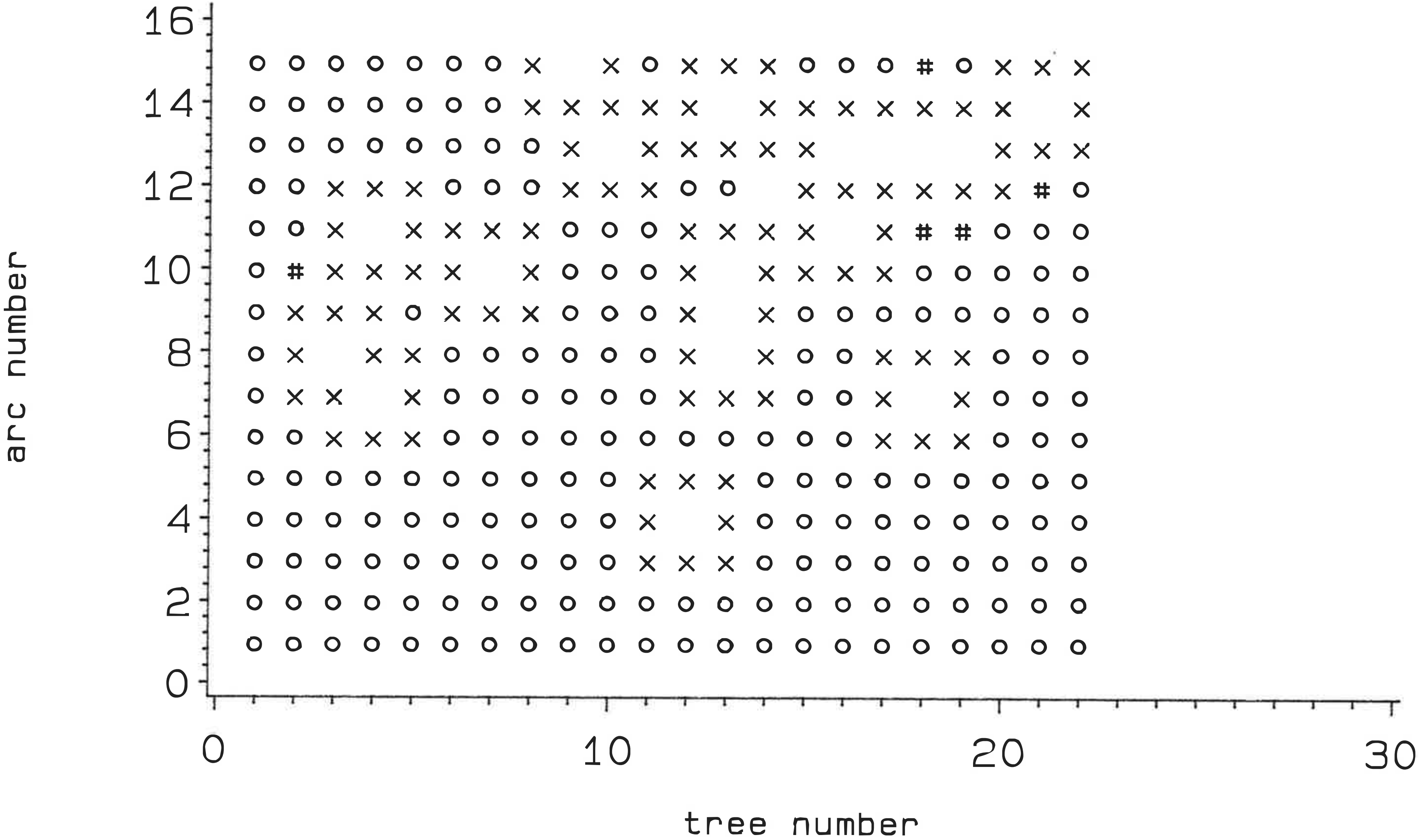


MORT
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
INITSPH
TRIAL
conventional
nelder 1
nelder 2

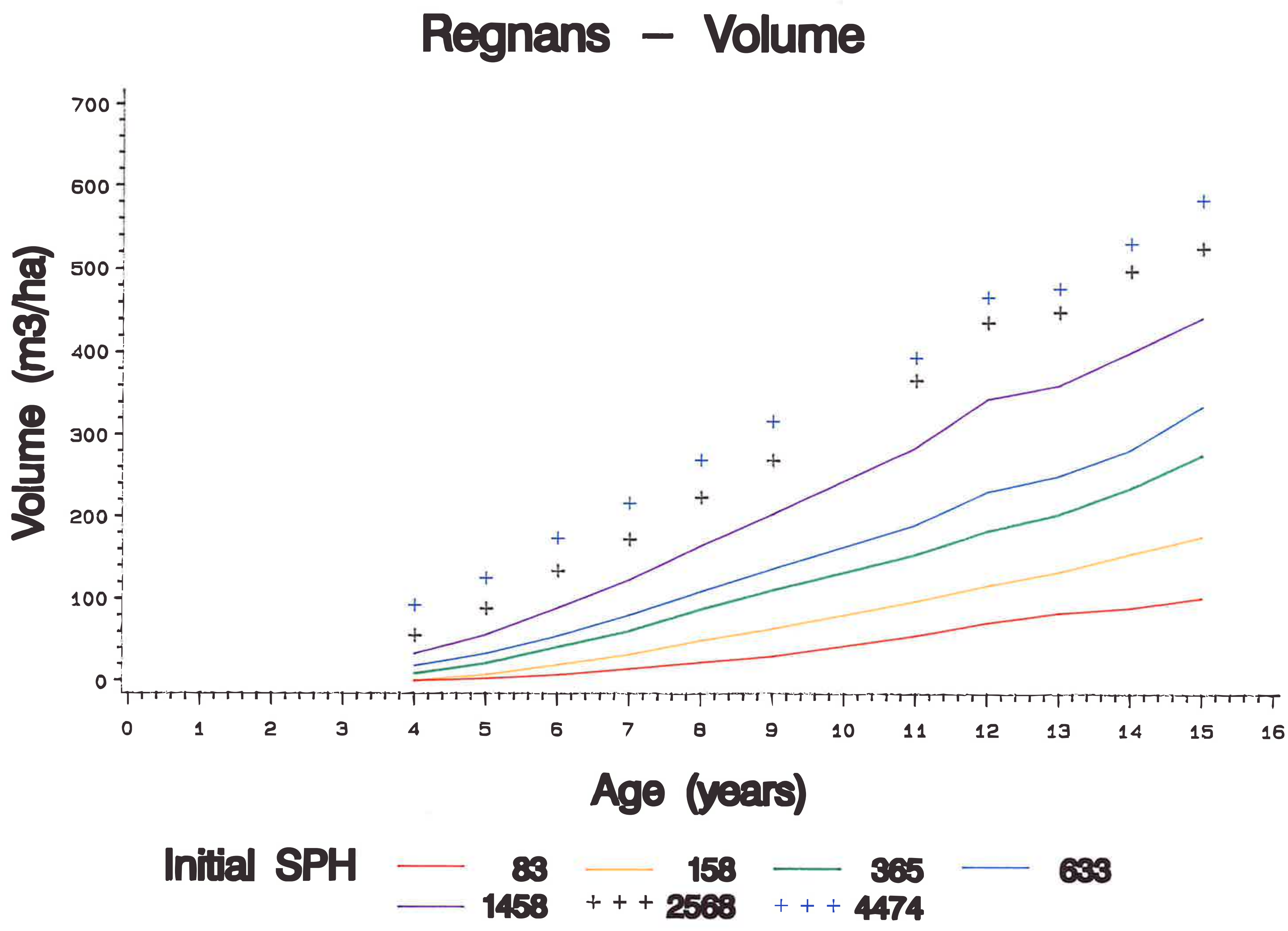

REGNANS NELDER TRIAL
PLOTNO=1
arc number
tree number
0
2
4
6
8
10
12
14
16
0
10
20
30
STATUS
o o o
Double Leader
x x x edge tree

REGNANS NELDER TRIAL

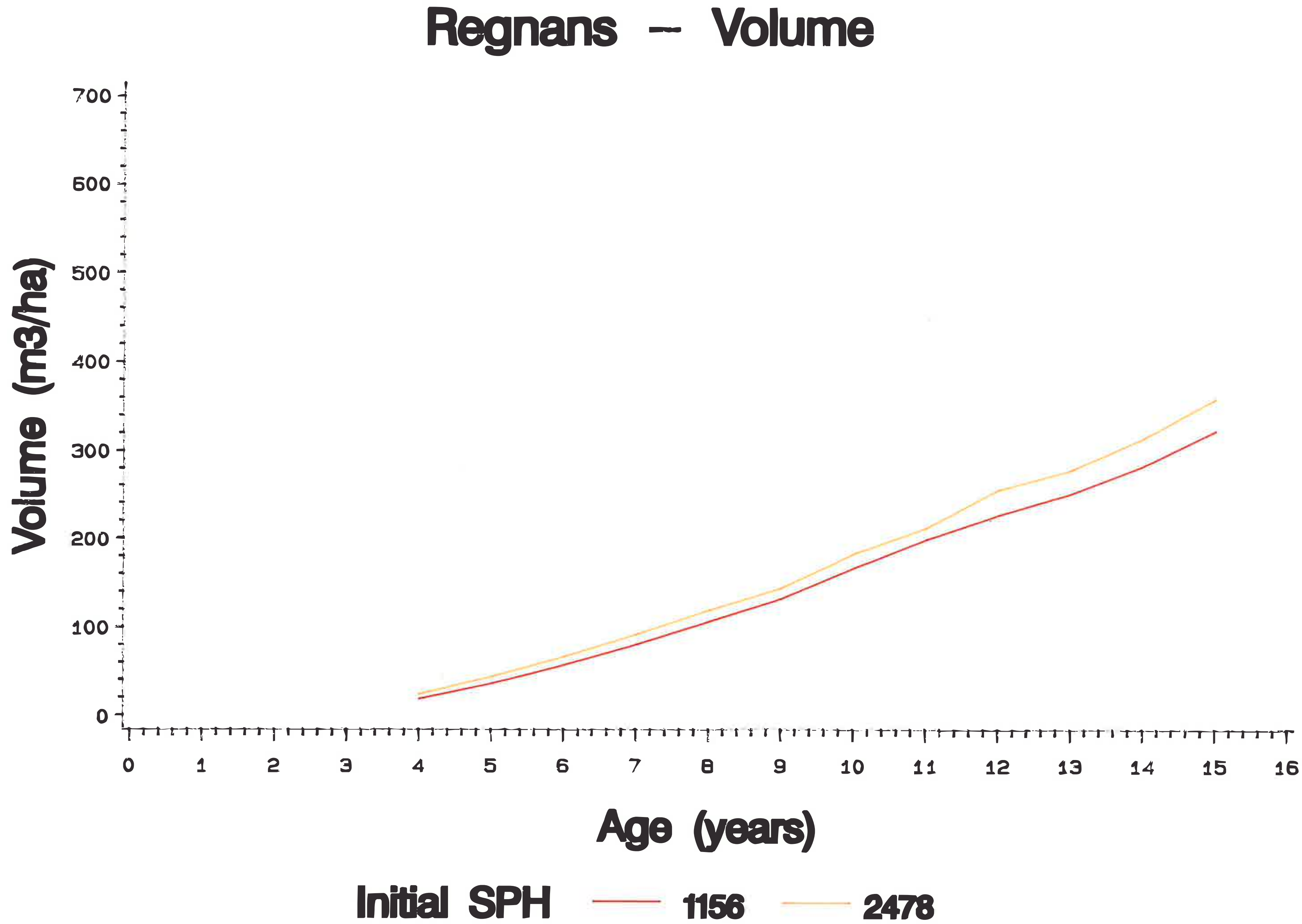
PLOTNO=2

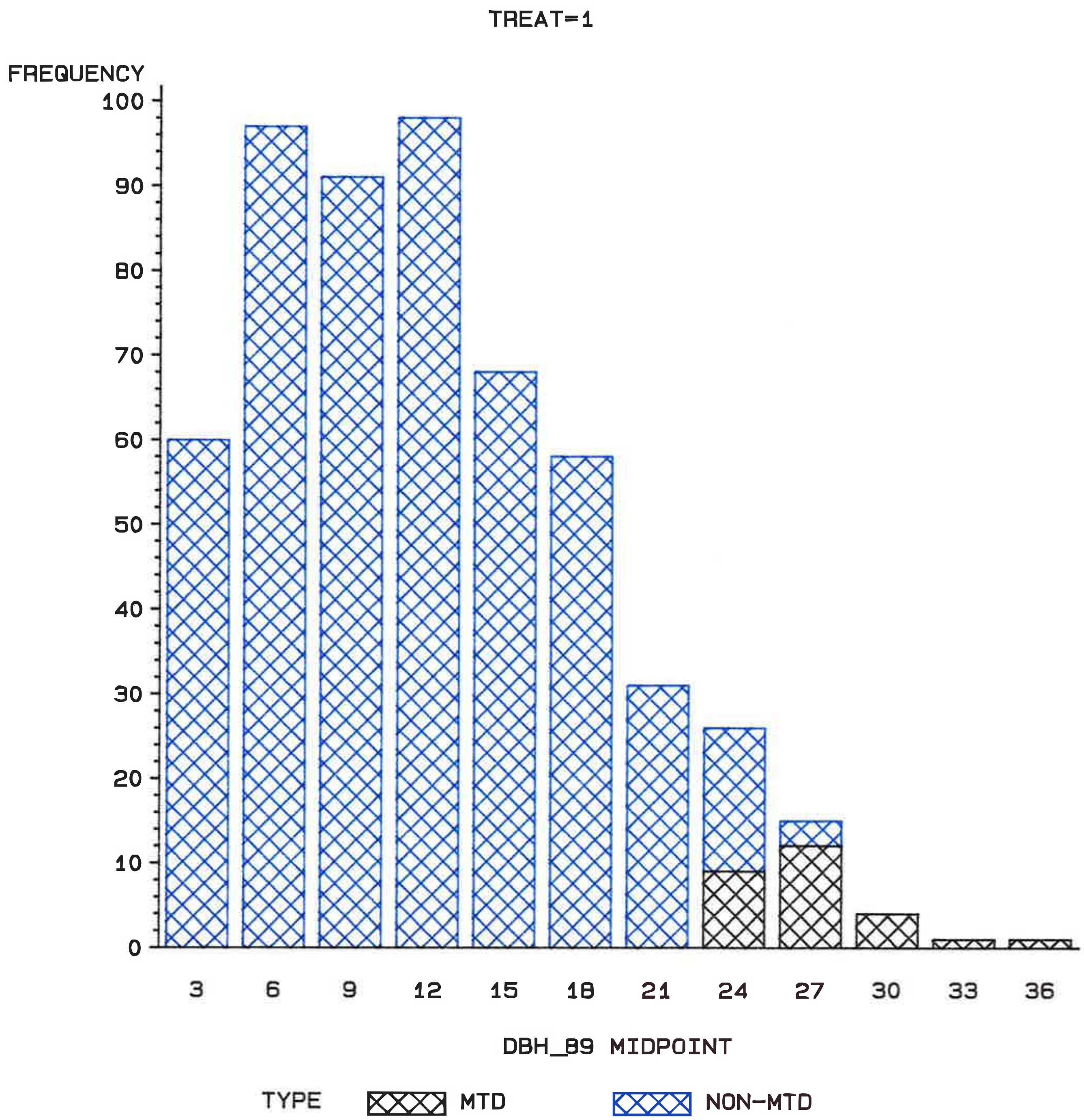


STATUS o o o   # # # Double Leader   x x x edge tree

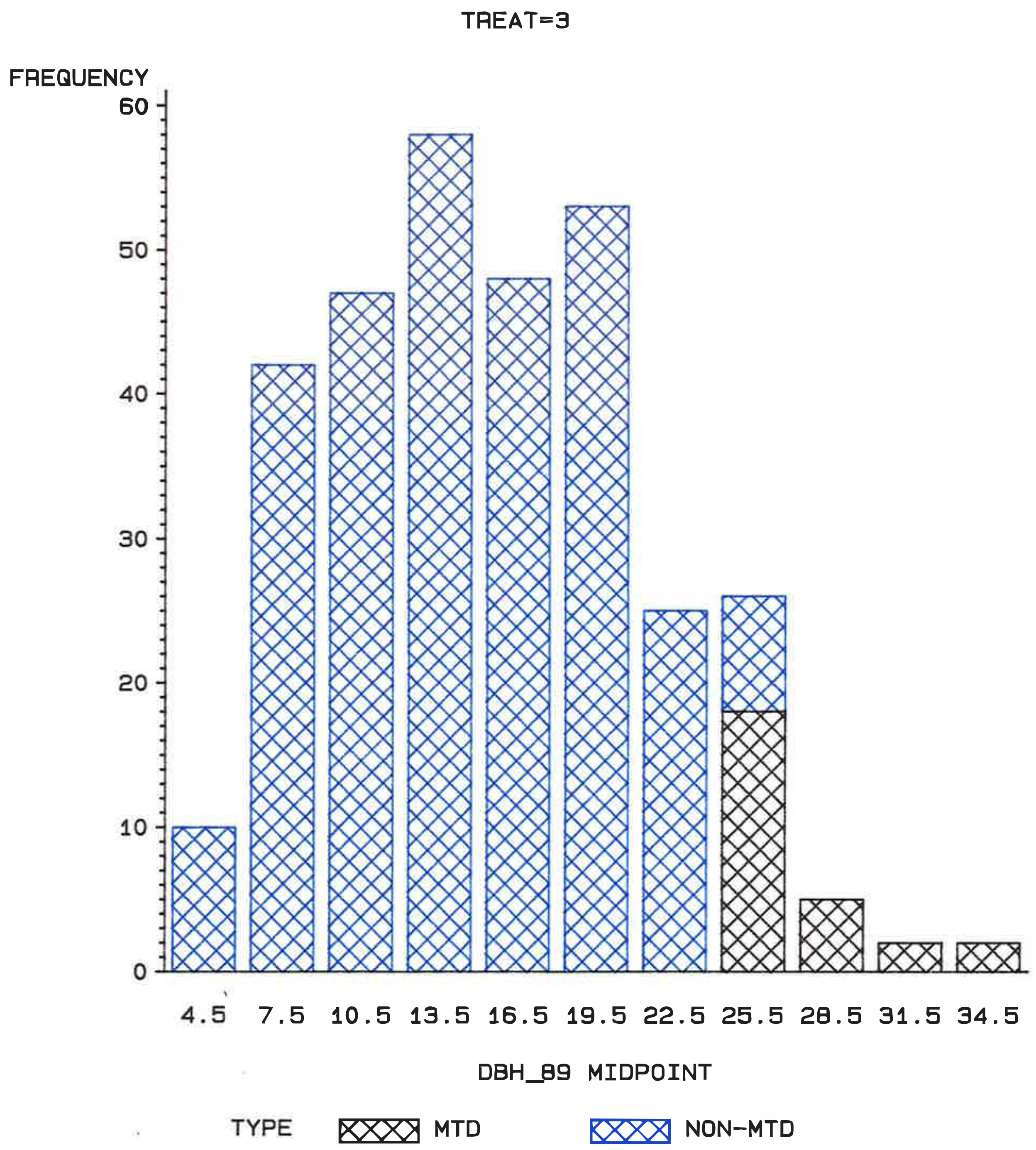


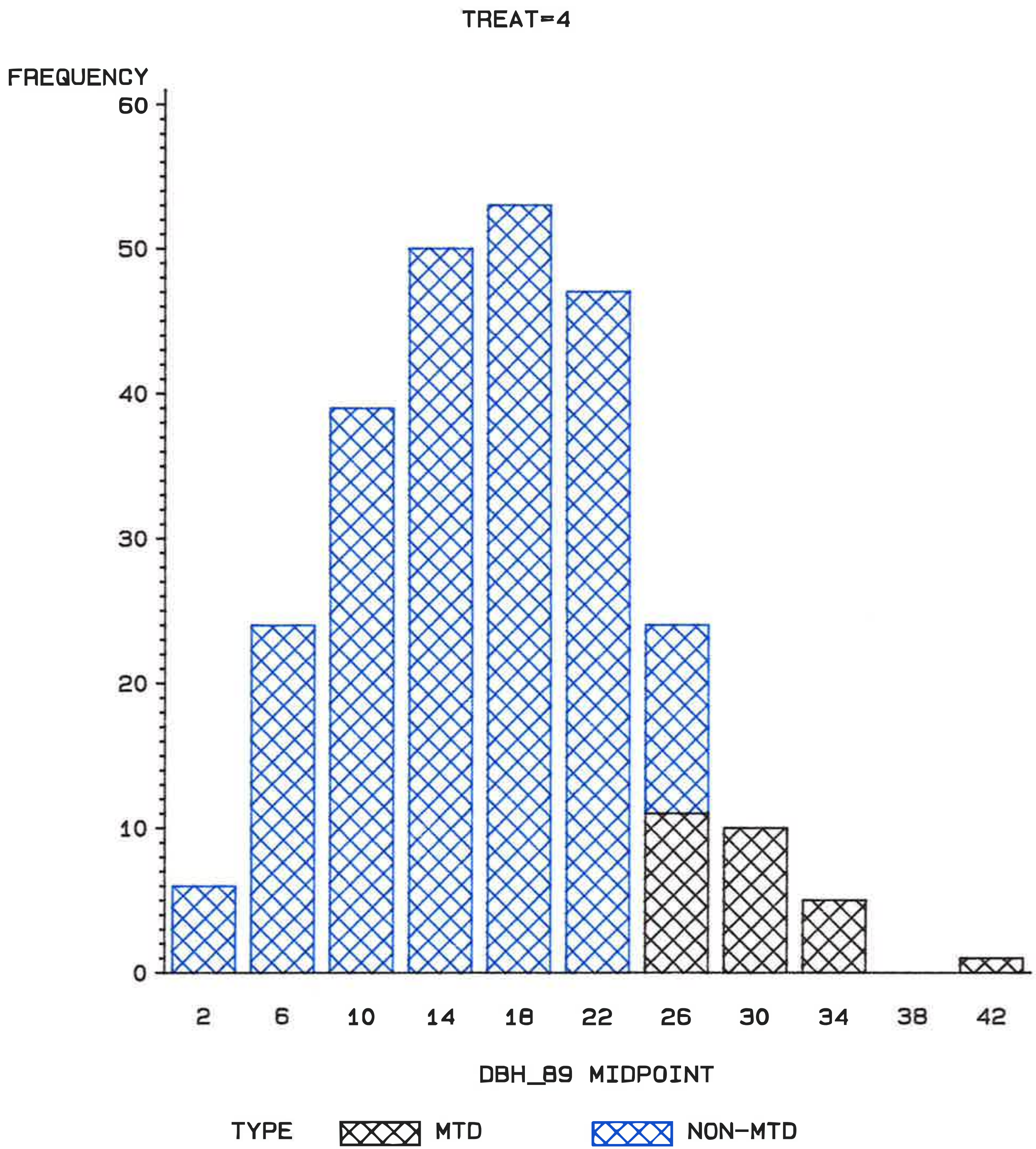
Regnans – Volume
Volume (m3/ha)
0
100
200
300
400
500
600
700
Age (years)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Initial SPH
83
158
365
633
1458
2568
4474

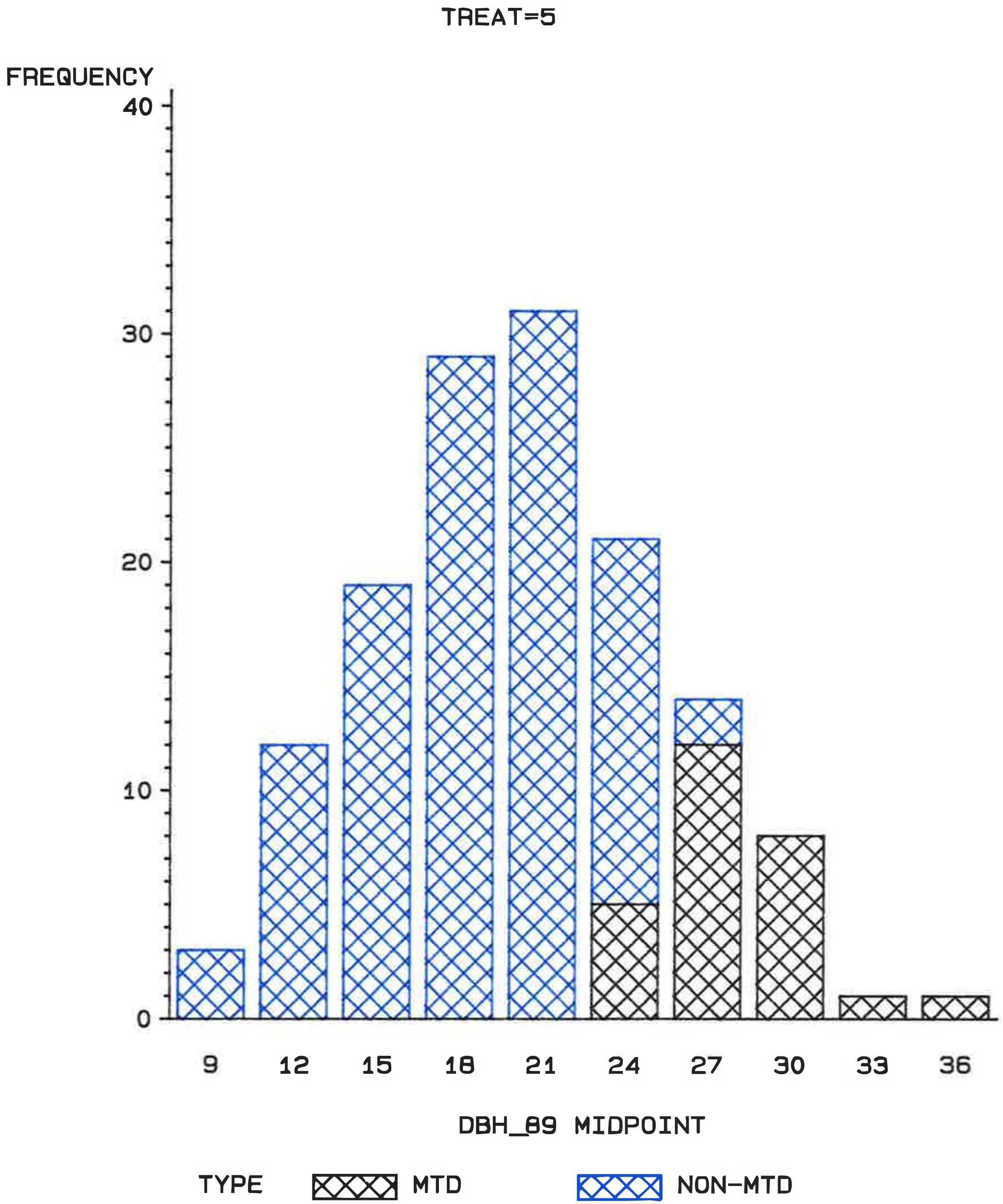

Regnans – Volume
Volume (m3/ha)
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Age (years)
Initial SPH
1156
2478

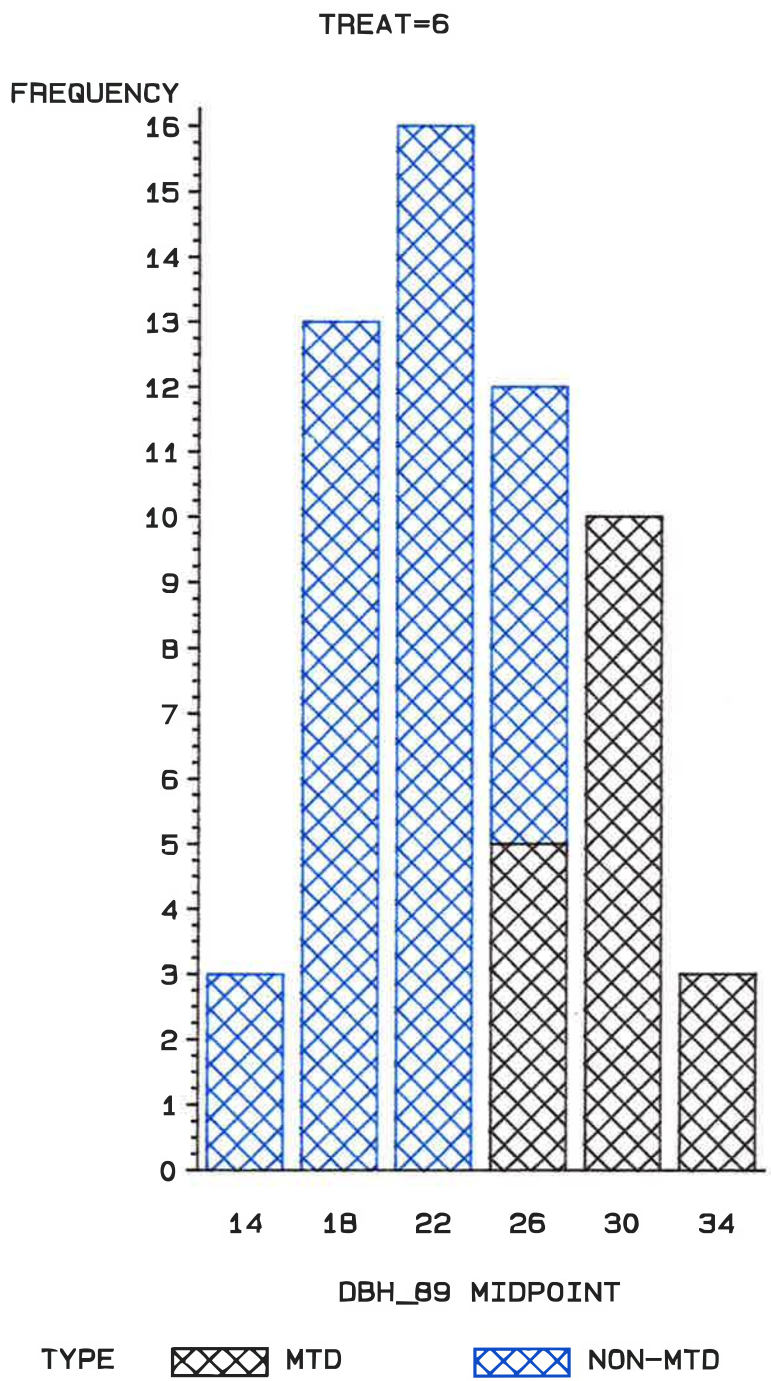


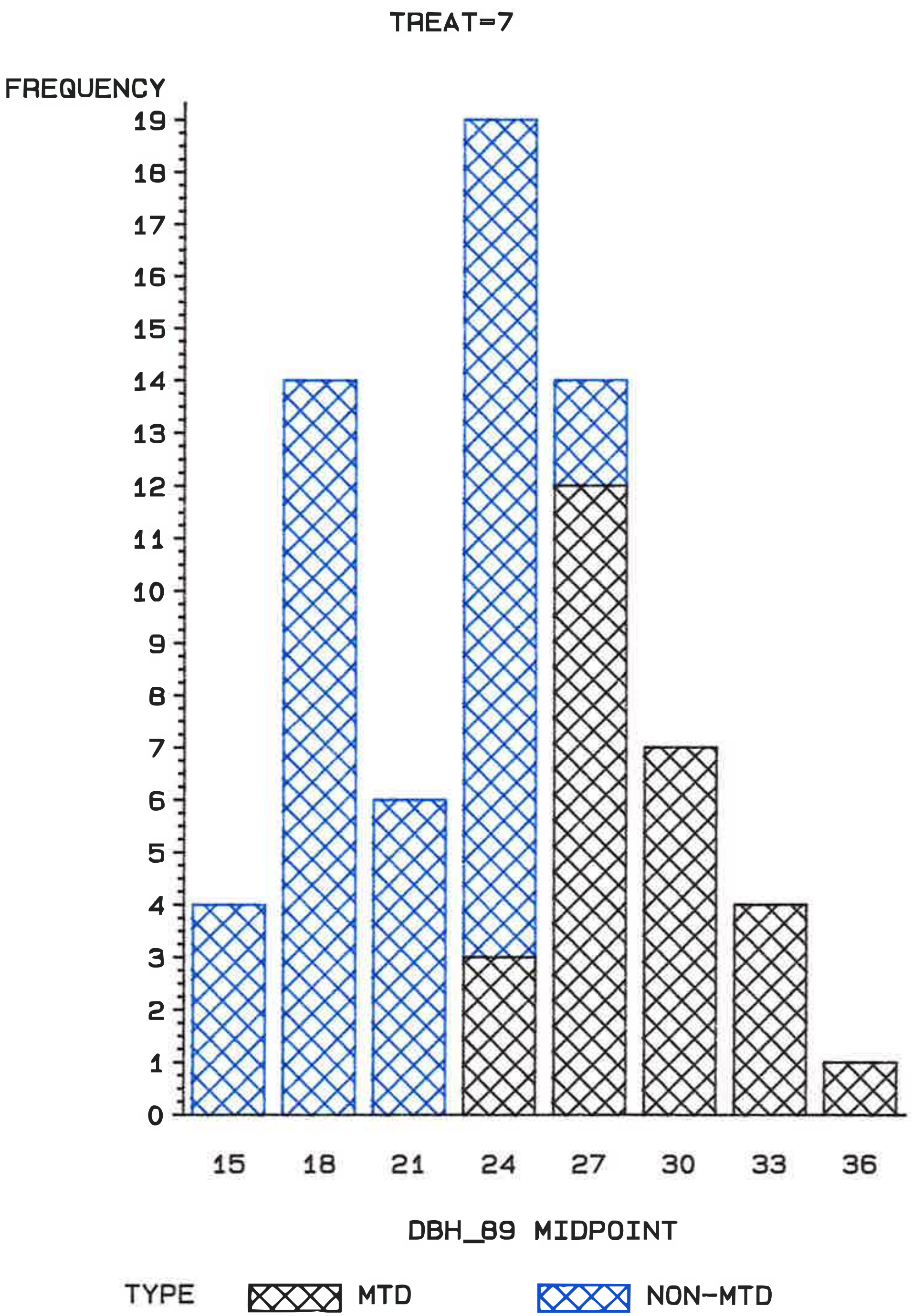
TREAT=1
FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
3
6
9
12
15
18
21
24
27
30
33
36
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

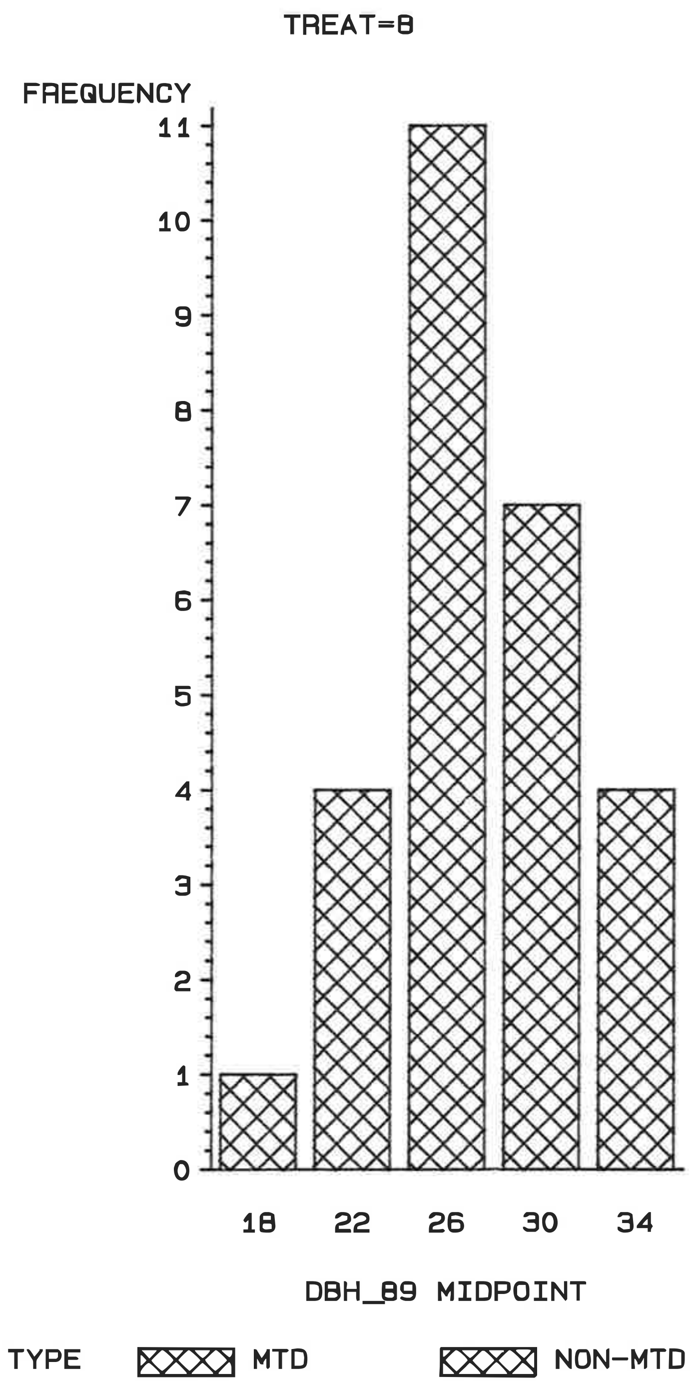

TREAT=3
FREQUENCY
60
50
40
30
20
10
0
4.5
7.5
10.5
13.5
16.5
19.5
22.5
25.5
28.5
31.5
34.5
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

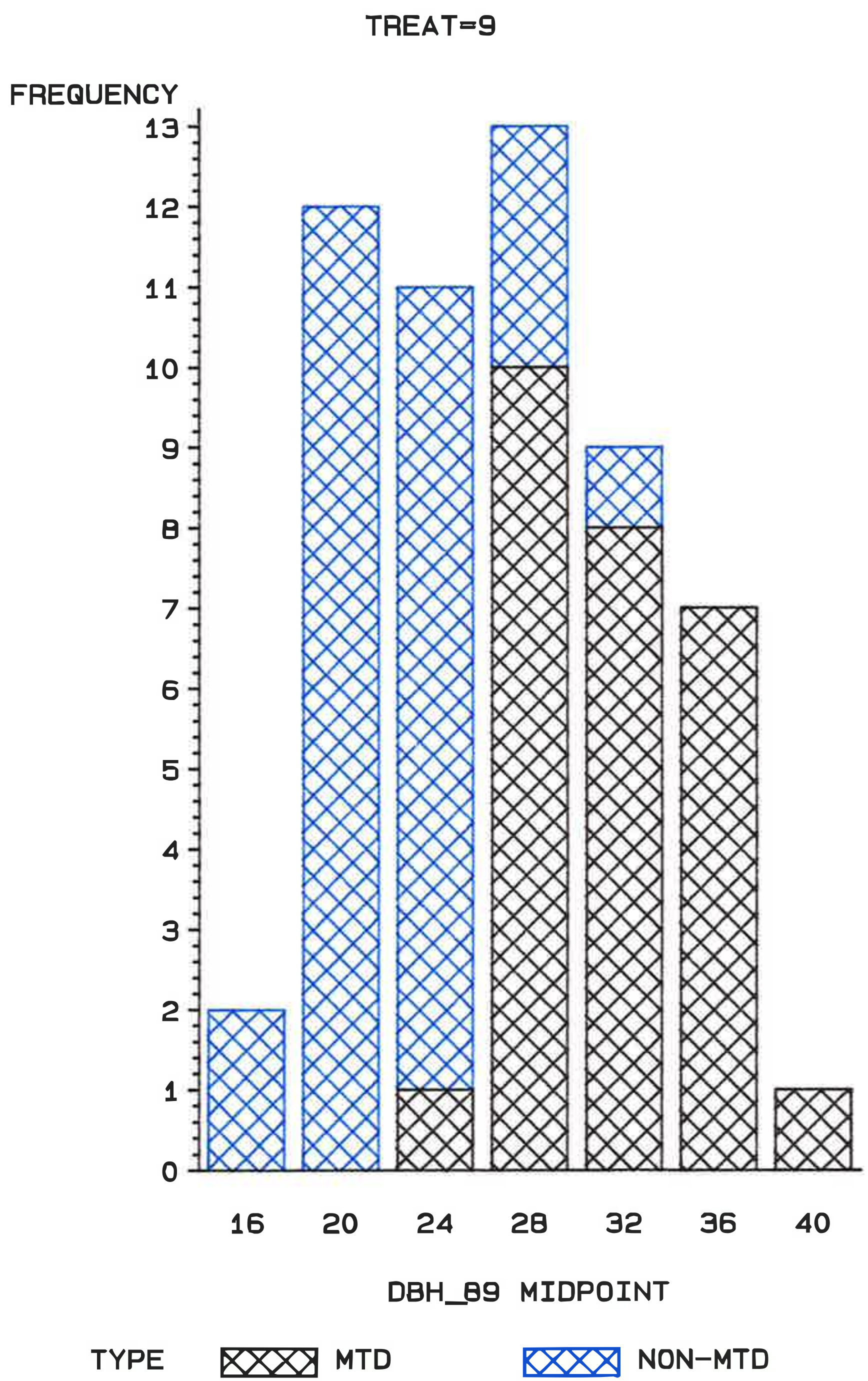

TREAT=4
FREQUENCY
60
50
40
30
20
10
0
2
6
10
14
18
22
26
30
34
38
42
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

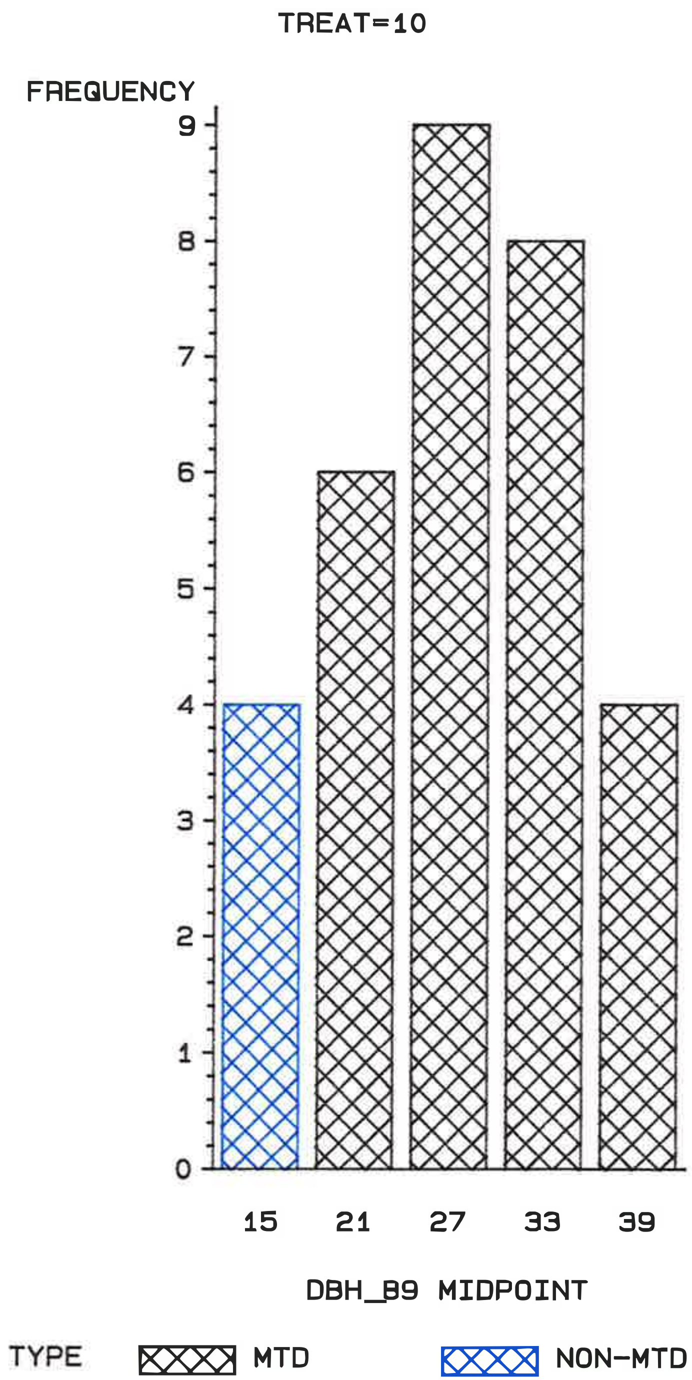

TREAT=5
FREQUENCY
40
30
20
10
0
9
12
15
18
21
24
27
30
33
36
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

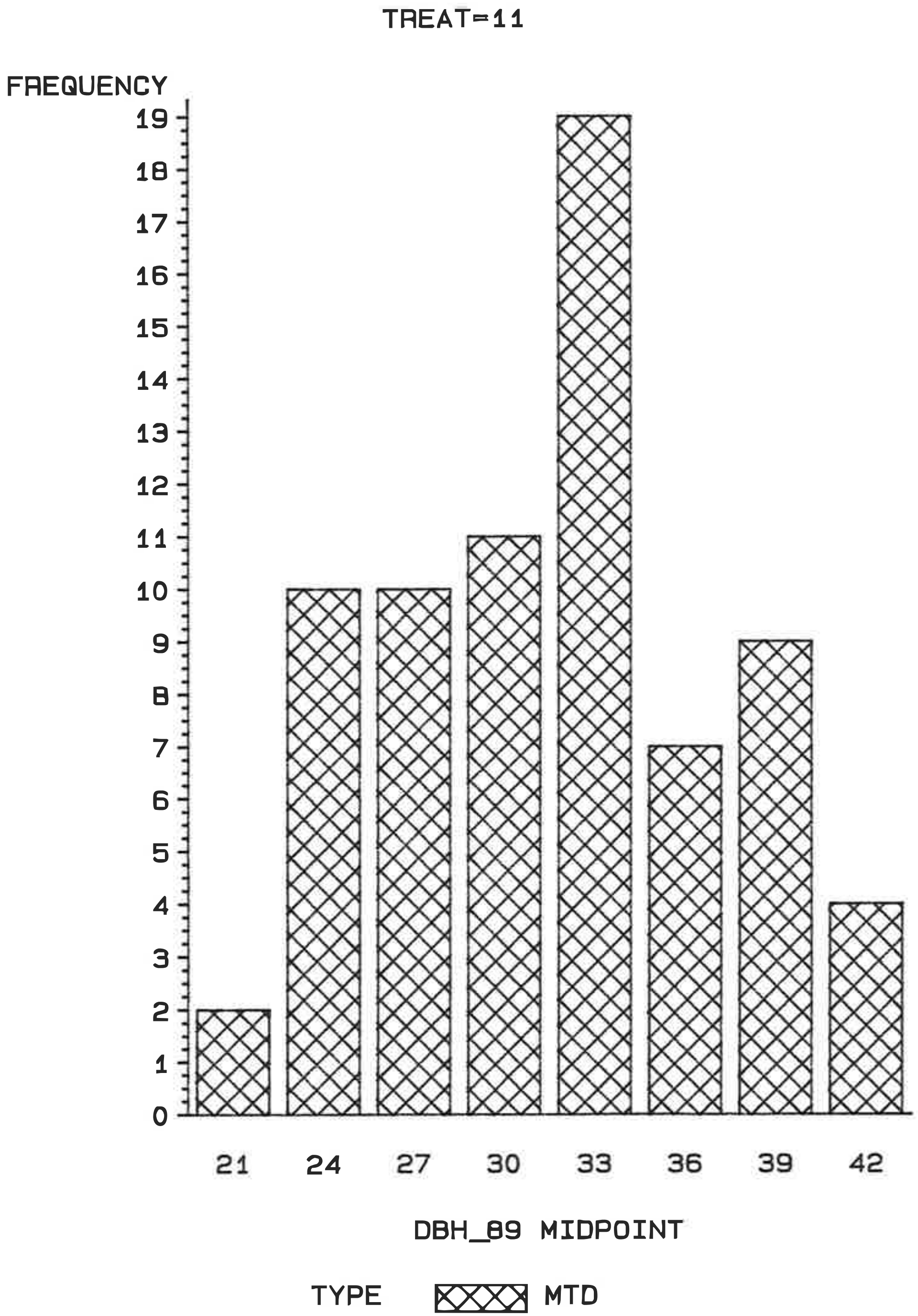

TREAT=6
FREQUENCY
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
14
18
22
26
30
34
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD


TREAT=7
FREQUENCY
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
15
18
21
24
27
30
33
36
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

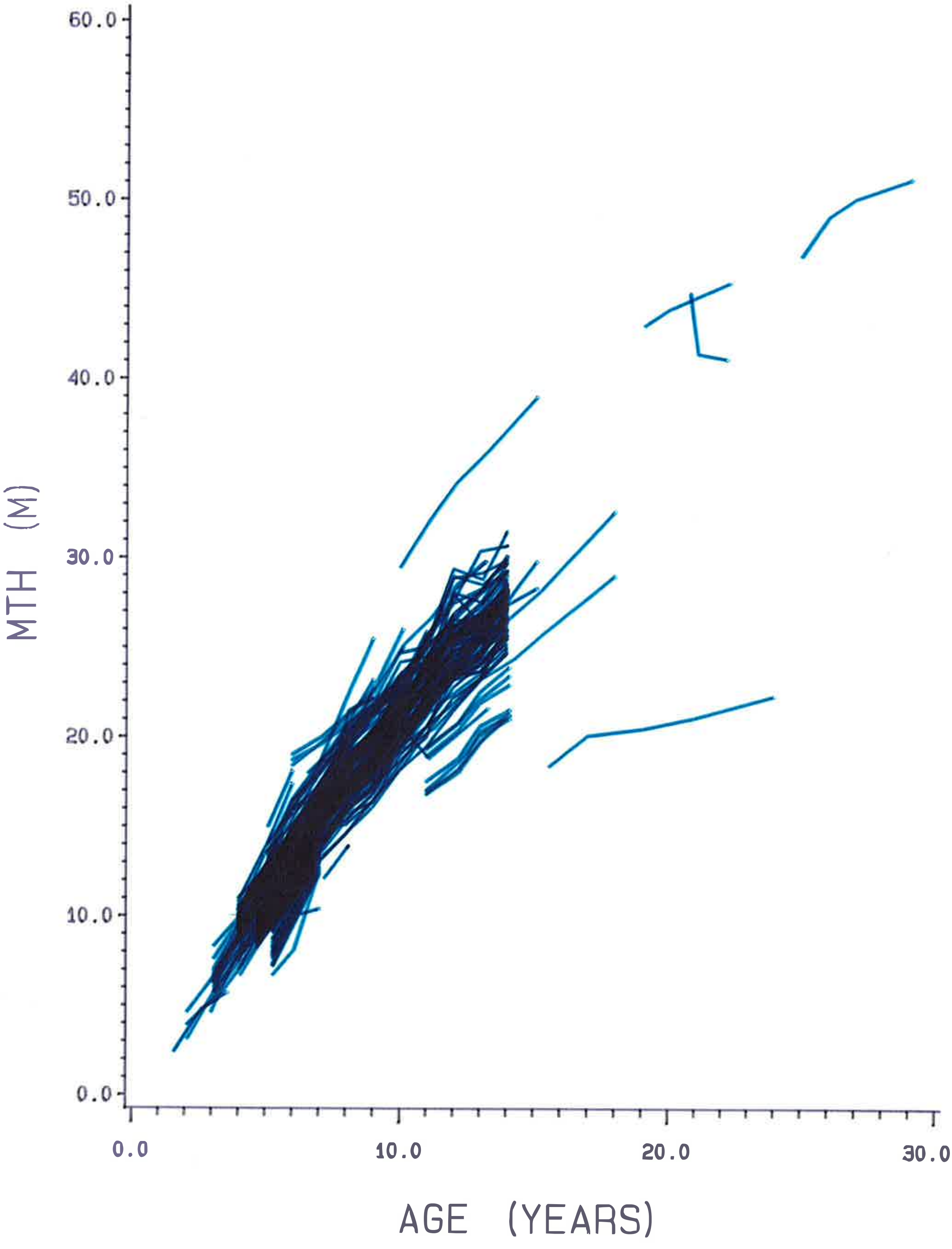

TREAT=8
FREQUENCY
11
10
9
8
7
6
5
4
3
2
1
0
18
22
26
30
34
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD


TREAT=9
FREQUENCY
13
12
11
10
9
8
7
6
5
4
3
2
1
0
16
20
24
28
32
36
40
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD

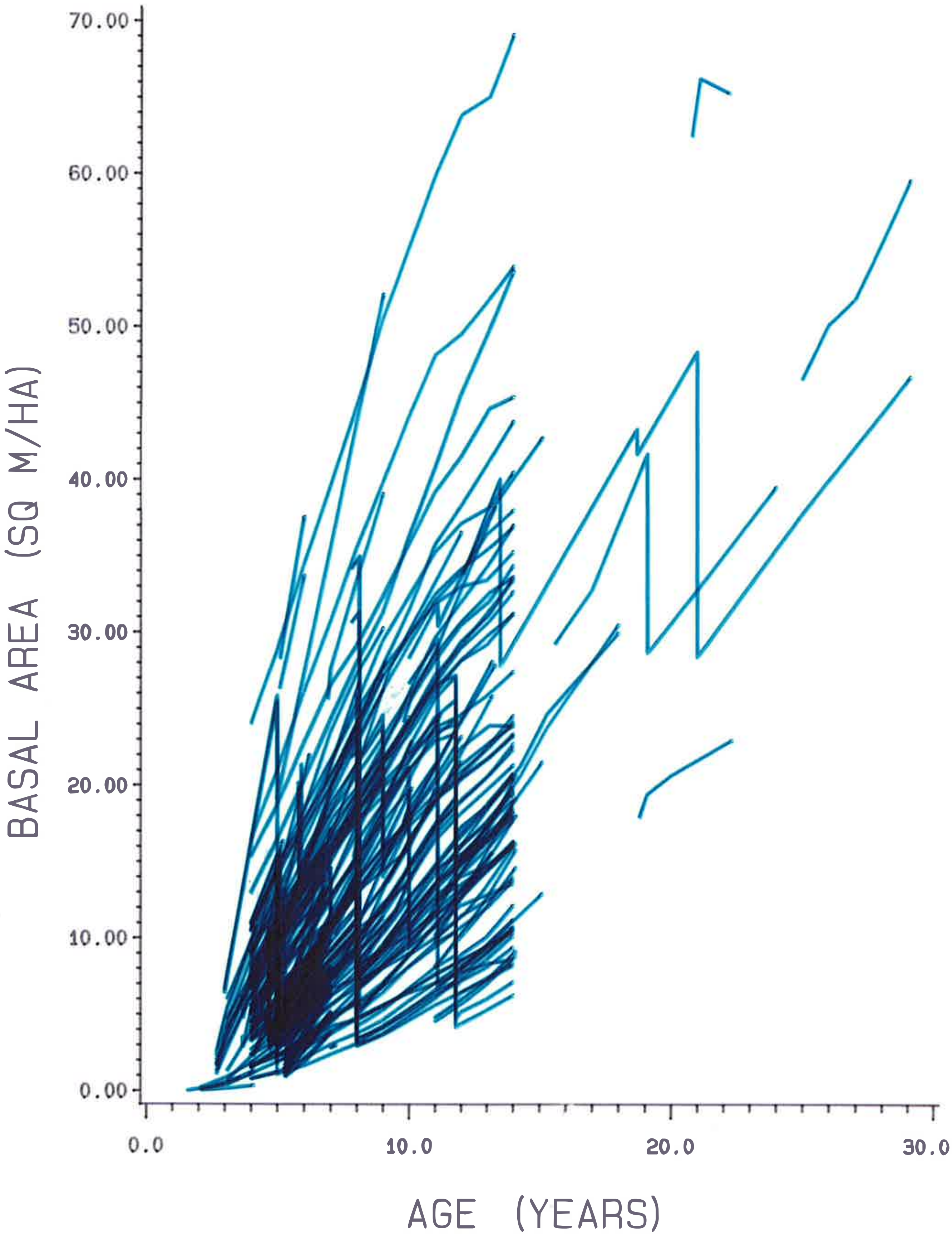

TREAT=10
FREQUENCY
9
8
7
6
5
4
3
2
1
0
15
21
27
33
39
DBH_89 MIDPOINT
TYPE
MTD
NON-MTD


TREAT=11
FREQUENCY
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
21
24
27
30
33
36
39
42
DBH_89 MIDPOINT
TYPE
MTD

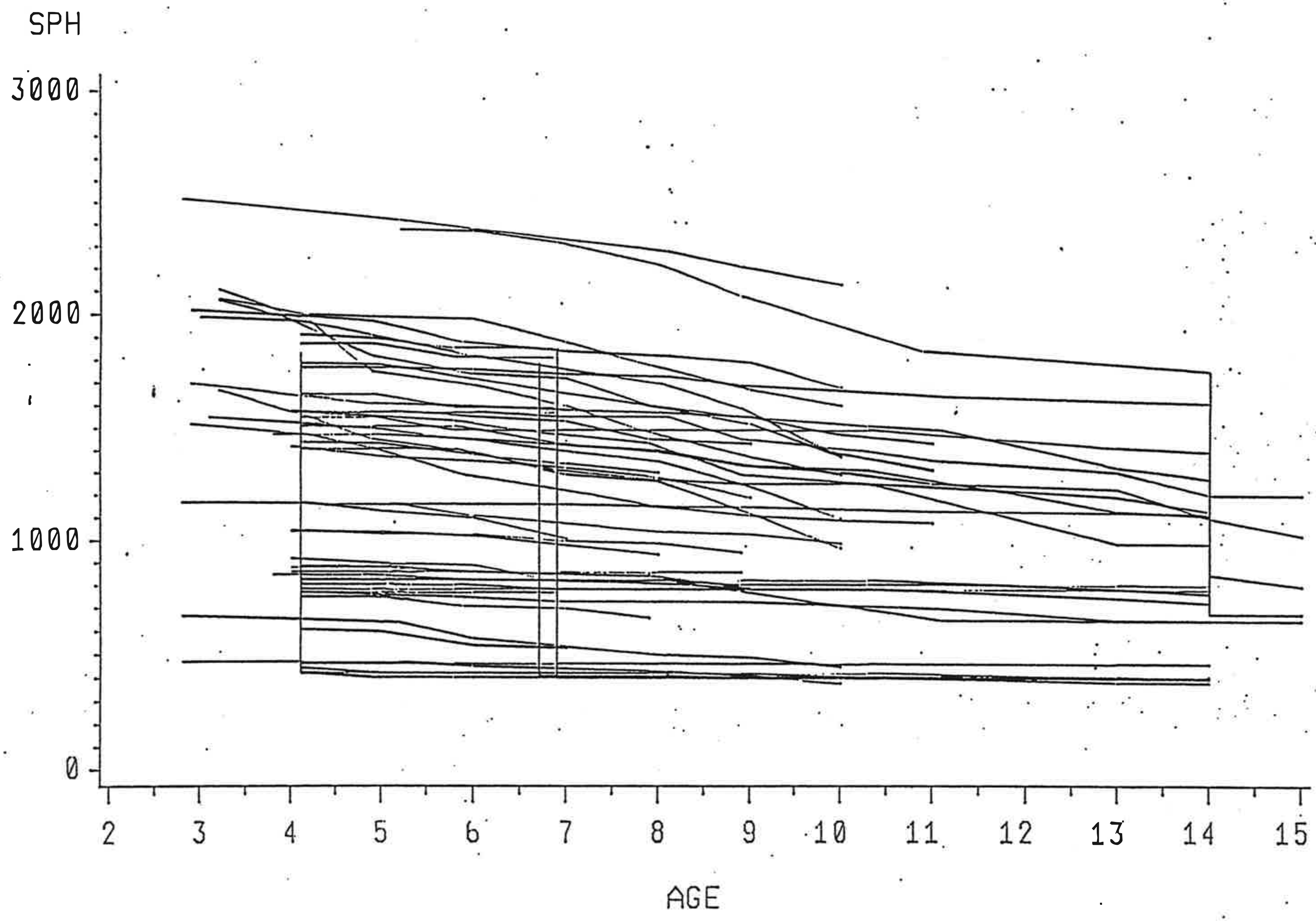
REGNANS DATA



REGNANS DATA



E.REGNANS DATABASE



MANAGEMENT OF EUCALYPTS COOPERATIVE

IN KIND CONTRIBUTION - THE NZFP FORESTS LIMITED

E.regnans GROWTH MODEL

NZFP Forests has a significant resource planted in Eucalyptus species in the Central North Island of New Zealand. Eucalyptus regnans account for approximately 65% of this total. A large growth database has been gathered from the remeasurements of PSP's (see the following graphs) and in 1988 the database was sufficiently representative of the resource, in terms of final crop stockings and age range, for a growth and yield model to be attempted.

The methodology employed in the model formulation has been well documented (see Clutter et al., Woollons and Hayward, 1983). Of the many yield assumptions modelled, the Schumacher yield function was found to best fit the data:

$$\ln(G) = \alpha + \frac{\beta}{T} + \gamma N \tag{1}$$

where G - Basal Area/ha

T - Time

N - Initial stocking/ha

α, β, γ - parameters to be estimated

Equation (1) can be differentiated with respect to T to derive the 'growth' function:

$$\frac{dG}{dT} = \frac{G}{T} \left(\alpha + \gamma N - \ln(G) \right) \tag{2}$$

and equation (2) can be integrated, incorporating the initial conditions that when T = T1, G = G1, to derive the 'projection' function:

$$\ln(G2) = \ln(G1) \left(\frac{T1}{T2}\right) + \alpha \left(1 - \frac{T1}{T2}\right) + \gamma N \left(1 - \frac{T1}{T2}\right) \tag{3}$$

Equation (3) has the desirable properties of

(a) consistency - as T2 → T1, G2 → G1

(b) invariance - projection from T1 to T3 results in the same estimate of Basal area as if the path from T1 to T2 and then T2 to T3 is taken.

Examples of some of the other yield models and their associated projection equations that were explored are

(a) Chapman-Richards and its various modifications

(b) Gompertz and its modifications

(c) Umuemura

However, none performed as well as the Schumacher in terms of Residual Mean Square, Furnival Index and patterns of Residuals.

Model functions were derived for Basal Area, Mean Top Height and Volume per hectare.

Basal Area

Model

$$\ln(G2) = \ln(G1)\left(\frac{T1}{T2}\right) + \alpha 1\left(1 - \left(\frac{T1}{T2}\right)\right) + \alpha 2.N\left(1 - \left(\frac{T1}{T2}\right)\right)$$

Where G1 = Basal area/ha at age = T1

G2 = Basal area/ha at age = T2

N = Initial Stocking/ha

$\alpha 1$ = 4.5352

$\alpha 2$ = -0.0000937

Both parameter estimates are significantly different from zero at the 95% confidence limit.

Mean Top Height

Model

$$\ln(H2) = \ln(H1)\left(\frac{T1}{T2}\right)^{\beta 1} + \beta 2\left(1 - \left(\frac{T1}{T2}\right)^{\beta 1}\right)$$

where H1 = Plot Mean Top Height at age = T1

H2 = " " " " " " = T2

$\beta 1$ = 0.5356

$\beta 2$ = 4.7541

Note The model used for the Mean Top Height function is derived from the 'yield' equation

$$\ln(H) = \beta 1 + \frac{\beta 3}{T^{\beta 2}}$$

Following the steps outlined previously, the above Mean Top Height projection function is derived. Again, both parameter estimates are significantly different from zero at the 95% confidence limited.

Volume

Model

$V = \gamma 1.G.H.EXP(\gamma 2/H)$

where
V = Volume/ha
G = Basal area/ha
H = Mean Top Height
$\gamma 1$ = 0.4088
$\gamma 2$ = -1.4499

Rearranging the above volume equation in terms of the stand form factor indicates a value of approximately 0.39 would be applicable at a rotation age of 20.

Note: Graphs of the Model Residuals against the various predicted values are incuded in this report and show no sign of predicted bias.

Although a validation dataset was not available, percentage bias was calculated by age class for each of the three models using the original dataset.

$$\text{Bias is calculated as } \frac{(\text{Actual-Estimated})}{\text{Estimated}} \times 100$$

Ages	Basal Area Bias	Mean Top Height Bias	Volume Bias	N
7	- 1.3	2.5	- 5.4	18
8	- 0.1	- 0.1	- 0.9	45
9	- 0.5	- 0.6	- 2.0	39
10	0.3	0.5	0.8	25
11	1.6	0.2	0.6	10
13	1.0	0.5	2.0	24
14	0.0	- 1.1	- 0.5	4
Overall	0.0	0.2	- 0.9	165

No significant functional bias is evident indicating that the overall model does an adequate job in estimating the growth of *E.regnans* on the volcanic plateau.

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References

- Clutter, J.L., Fortson, J.C., Pienaar, L.V., Brister, G.H., Bailey, R.L. 1983, Timber Management - a quantitative approach. Wiley 333 pp.

- Woollons, R.C., Hayward, W.J., 1983, Revision of a Growth and yield model for Radiata pine in New Zealand, For.Ecol. and Management.

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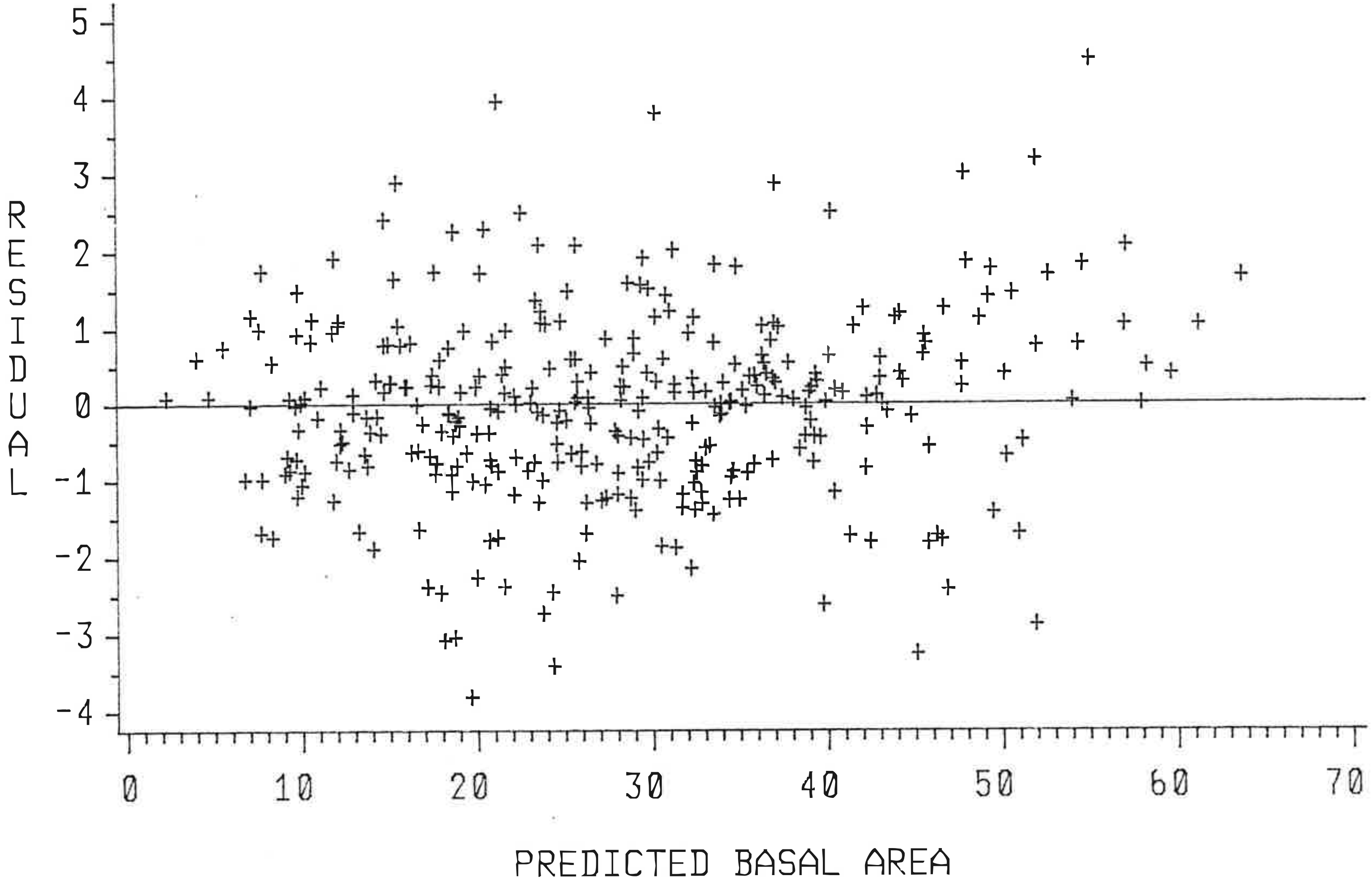
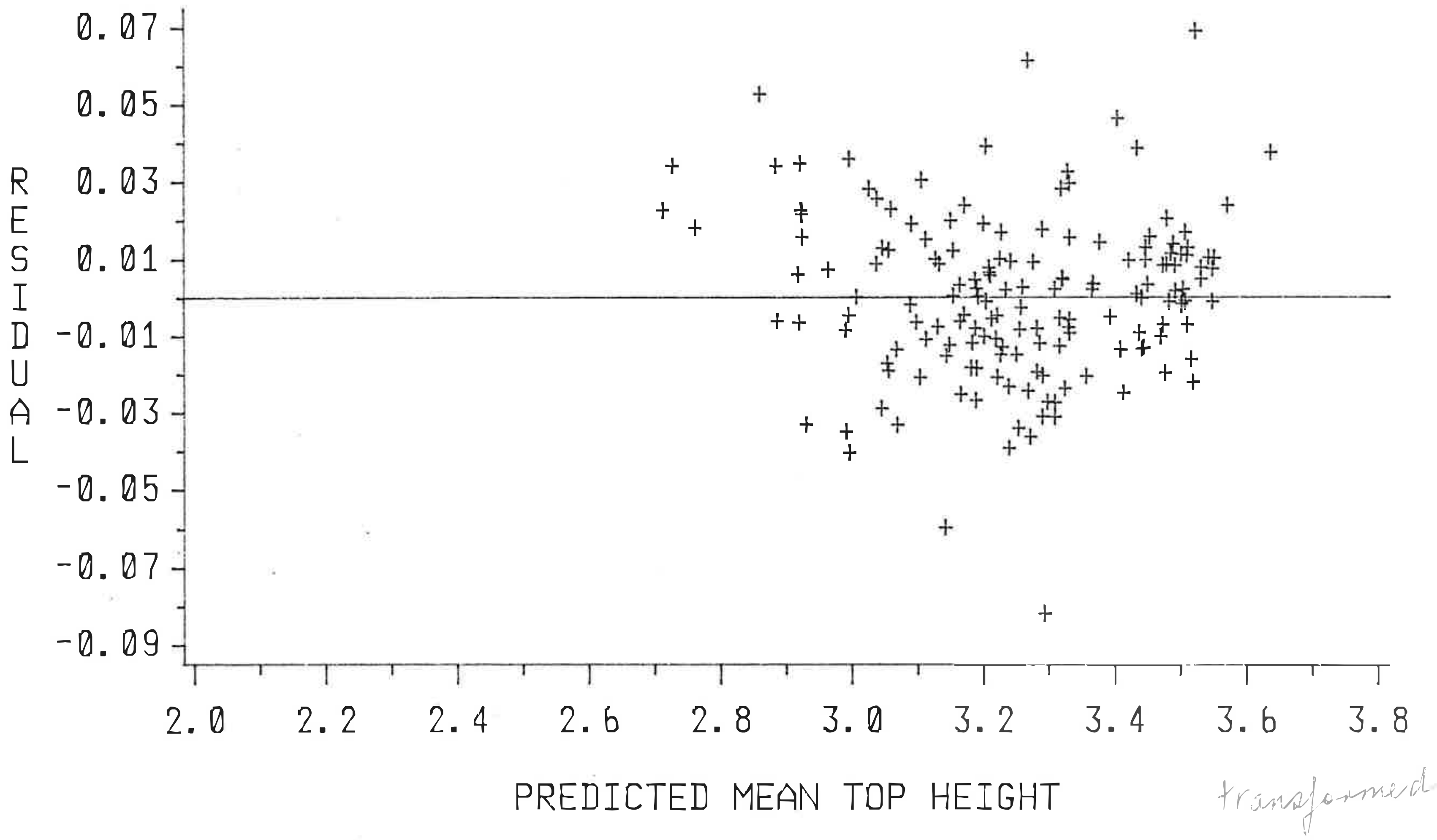
18.11.88

REGNANS GROWTH MODEL



REGNANS GROWTH MODEL



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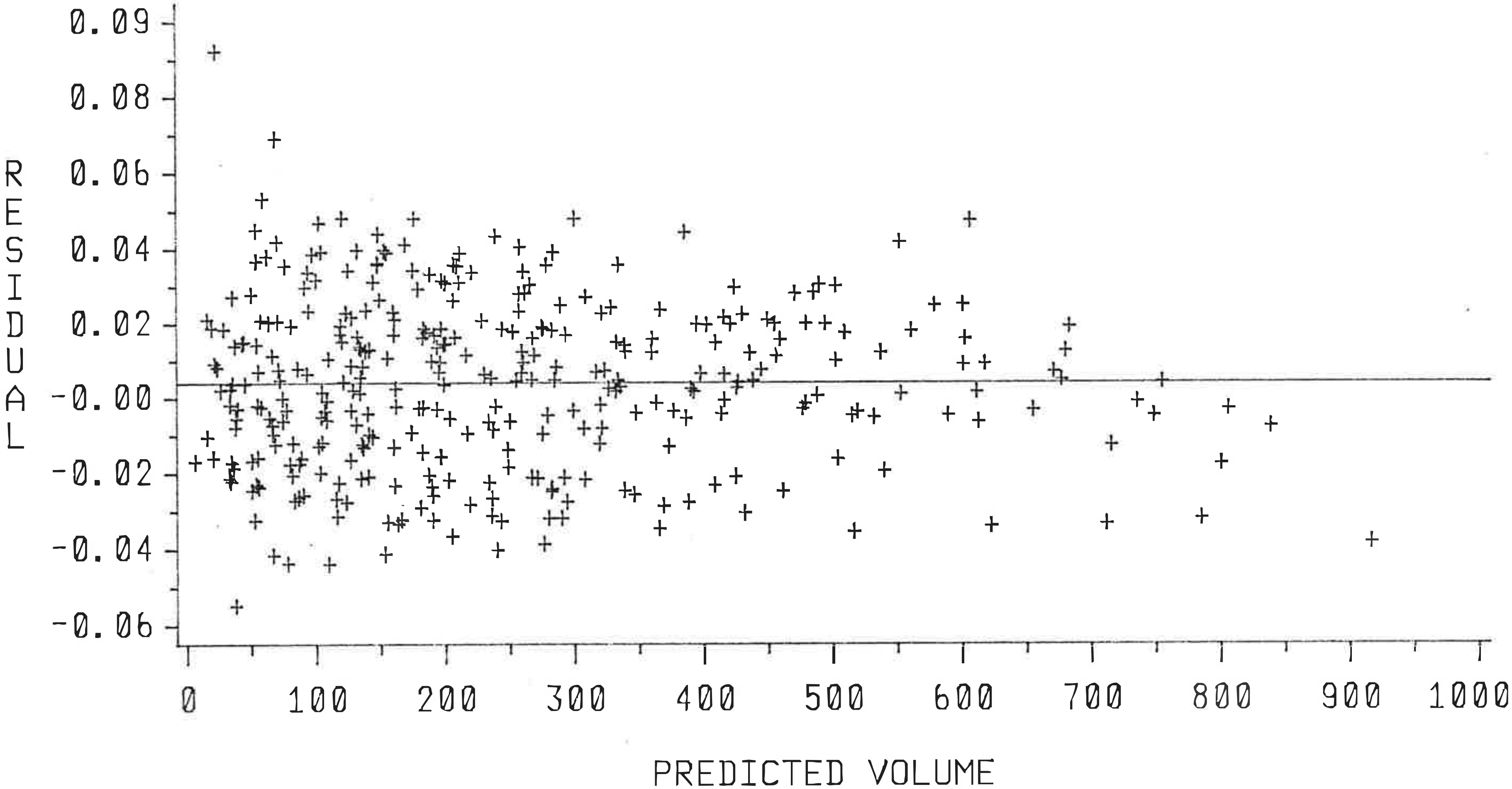
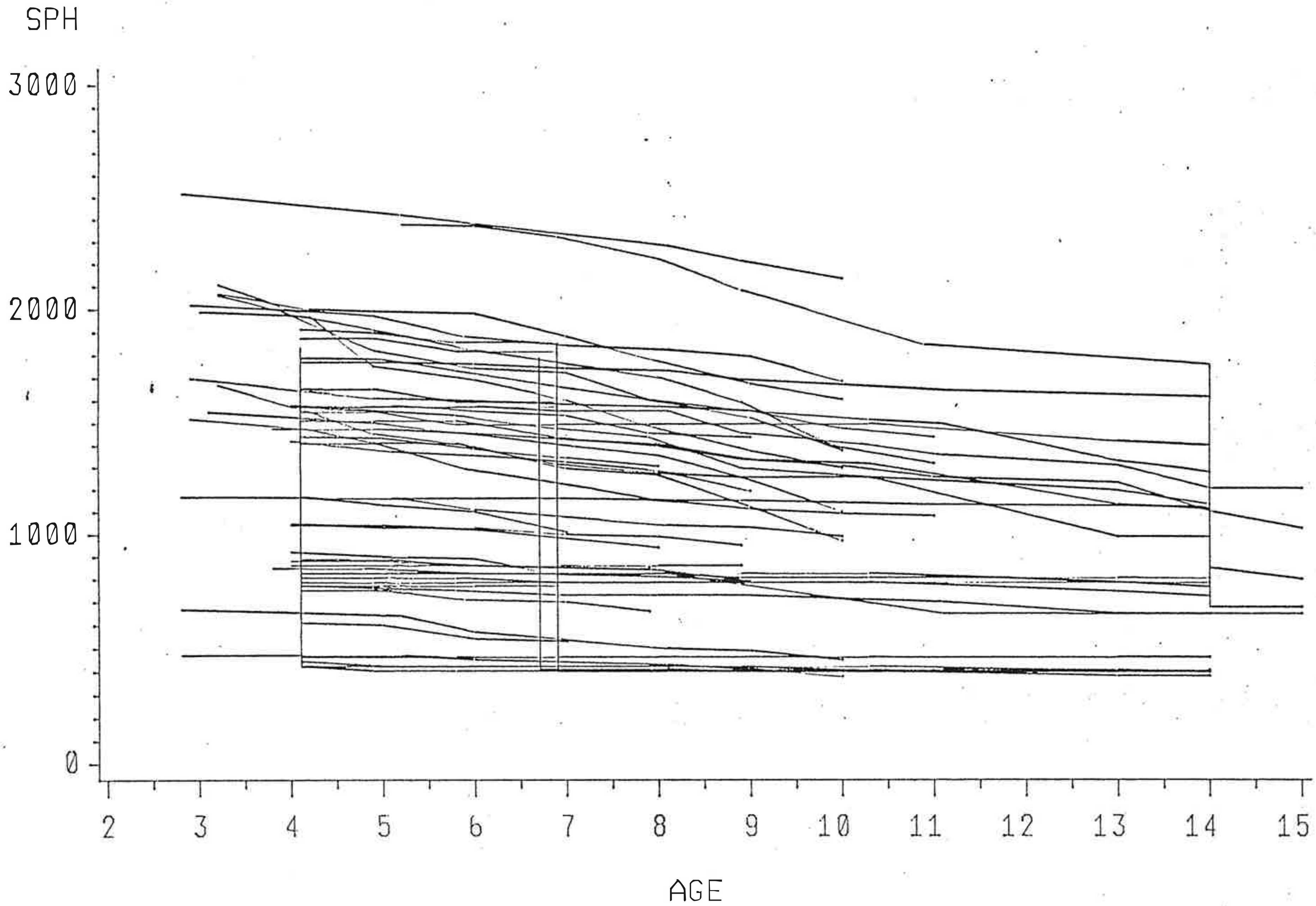


E.REGNANS DATABASE



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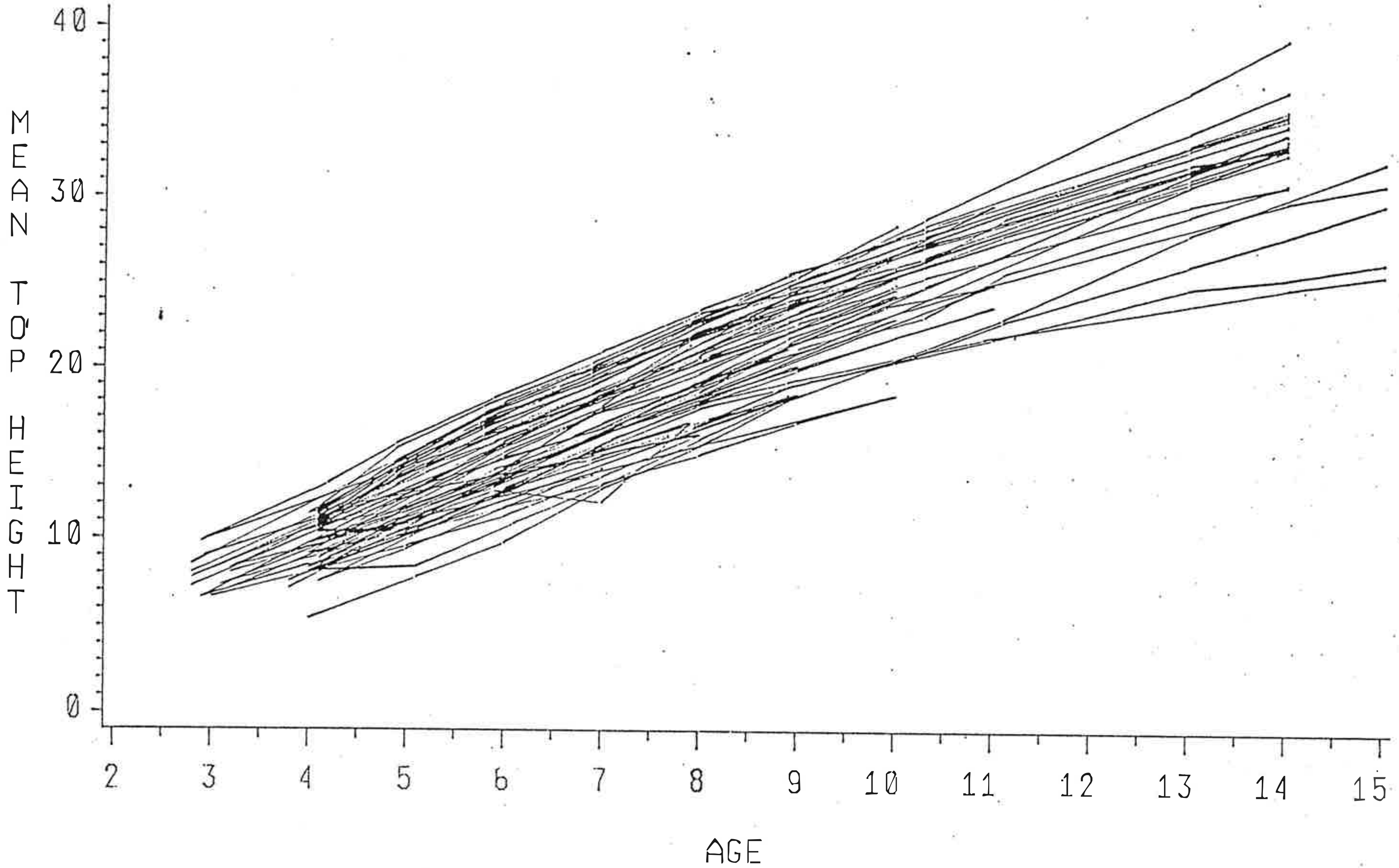

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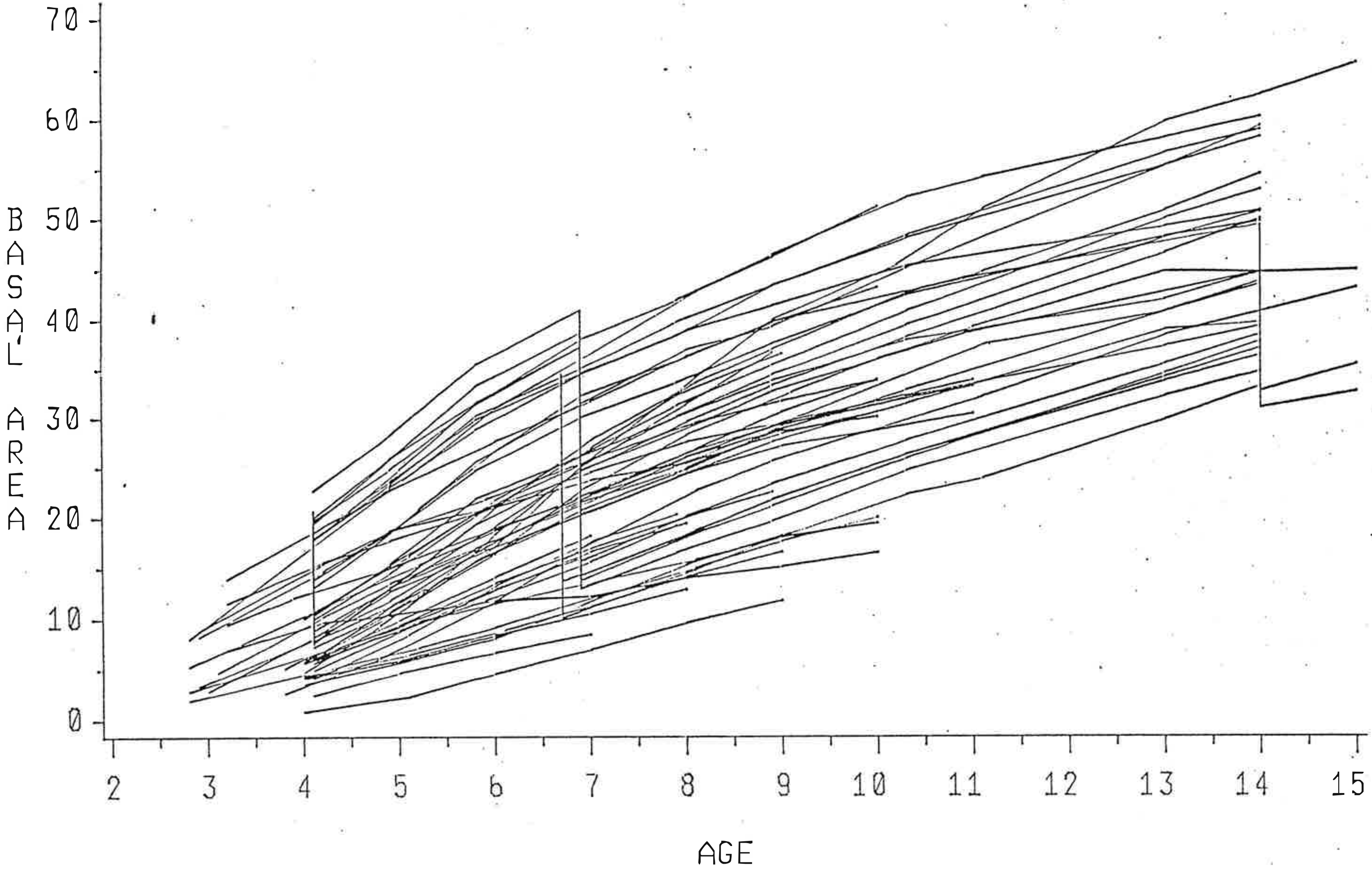

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