Forest Research Project Record

No. 6051

MODELLING the POSITION of the BRANCH PITH THROUGH TIME

M. BUDIANTO
J.C. GRACE

REPORT No. 65 April 1998

EXECUTIVE SUMMARY

The objective of the current study is to model the position of the branch pith through time. Two sets of data have been measured for this study: 16 trees from Compartment 905, and 13 trees from Experiment RO905 both in Kaingaroa forest.

Due to the detailed measurements required, it was only possible to sample a few trees. Hence the results will only be an indication of likely trends.

BACKGROUND TO DATA COLLECTION

STAND CHARACTERISTICS

COMPARTMENT 905

As part of a study of the influence of branch cluster frequency breeding values on mean internode length, Turner *et al* (1997) selected and measured 10 "crop" trees from each of ten control pollinated crosses in the "850" diallel that was planted in 1975. The parents of the trees in the "850" diallel were selected for multinodality.

The progeny within the 1975 "850" diallel were planted at 5m * 5m. At the same time filler trees were planted between the rows in one direction. However these trees were removed at a very young age and are unlikely to have had any influence on the branches still present on the trees. The current stocking is approximately 400 SPH. The trees were pruned to 6 m.

10 "crop" trees from progeny of each of 10 open-pollinated parents in the 1972 "870" uninodal progeny test were also randomly chosen and measured by Turner *et al* (1997). The parents of the trees in this trial were from an intensive selection for long internodes, and the families were chosen to cover the range in the branch cluster frequency breeding value present within the trial. The uninodal progeny trial was planted in 1972 at a spacing of 4m * 2m. The trial was thinned in 1978 and pruned to 2 m. The current stocking is now approximately 450 SPH.

For the current study, 16 trees measured by Turner *et al* (2 trees from each of 4 families in each experiment) were felled and intensively measured for branching characteristics. Table 1 shows the data summary of the sample trees collected by Turner *et al* from Compartment 905 in Kaingaroa forest. Details of this data collection is discussed by Grace *et al* (1998). A total of 271 sample branches were selected from the 16 sample trees. The measurements recorded for these sample branches are discussed under measurement techniques.

Table 1. List of sample trees from Compartment 905, Kaingaroa Forest.

Experiment	Family Code	Tree Number	DBH (cm)	MIL (m)
Diallel	M1	1	36.1	0.35
(Multinodal)		2	57.7	0.51
	M2	3	41.4	0.46
		4	46.0	0.34
	M3	5	32.9	0.35
		6	57.0	0.87
	M4	7	42.2	0.80
		8	52.4	0.35
Uninodal	U1	9	37.0	0.34
		10	48.6	0.71
	U2	11	29.0	0.64
		12	46.3	0.38
	U3	13	33.5	1.27
		14	49.3	0.48
	U4	15	29.2	0.64
		16	44.0	1.55

where DBH is Diameter at Breast Height (cm).
MIL is Mean Internode Length (m) between 6.3 m and 11.8 m.

EXPERIMENT RO905

13 trees from Experiment RO905, which was planted in 1967, were felled during summer 1996. The trial had an original stocking of 3086 SPH. A variety of thinning treatments were applied. Further details about data collection relating to the branching characteristics of these trees were discussed by Grace *et al.* (1996). Table 2 shows the thinning treatments for these 13 trees.

Table 2. Sample trees felled in Experiment RO905

Tree	DBH (cm) at time of felling	Year of thinning	Nominal stocking after thinning (stems/ha)
1	65.8	1974 and 1983	300 then 200
2	51.0	1974 and 1983	400 then 200
3	42.5	1974 and 1983	400 then 200
4	66.4	1979	200
5	53.5	1979	200
6	63.8	1979	200
7	54.8	1976	200
8	46.6	1976	400
9	33.8	1976	400
10	61.1	1974	200
11	54.4	1974	200
12	43.3	1974	400
13	33.8	1974	400

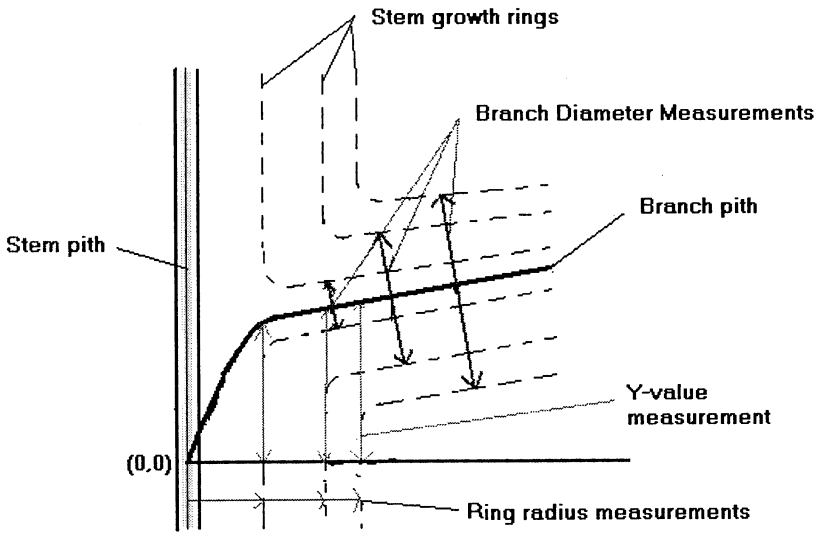
182 sample branches were selected from clusters formed either 2-5 years prior to thinning or after all treatments were completed.

MEASUREMENT TECHNIQUE

The selected sample branches were cut from the branch cluster, planed to expose both the branch and stem pith and then the following were measured:

- The radius of the stem at the end of each growth ring was measured along the line perpendicular between the centre of the stem pith and the point where the branch pith joints the stem pith as shown in Figure 1. The radii were collected in order to see if branch diameter growth was related to stem diameter growth.
- The branch diameter, perpendicular to the branch pith was measured for at least each year that the branch had grown. The branch diameter corresponding to the last stem growth ring was also measured. The point where these under-bark measurements were taken was just above any obvious swelling.
- Yvalue, the vertical distance from the end of a stem growth ring to the branch pith was measured for each growth ring. These data were collected to determine the change in branch pith (angle) over time.

Figure 1. Diagram showing how the Y-value , ring radius, and branch diameter were measured.



After preliminary analysis of the data, it was realised that in some instances the line drawn perpendicular to the stem pith was lower in Compartment 905 compared to Experiment RO905. The samples from Compartment 905 were checked again and the position of the line adjusted if necessary. This enabled the two sets of data to be combined in order to develop an overall model.

DATA ANALYSIS

MODEL BUILDING

The objective was to develop an equation to predict Yvalue. The data from each site were analysed separately and then combined to develop a general equation.

Jacobs (1938) identified a linear relationship between branch diameter and branch angle. Our observation of the branch samples clearly indicated that there was a curvilinear relationship between branch angle and branch age. The angle, $\frac{Yvalue}{Radius}$ is the tangent of the angle formed by a straight line joining the point (0,0) to the current position of the branch pith and the horizontal line (see Figure 1).

The measured variables which could be used to predict Yvalue are therefore:

- Radius
- Branch diameter
- Branch age

These 3 variables were found to have a high correlation with Yvalue as shown in Appendix 1.

Figure 2 shows the relationship between Yvalue and radius.
Figure 3 shows the relationship between Yvalue and branch diameter.
Figure 4 shows the relationship between Yvalue and branch age.
A quadratic trend line was also overlaid on each figure.

These graphs (Figures 2-4) indicate that the branch angle behaves non-linearly with respect to these variables. In each case there is a lot of scatter and little obvious difference between the two data sets.

Figure 5.1 shows the relationship between Yvalue and radius while Figure 5.2 shows the relationship between Yvalue and branch diameter for diallel (multinodal) and uninodal trials in Compartment 905. These figures indicate that there were no obvious differences in steepness between diallel (multinodal) and uninodal data hence the multinodal and uninodal data can be combined.

'BRANCH ANGLE' MODEL

From examining the above graphs, it was considered that the branch angle behaves non-linearly hence it was considered that the following was appropriate for predicting Yvalue:

$$Yvalue = a * radius^{\alpha} * bdiam^{\beta} * age^{\phi}$$

where: *bdiam* is the branch diameter of each stem growth ring in mm.
radius is the stem radius corresponding to the branch diameter in mm.
age is the age of the branch corresponding to the branch diameter in years.

It is possible that situations arise where one knows the stem radius and branch diameter but not age. Therefore the same model, but excluding age, was also fitted.

The residual mean square error from fitting these models to the data are shown in Table 3. For Compartment 905, the analysis did not differentiate the Uninodal and Multinodal trees as Figure 5 shows there was little difference.

Table 3. The Mean Square Errors from each model.

MSE	Compartment 905	Experiment RO905	Combined data
With variable 'Age'	339.786	626.087	507.771
Without variable 'Age'	352.323	626.404	518.183

As the variable age has a very small contribution to reducing the MSE, it was decided to select the model with radius and branch diameter only. This has a major advantage in applications in that we do not need to know the stem age.

Table 4. The mean bias and standard deviation on the Yvalue errors.

	Mean bias (mm)	Std. Deviation (mm)
General Model	0.48	22
Compartment 905	0.21	18.8
Experiment RO905	0.51	25

The following section will discuss output of the preferred model in detail.

OUTPUT

The models were examined by plotting the residuals against different variables. The residual in the estimated Yvalue was calculated as the actual minus the predicted.

COMPARTMENT 905

The fitted model: $Yvalue = 0.943539 * radius^{0.596503} * bdiam^{0.479030}$ was tested by calculating estimates of Yvalue on all branches.

The residuals were plotted against:

- Predicted Yvalue (Figure 7).
- Radius (Figure 8).
- Branch Diameter (Figure 9).
- Maximum Branch Diameter of a branch (Figure 10).
- Branch Age (Figure 11).

Figures 7-8 show Yvalue appears to be under-predicted for small values of radius, ie. when the branch is young (Fig 8). For figures 9-11, the residuals were grouped by a characteristic and the mean and confidence interval for each group calculated and shown. Figure 9-10 show Yvalue was over-predicted for larger branch diameters and for the larger branches. Most of the big residuals came from tree 15. In the field it was noted that tree 15 had several leader replacements during its life and clusters with leader replacement appeared to have steeper branches than "normal clusters". It is possible that these points are the main cause of the trend. Figure 11 shows a trend with branch age. Below 3rd year and above 11th year of branch growth ring the Yvalue is under-estimated.

84% of the predicted Yvalue of sample branches falls within ±3cm and 62% falls within ±2cm of the actual value for the last ring.

EXPERIMENT RO905

The fitted model: $Yvalue = 0.377702 * radius^{0.919032} * bdiam^{0.328992}$ was examined by plotting the residuals against

- Predicted Yvalue (Fig 12)
- Radius (Fig 13)
- Branch Diameter (Fig 14)
- Maximum Branch Diameter for the branch (Fig 15)
- Branch Age (Fig 16)

Figures 12-13 show Yvalue appears to be under-predicted for small values of radius, i.e when the branch is young (Figure 13). However the trend is not so obvious as in Compartment 905. Figures 12-13 also show that Yvalue was under-predicted for the steep branches, from trees 1, 2, 7, 8, and 13. Figures 14-16 show the mean and confidence interval for each group. In contrast to Compartment 905, there was not an obvious trend in the residuals with branch diameter or maximum branch diameter for the branch (Figures 14-15). The correlation analysis shows insignificant relationship of the residuals with branch diameter and maximum branch diameter (see Appendix 1). There was no obvious trend in the residuals with age for branches younger than 20 years. However Yvalue was underestimated for the branch growth ring above 21st year as shown in Figure 16.

73% of the predicted Yvalue of sample branches falls within ±3cm and 54% falls within ±2cm of the actual value for the last ring.

GENERAL MODEL

This model was built to incorporate the equation in the branch growth model. The model fitted to the combined data set $Yvalue = 0.512992 * radius^{0.818837} * bdiam^{0.367206}$ was examined by plotting the residuals against:

- Predicted Yvalue (Figure 17)
- Radius (Figure 18)
- Branch Diameter (Figure 19)
- Maximum Branch Diameter for the branch (Figure 20)
- Branch Age (Figure 21)

The steep branches from Experiment RO905 were still under-predicted (Figures 17-18). Yvalue of Compartment 905 was under-predicted on branch growth ring below the 4^{th} year (Figure 21).

58% of the predicted Yvalue of branches from Compartment 905 and 54% of the predicted Yvalue of branches from Experiment RO905 falls within ±2cm of the actual value for the last ring. For the 5^{th} ring, all of Yvalue from Compartment 905 and Experiment RO905 falls within ±2cm of the actual Yvalue.

GENERAL SUMMARY

Discussion

The general model shows the likely trend in Yvalue for trees in Kaingaroa forest. A few differences between the two trials were noted during data collection and analysis. The position of the line perpendicular to the stem pith was intended to be at the same point in both data sets. The point where the branch and stem pith join is however subjective. From initial analysis, it appeared that the join point was lower in Compartment 905 compared to Experiment RO905. This could have occurred for 2 reasons:

1. Both times the data were marked and measured as intended, but the difference is real.
2. The line was drawn lower in Compartment 905.

It was found that the second reason was true and the data adjusted where necessary.

However, the curves as shown in Figure 21 indicate that there are also differences between the 2 trials. The trends indicate that branches in Experiment RO905 have a flatter angle at an early stage and then curve downward. In Compartment 905 branches tended to curve upward at a steeper rate throughout the growth period.

To check the influence of stocking on Yvalue, Experiment RO905 data were categorised into 2 groups: branches formed before and after thinning. The original stocking for Experiment RO905 was 3000 SPH. The current stocking after 2 thinning treatments is 200-400 SPH. The correlation analysis showed no significant relationship between the residuals and the stocking groupings.

Yvalue for large branches tend to be over-predicted for large branches. The trace of branch pith over time tends to become flatter more quickly than predicted by the exponential/power model. Perhaps it is due to the weight of the foliage. We have considered alternative model formulations given in Ratkowsky (1990) that might account for this trend without success. One possibility was to fit a model with an upper asymptote like a logistic model, $y = \phi + \frac{\alpha}{1 + \exp(\beta - \theta X)}$ for fitting a sigmoidal response. However the disadvantage of this approach is the need to define an upper asymptote and the fact that cell branches would not have the same asymptote.

Fleming (1967) showed that the branch angle of *Pinus radiata* in the Australian Capital Territory tend to be steeper on the northern side than the southern side of the stem for different branch diameters. Fleming's finding reconfirmed previous studies done by Busgen and Munch (1929), Liese and Dadswell (1959) and Forestry Commission (1958) who studied the difference between north and south side on various parts of the tree crown.

Unfortunately, azimuth angle was not recorded for all sample branches and there were insufficient data to confirm whether branch angle varied with azimuth. This measurement has been planned to be included in the coming data collection.

The most appropriate models for predicting Yvalue through time are therefore:

Compartment 905 model:	$Yvalue = 0.943539 * radius^{0.596503} * bdiam^{0.479030}$
Experiment RO905 model:	$Yvalue = 0.377702 * radius^{0.919032} * bdiam^{0.328992}$
General model:	$Yvalue = 0.512992 * radius^{0.818837} * bdiam^{0.367206}$

Acknowledgments

Our thank to Andy Gordon and David Pont for their contribution in revising the initial drafts.

Our thanks to everyone who helped with the data collection.

Thanks to Forestry Corporation Limited/ Fletcher Challenge Forests Limited for allowing us to destructively sample the trees.

References

Busgen, M and Munch, E. 1929: The Structure and Life of Forest Trees. Chapman and Hall Ltd. London.

Fleming, J.M. 1967: Some characteristics of the crown and stem of *Pinus Radiata*. *Forestry and Timber Bureau Australia.* Bulletin no. 43.

Forestry Commission. 1958: Cultivation of the cricket bat willow. Bulletin 17. H.M. Stat. Office. London.

Grace, J.C; Lundgren, C; Blundell, W. 1996: Branching characteristics of radiata pine in Experiment RO 905: Data Collection. Stand Growth Modelling Report No. 52.

Grace, J.C.; Pont, D; Blundell, W; Duyvesteyn, D. 1998: Branching characteristics of radiata pine in Compartment 905, Kaingaroa: Data Collection.

Jacobs, M.R. 1938: Part 1 Observations on features which influence pruning. *Commonwealth Forestry Bureau.* Bulletin No. 23.

Liese, W And Dadswell, H.E. 1959: The influence of the cardinal points on the lengths of wood fibres and tracheids. *Holz Roh-u Werkstoff 17(11):421-7.*

Ratkowsky, D.A. 1990: Handbook of non-linear regression models. Marcel Dekker Inc.

Turner, J.A.; Carson, S.D; Manley, B.R; Grace, J.C; West. G.G. 1997: Genetic and site differences in *Pinus Radiata* internode length in New Zealand. Forest and Farm Plantation Management Cooperative Report no. 39.

Appendix 1 : Spearman Correlation Coefficients

Table 1: Rank Correlation matrix for Compartment 905

	YVAL	RADIUS	BDIAM	AGE	MAXD
YVAL	1.00000	0.76362	0.79843	0.66456	0.54973
RADIUS	0.76362	1.00000	0.55451	0.91969	0.19466
BDIAM	0.79843	0.55451	1.00000	0.40860	0.79090
AGE	0.66456	0.91969	0.40860	1.00000	0.02486
MAXD	0.54973	0.19466	0.79090	0.02486	1.00000

Table 2: Rank Correlation matrix for Experiment RO905

	YVAL	RADIUS	BDIAM	AGE	MAXD
YVAL	1.00000	0.87604	0.60196	0.81005	0.24806
RADIUS	0.87604	1.00000	0.46176	0.94433	0.06970
BDIAM	0.60196	0.46176	1.00000	0.37248	0.73646
AGE	0.81005	0.94433	0.37248	1.00000	-0.01697
MAXD	0.24806	0.06970	0.73646	-0.01697	1.00000

where:

- YVAL : Yvalue measurement as shown in figure 1.1
- RADIUS : Stem radius measurement as shown in figure 1.1
- BDIAM : Branch diameter measurement as shown in figure 1.1
- AGE : Branch growth ring number.
- MAXD : The largest branch diameter of the branch.

Appendix 2: Non-linear least squares summary

Dependent Variable: YVALUE. **Model:** $Yvalue = A \bullet Radius^{B} \bullet Bdiam^{C}$

Table 1: Statistics for the Compartment 905 model.

Source	DF	Sum of Squares	Mean Square
Regression	3	17357000.283	5785666.761
Residual	3129	1102419.717	352.323
Uncorrected Total	3132	18459420.000	
(Corrected Total)	3131	4476950.069	

Parameter	Estimates	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	0.9435379830	0.05555510412	0.83460789402	1.0524680719
B	0.5965027905	0.01368663373	0.56966662025	0.6233389606
C	0.4780300091	0.01071620513	0.45701812913	0.4990418890

Table 2: Statistics for the Experiment RO905 model.

Source	DF	Sum of Squares	Mean Square
Regression	3	15418067.100	5139355.700
Residual	2208	1383100.900	626.404
Uncorrected Total	2211	16801168.000	
(Corrected Total)	2210	5019478.989	

Parameter	Estimates	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	0.3777024308	0.03480040351	0.30945627512	0.44594858655
B	0.9190317330	0.01635028706	0.88696761520	0.95109585076
C	0.3289920187	0.01491649114	0.29973968039	0.35824435701

Table 3: Statistics for the general model.

Source	DF	Sum of Squares	Mean Square
Regression	3	30909110.285	10303036.762
Residual	5038	2610604.715	518.183
Uncorrected Total	5041	33519715.000	
(Corrected Total)	5040	9229394.503	

Parameter	Estimates	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
A	0.5129915838	0.02852082422	0.45707735151	0.56890581600
B	0.8188367436	0.01110023729	0.79707505670	0.84059843043
C	0.3672060737	0.00892807983	0.34970283725	0.38470931007

Figure 2. Relationship between Yvalue and stem radius
Kaingaroa forest

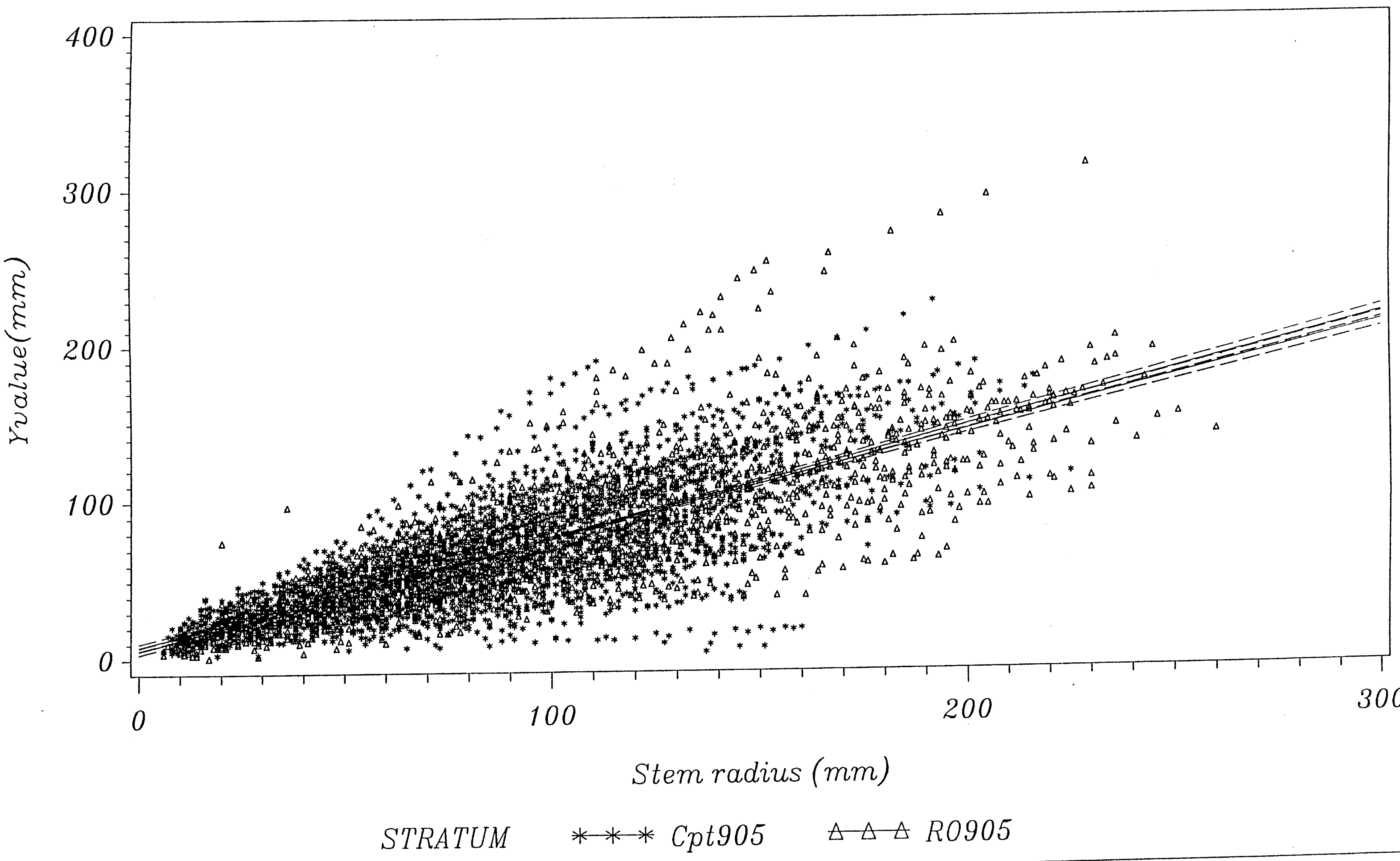


Figure 3. Relationship between Yvalue and branch diameter

Kaingaroa forest

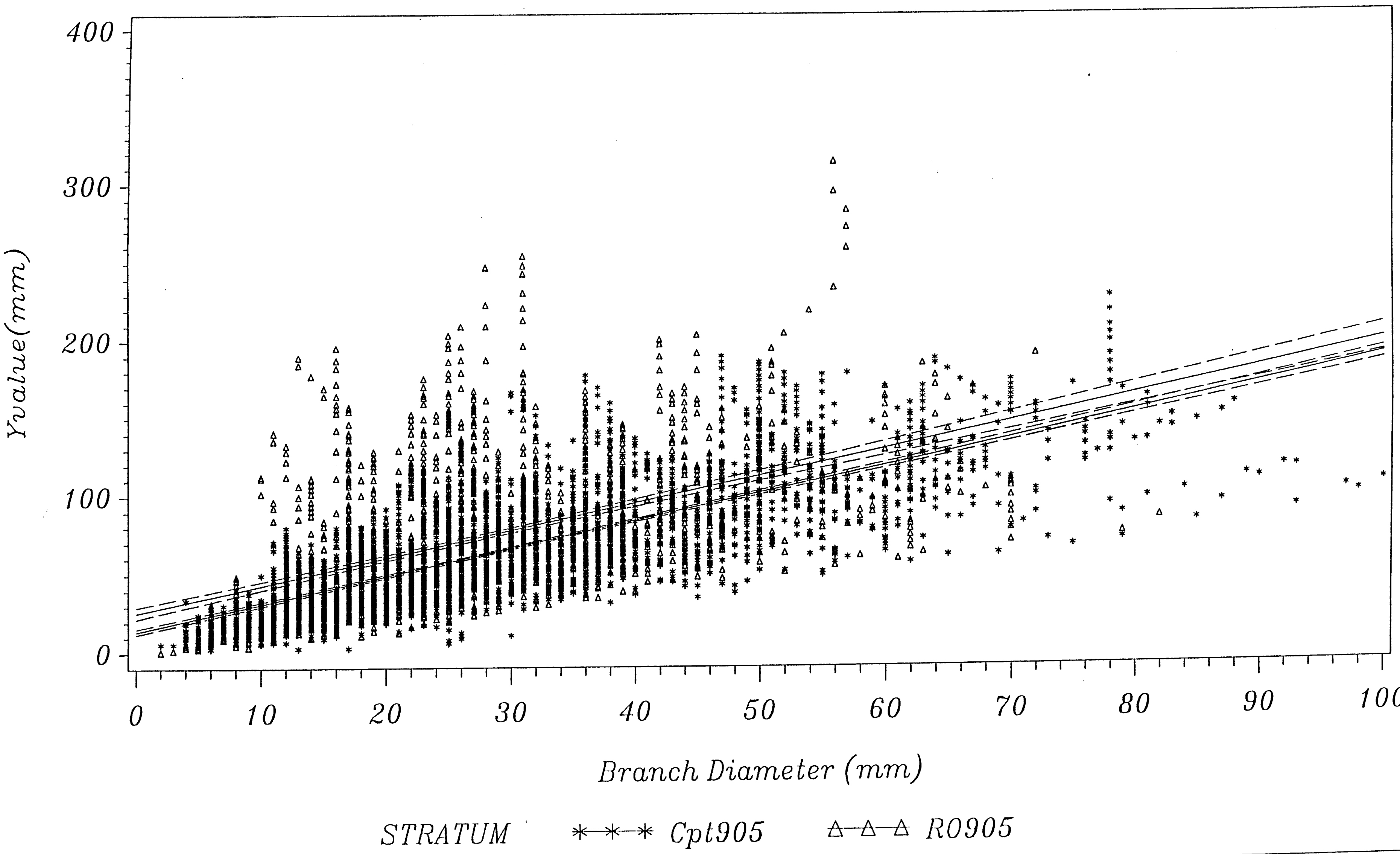


Figure 4. Relationship between Yvalue and branch age

Kaingaroa forest

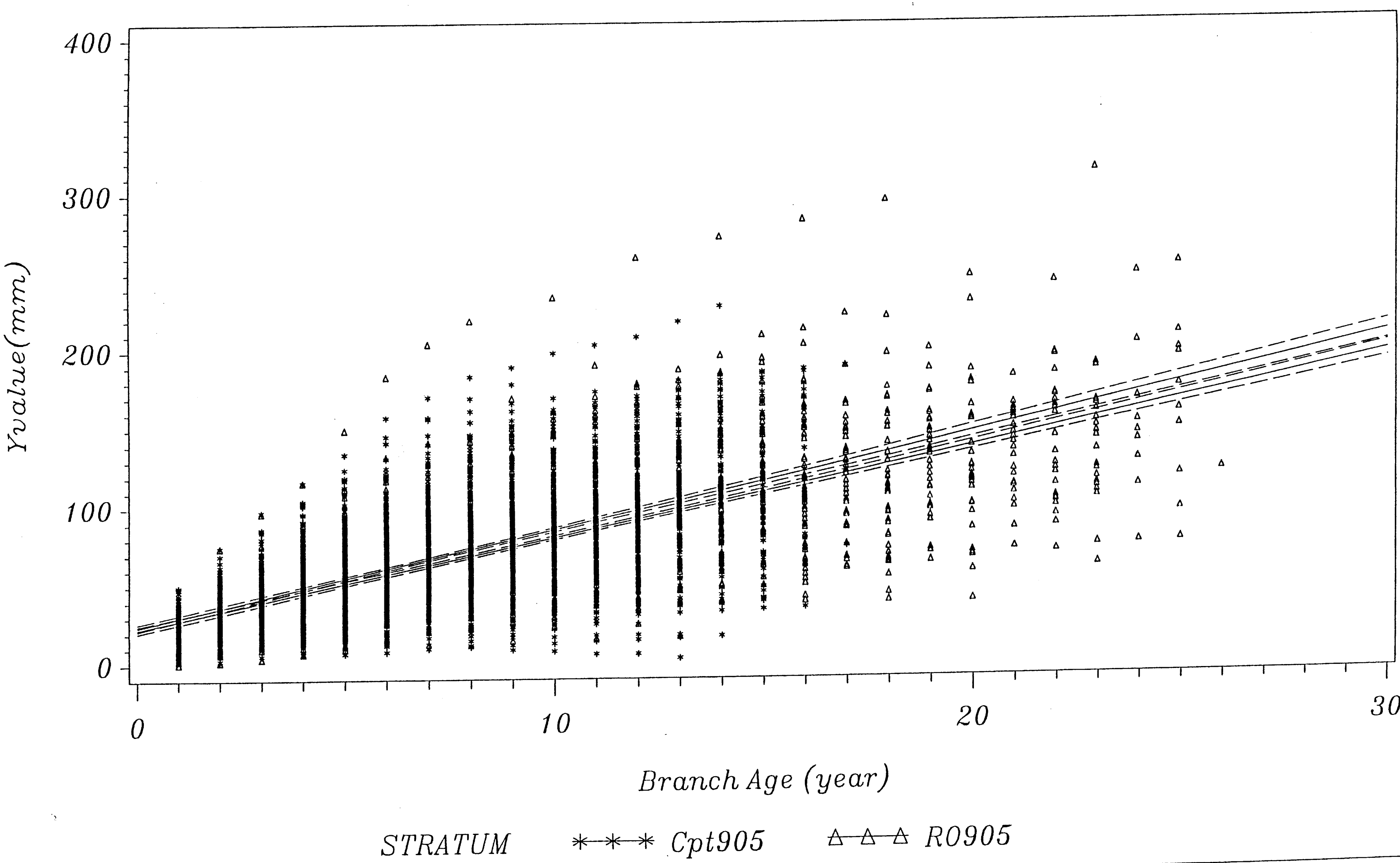


Figure 5.1 Relationship between Yvalue and Stem Radius

Compartment 905

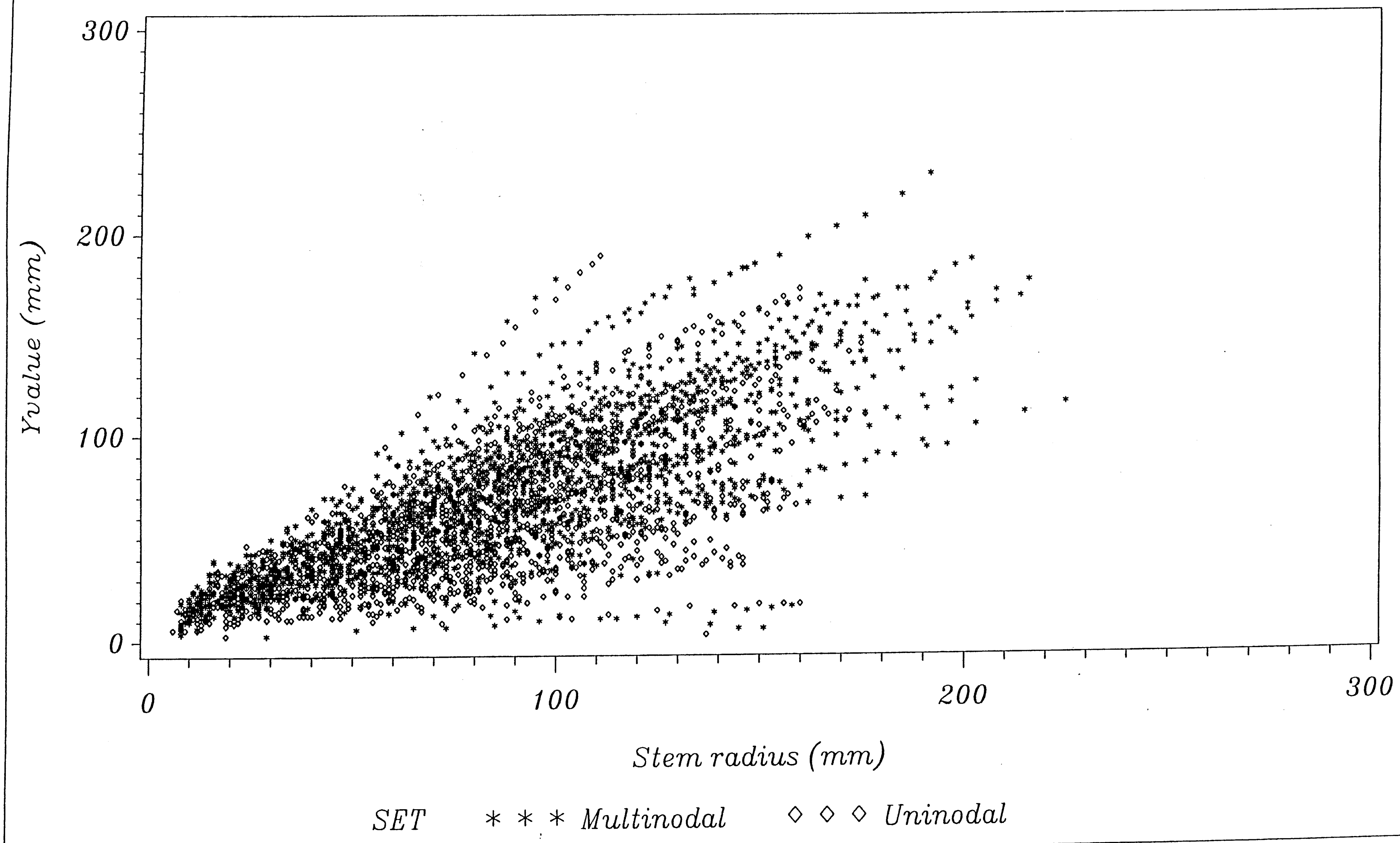


Figure 5.2 Relationship between Yvalue and Branch Diameter

Compartment 905

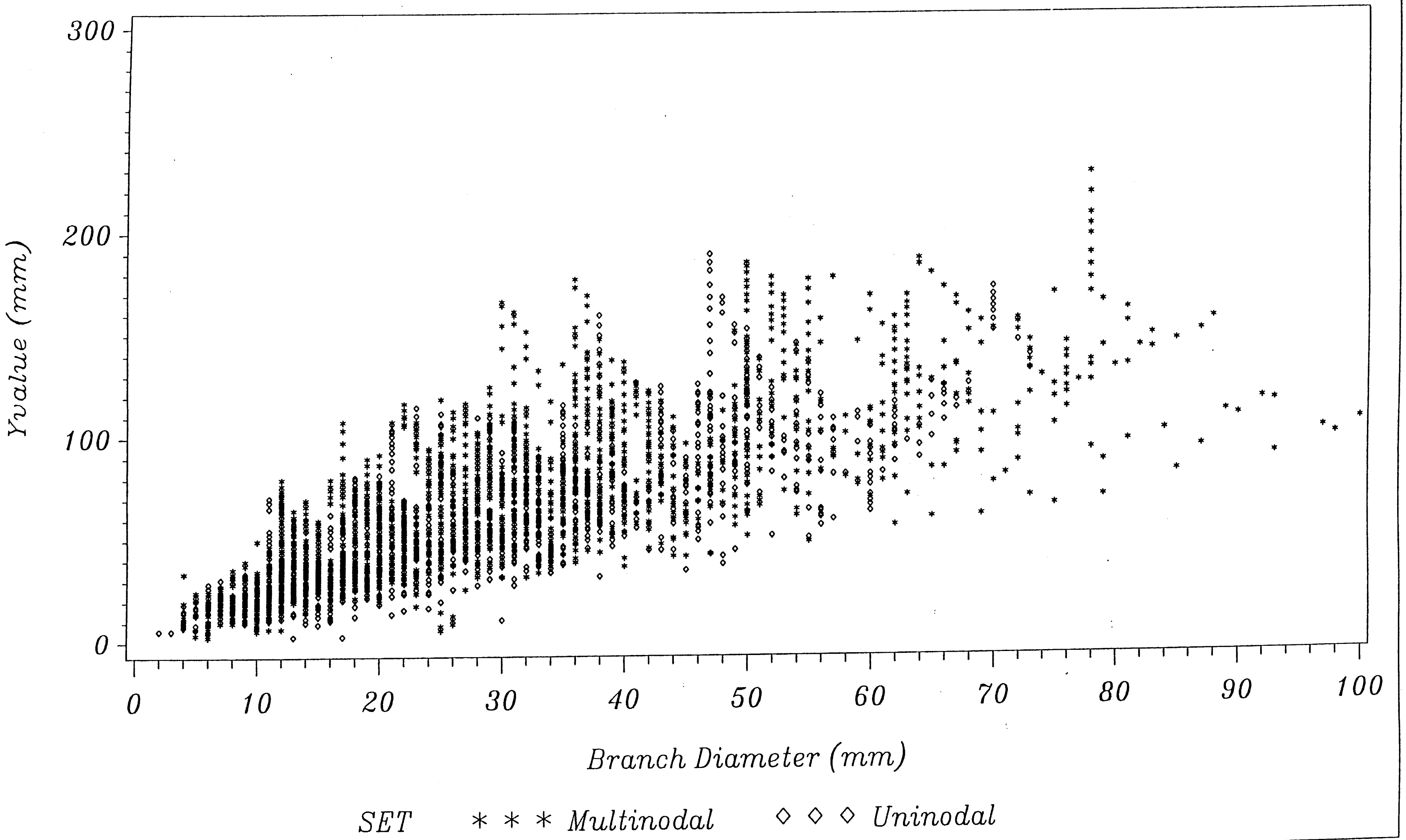


Figure 6. Sample branches from tree 9
Compartment 905

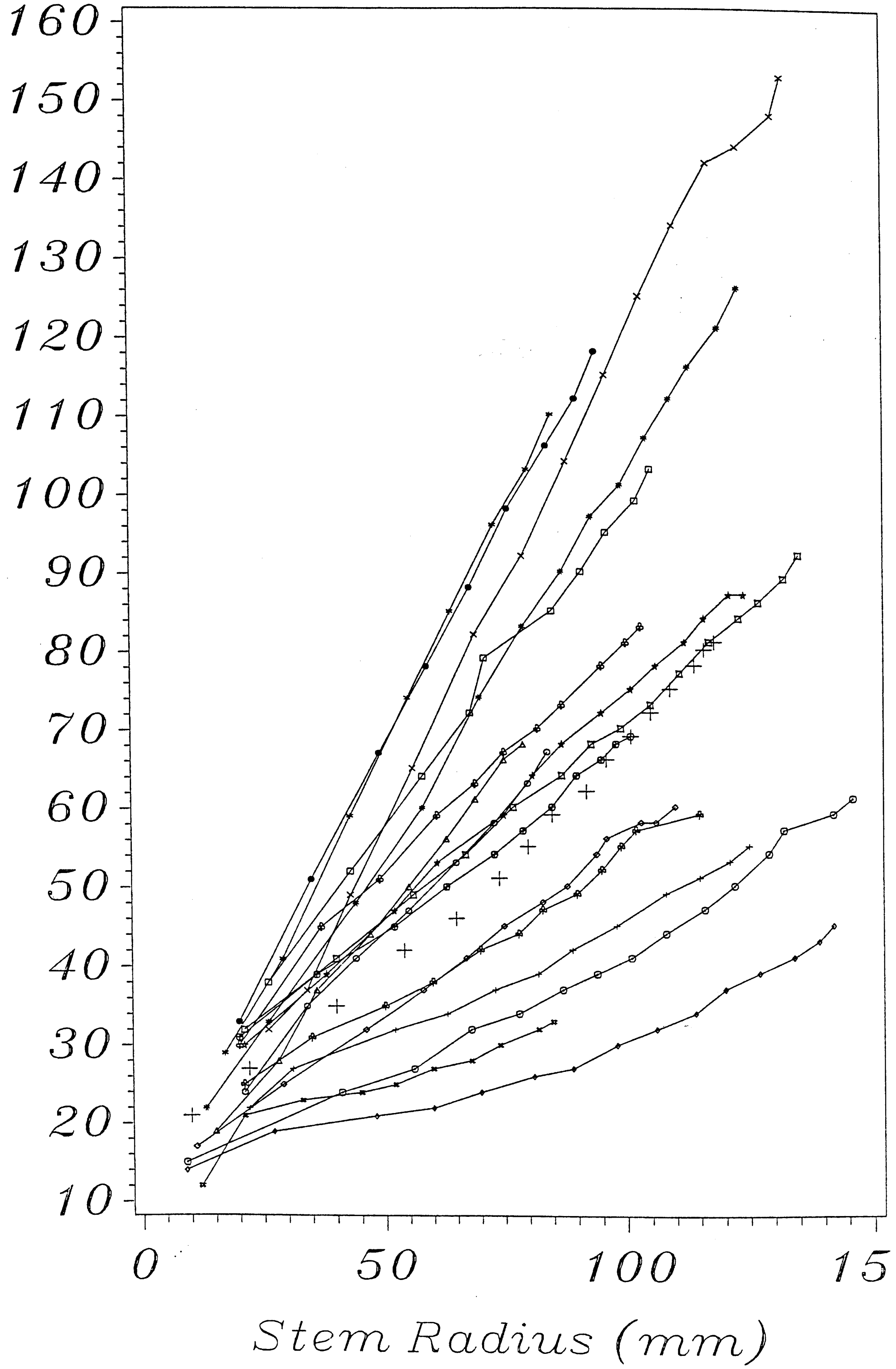


Figure 7. Residual vs Predicted Yvalue

Compartment 905

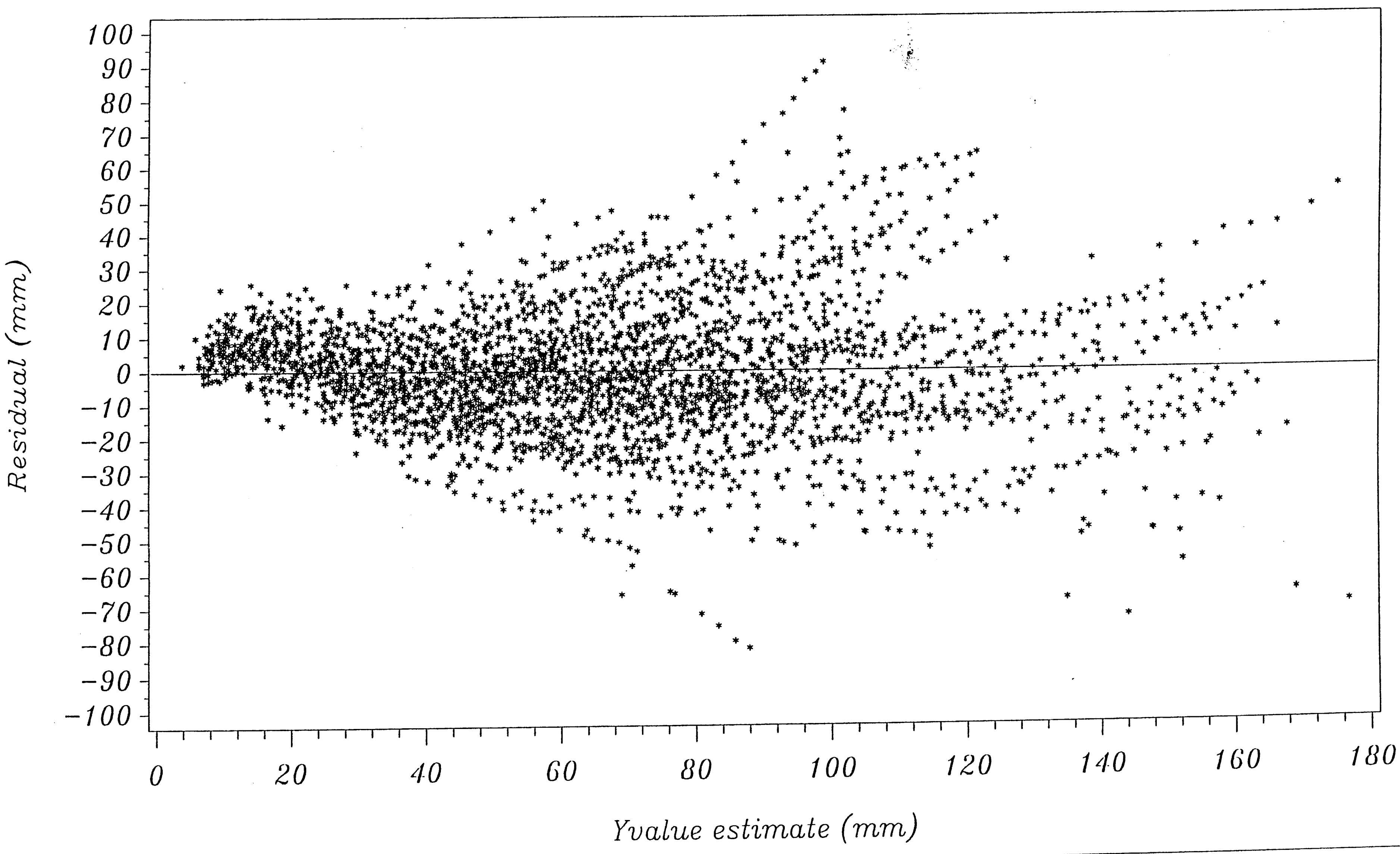


Figure 8. Residual vs Stem Radius
Compartment 905

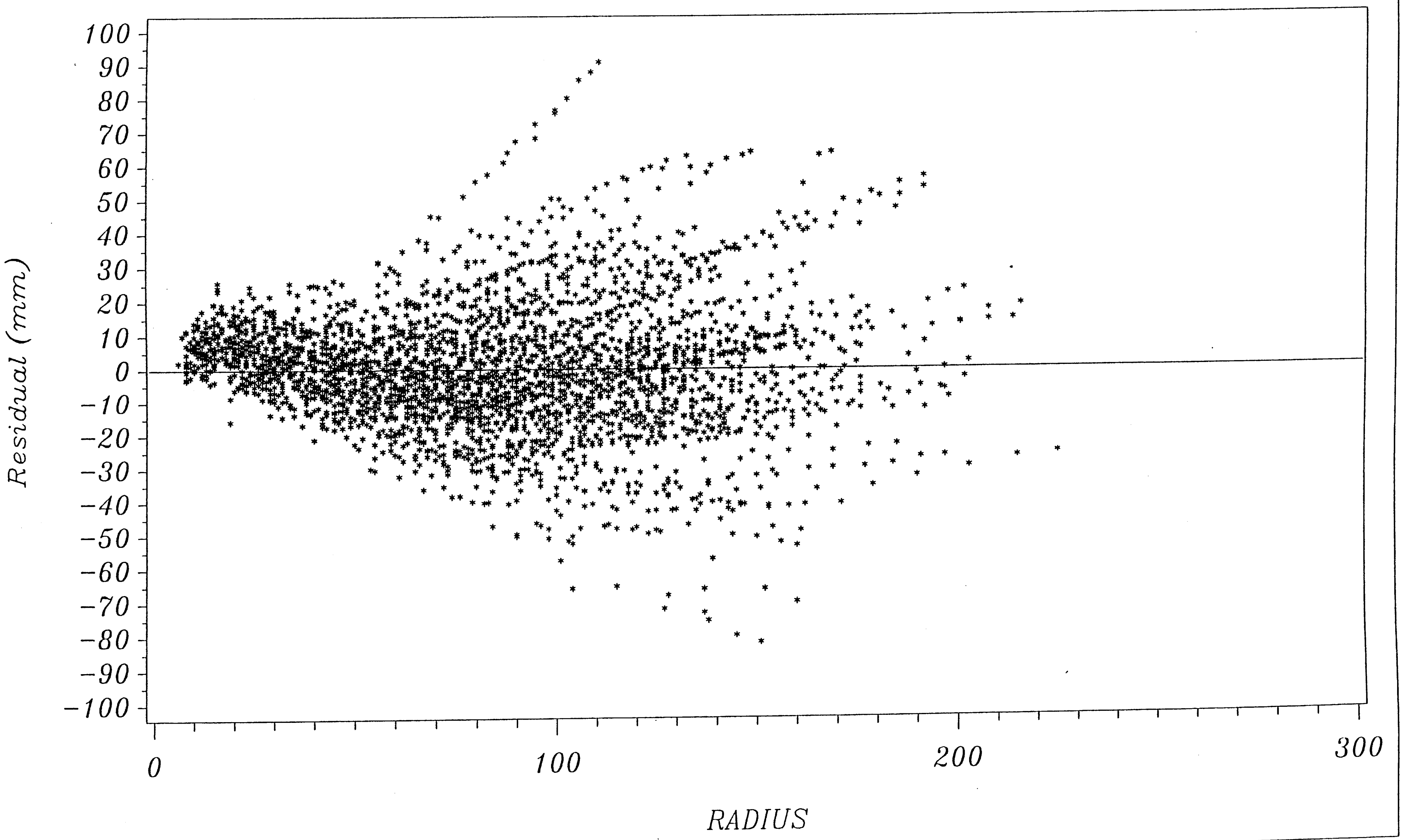


Figure 9. Residual vs Branch Diameter

Compartment 905

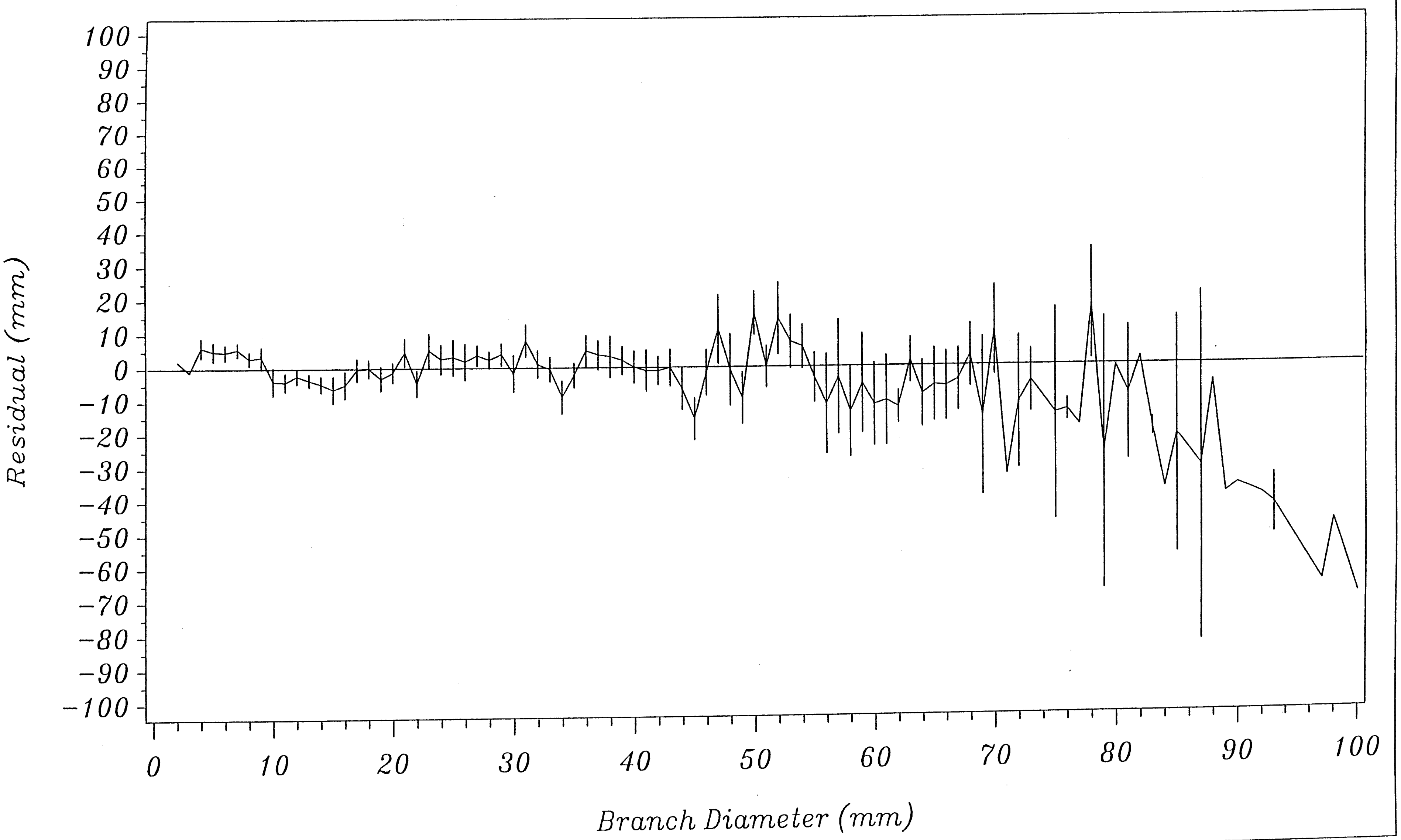


Figure 10. Residual vs Maximum Branch Diameter
Compartment 905

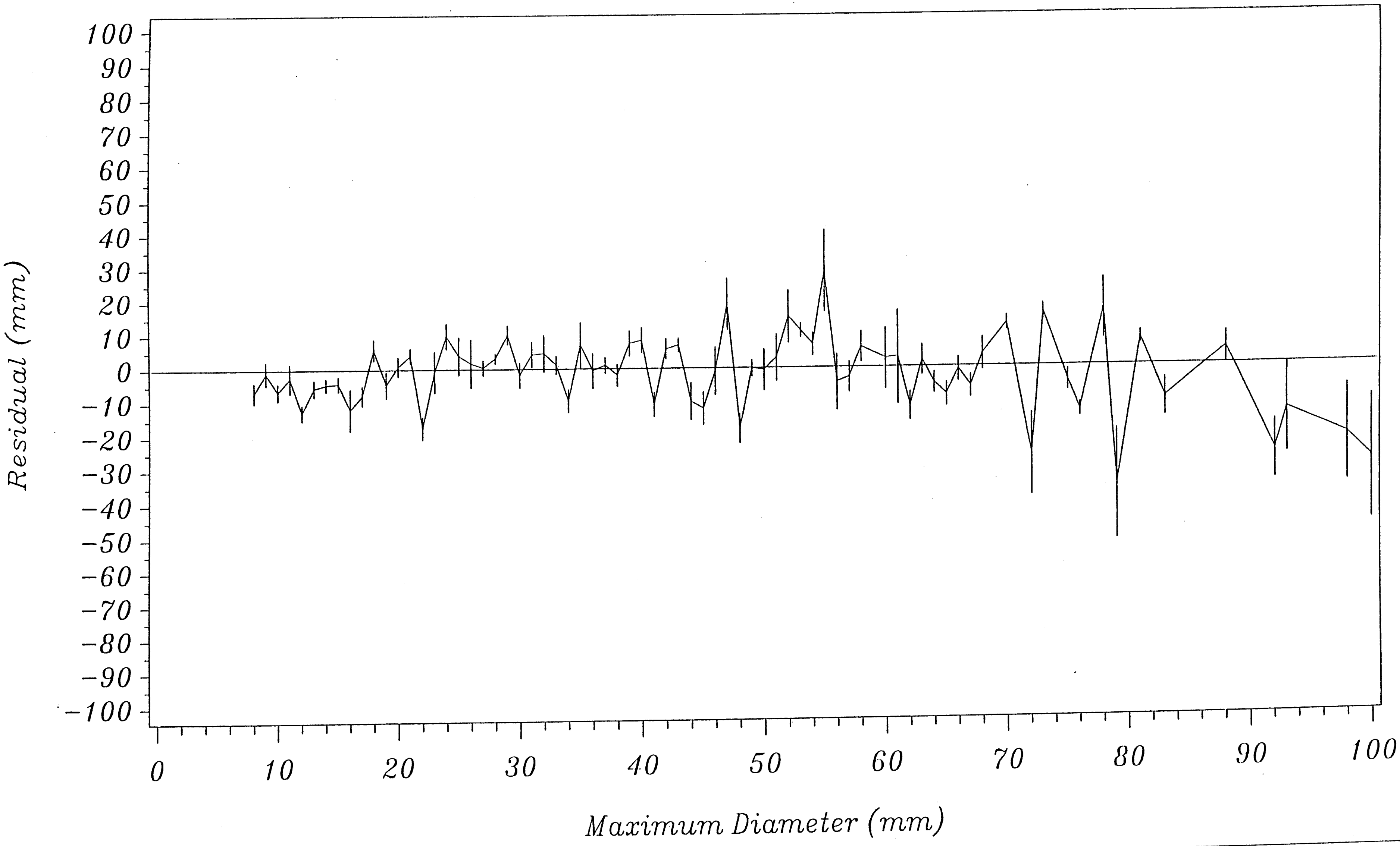


Figure 11. Residual vs Branch Age

Compartment 905

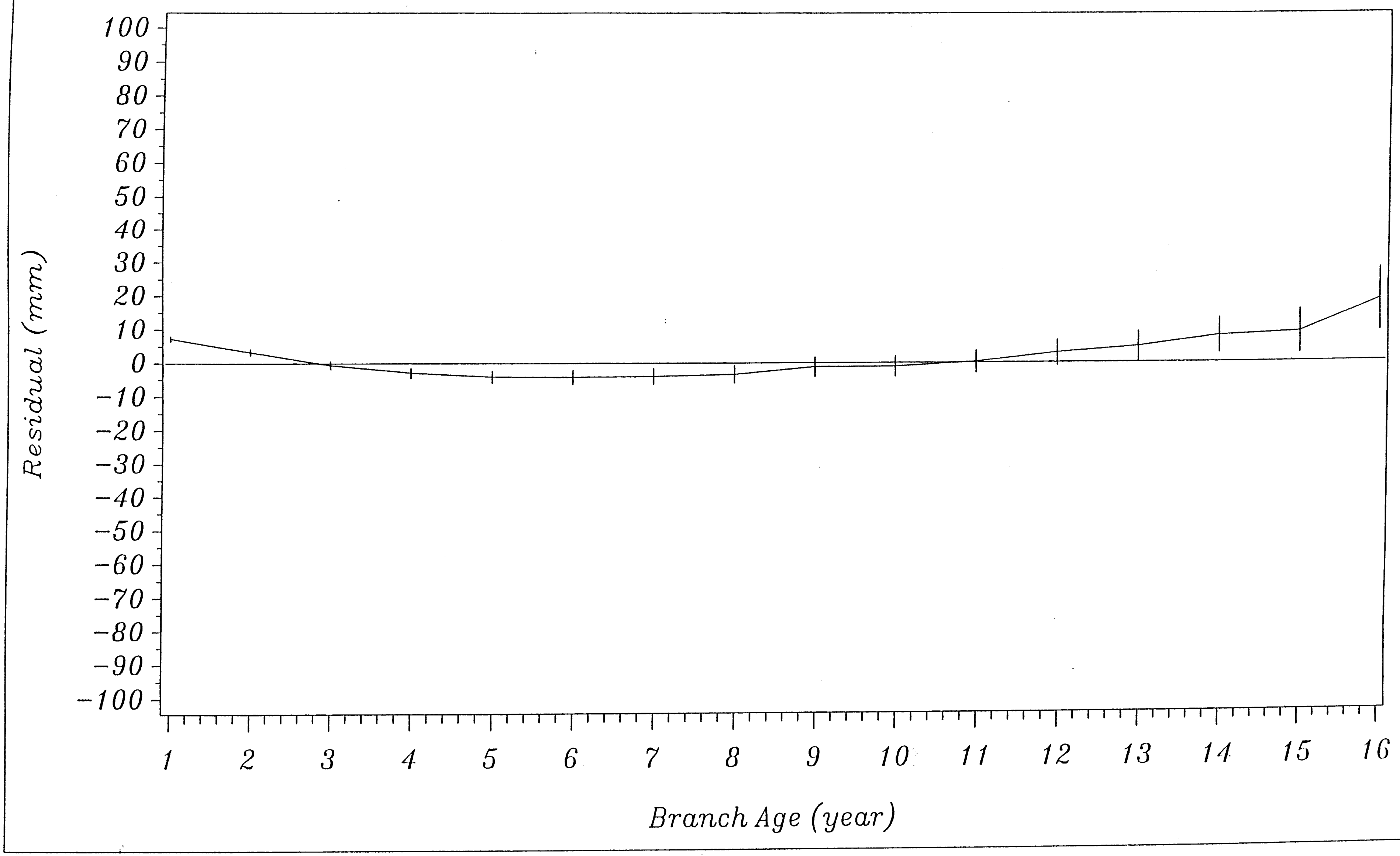


Figure 12. Residual vs Predicted Yvalue

Experiment R0905

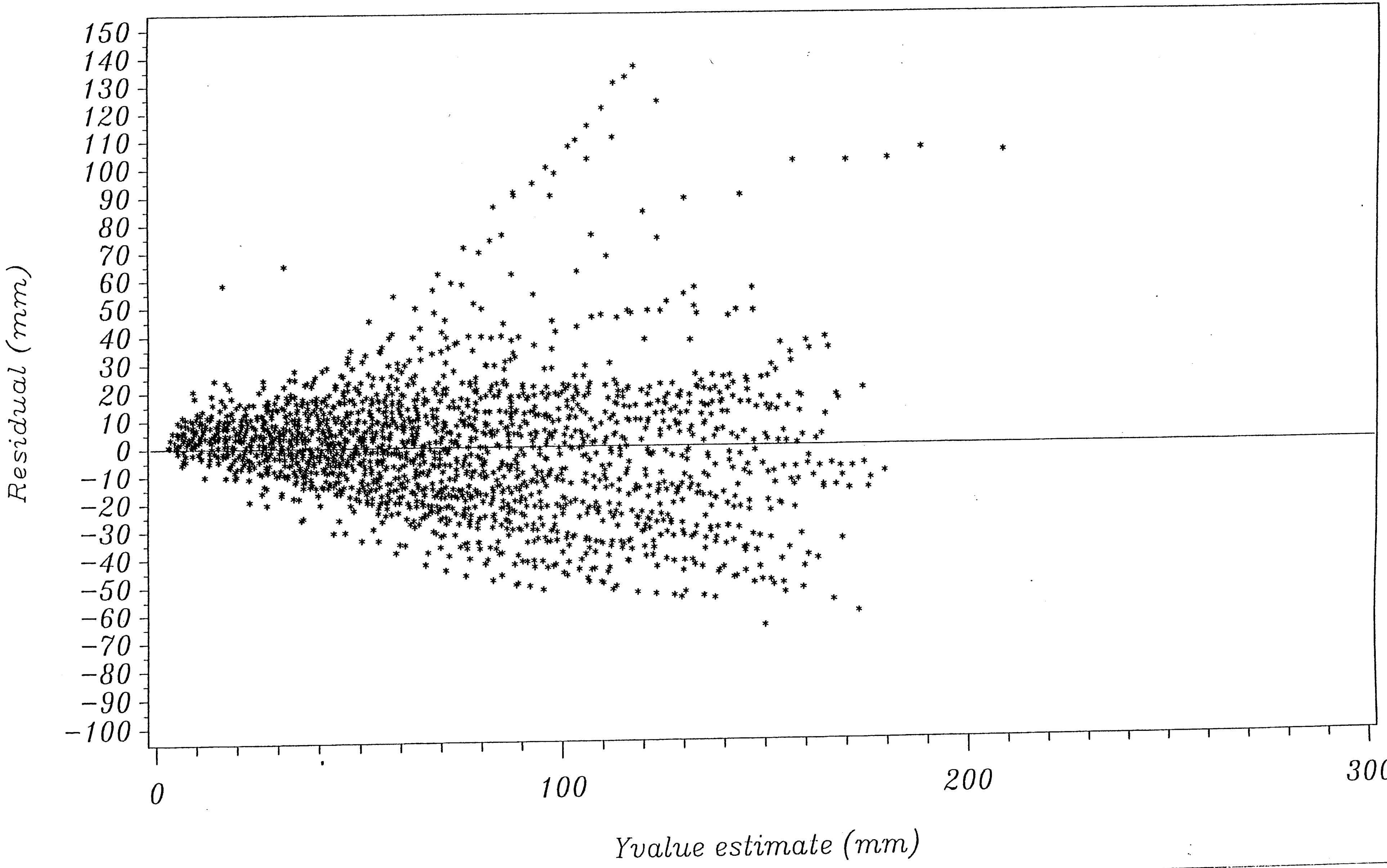


Figure 13. Residual vs Stem Radius

Experiment R0905

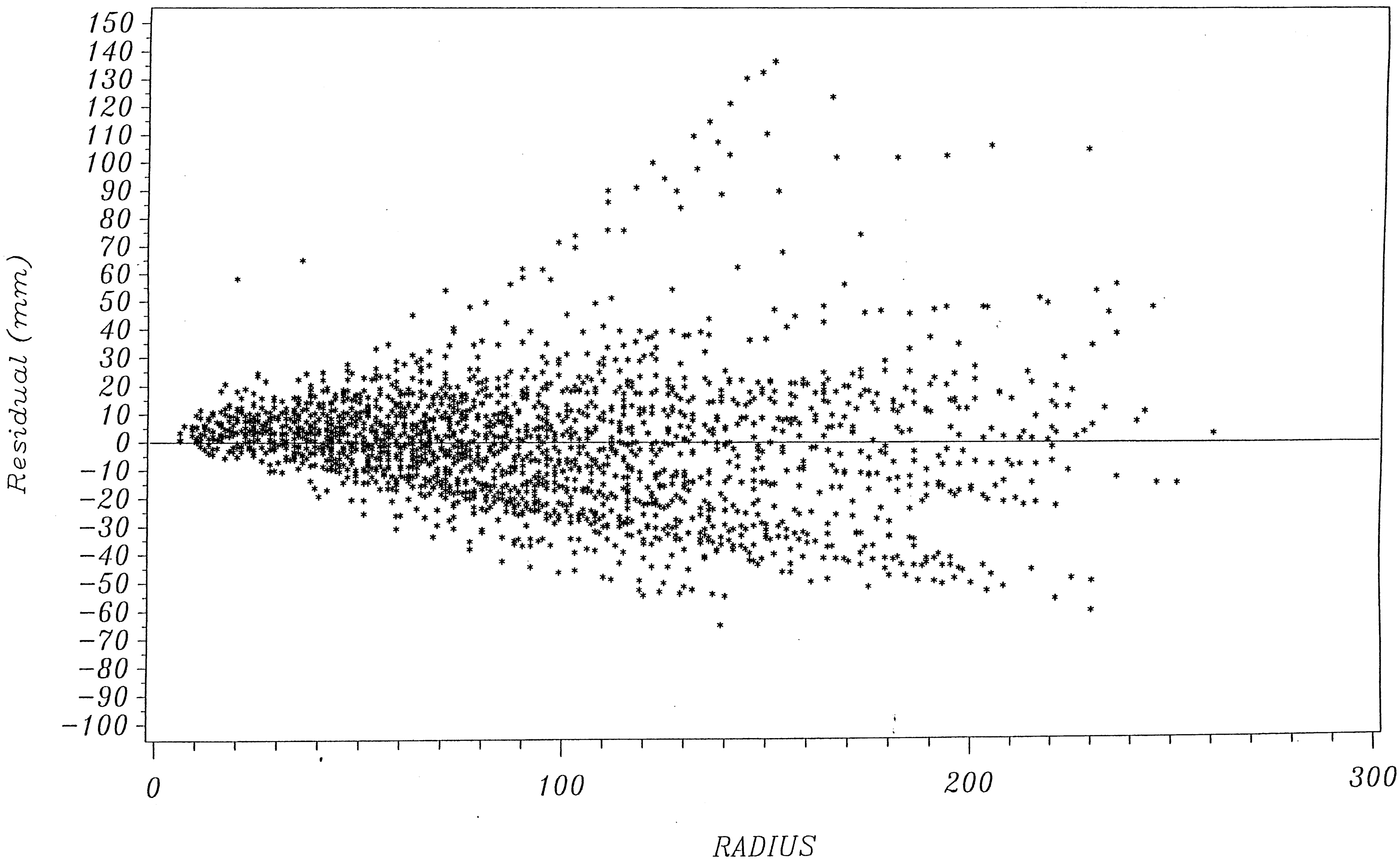


Figure 14. Residual vs Branch Diameter
Experiment R0905

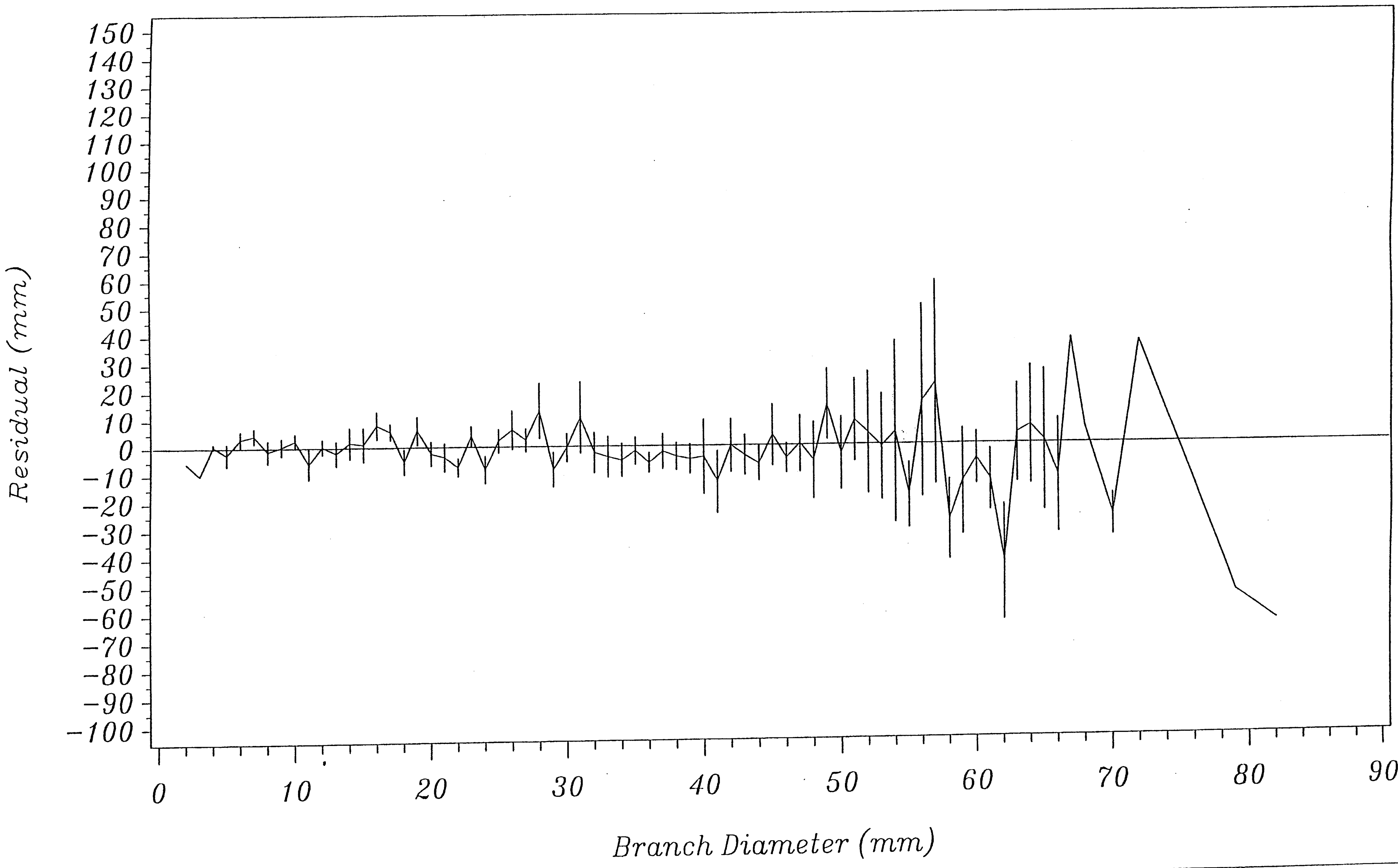


Figure 15. Residual vs Maximum Branch Diameter

Experiment R0905

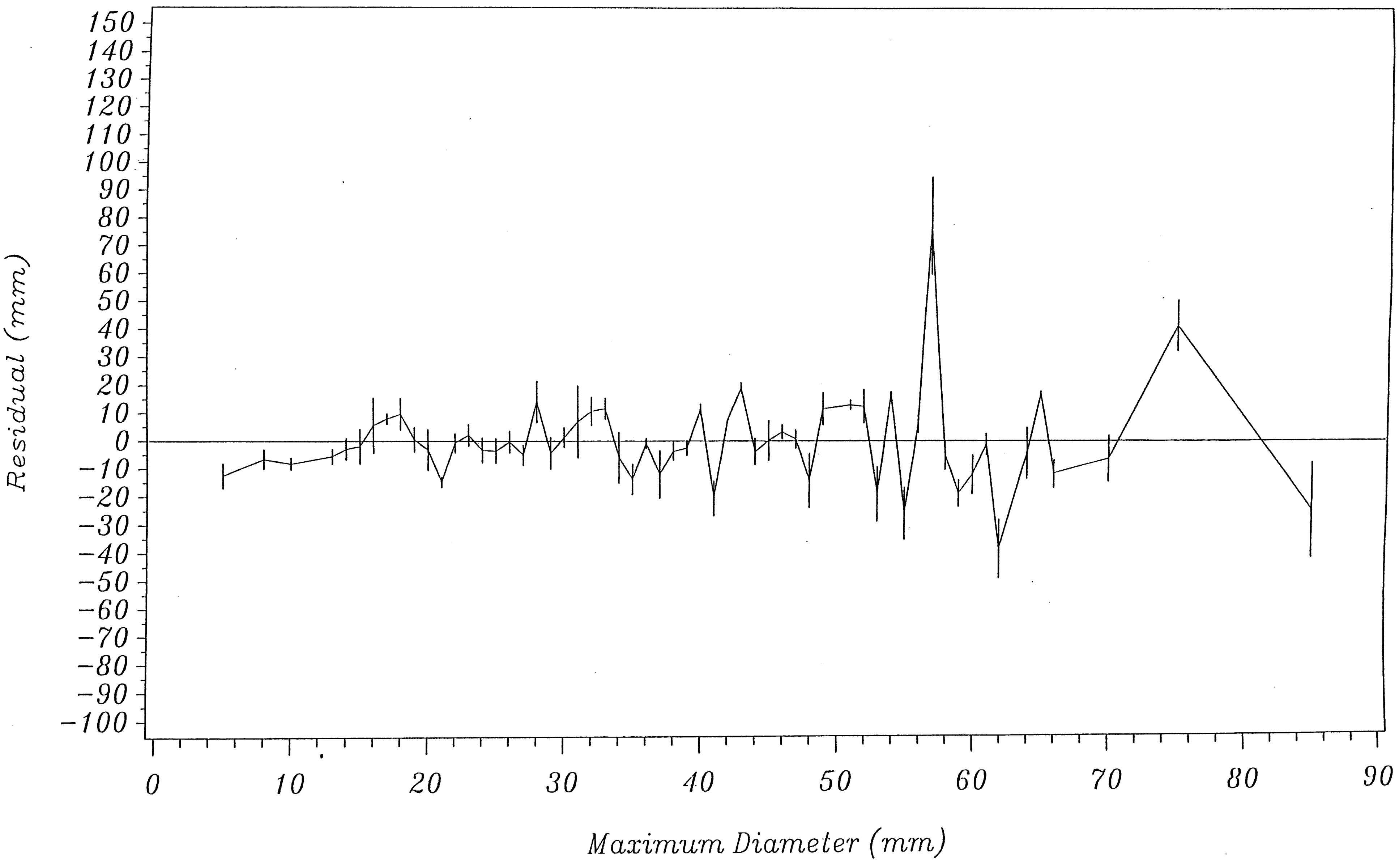


Figure 16. Residual vs Branch Age
Experiment R0905

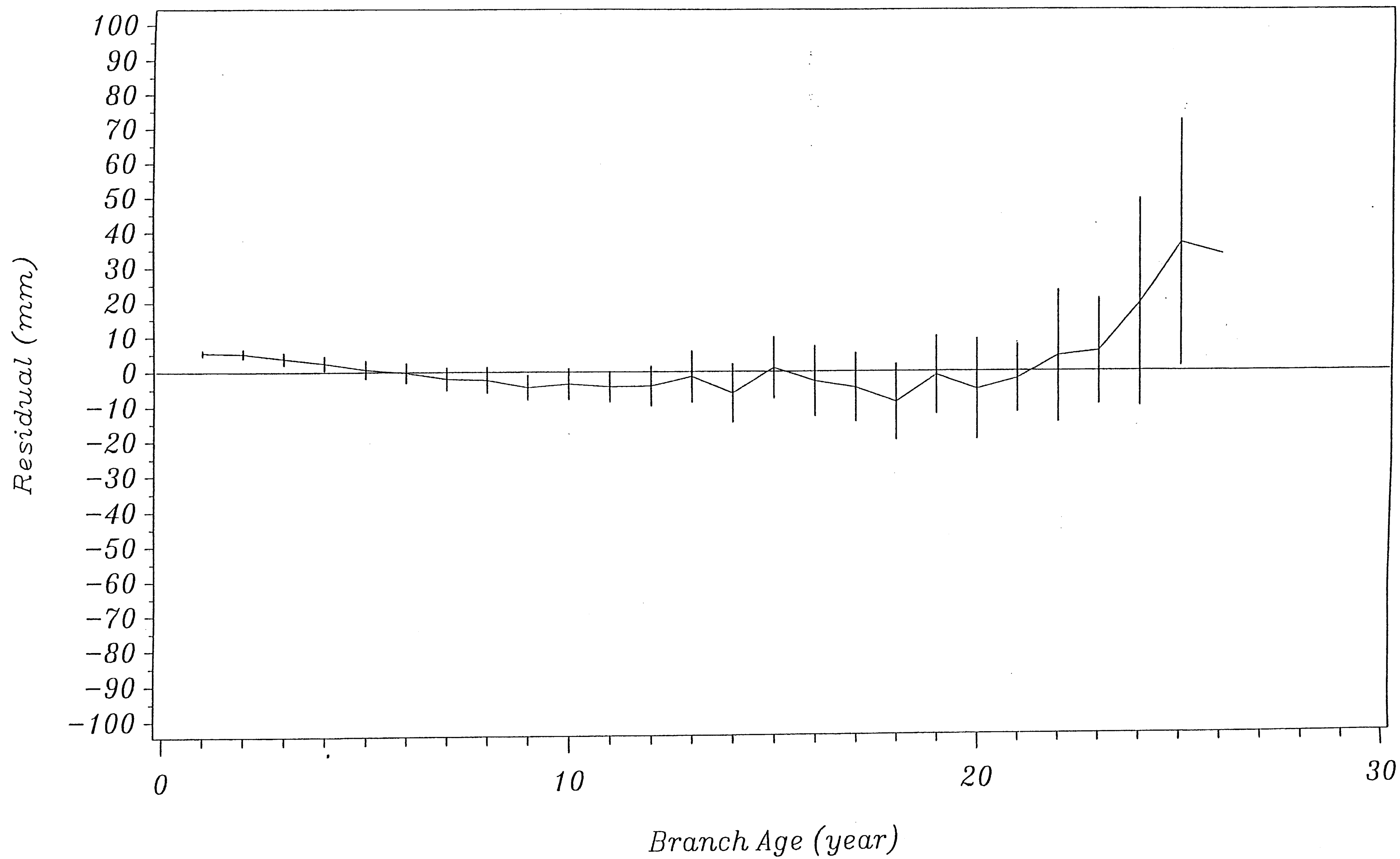


Figure 17. Residual vs Predicted Yvalue

Combined data

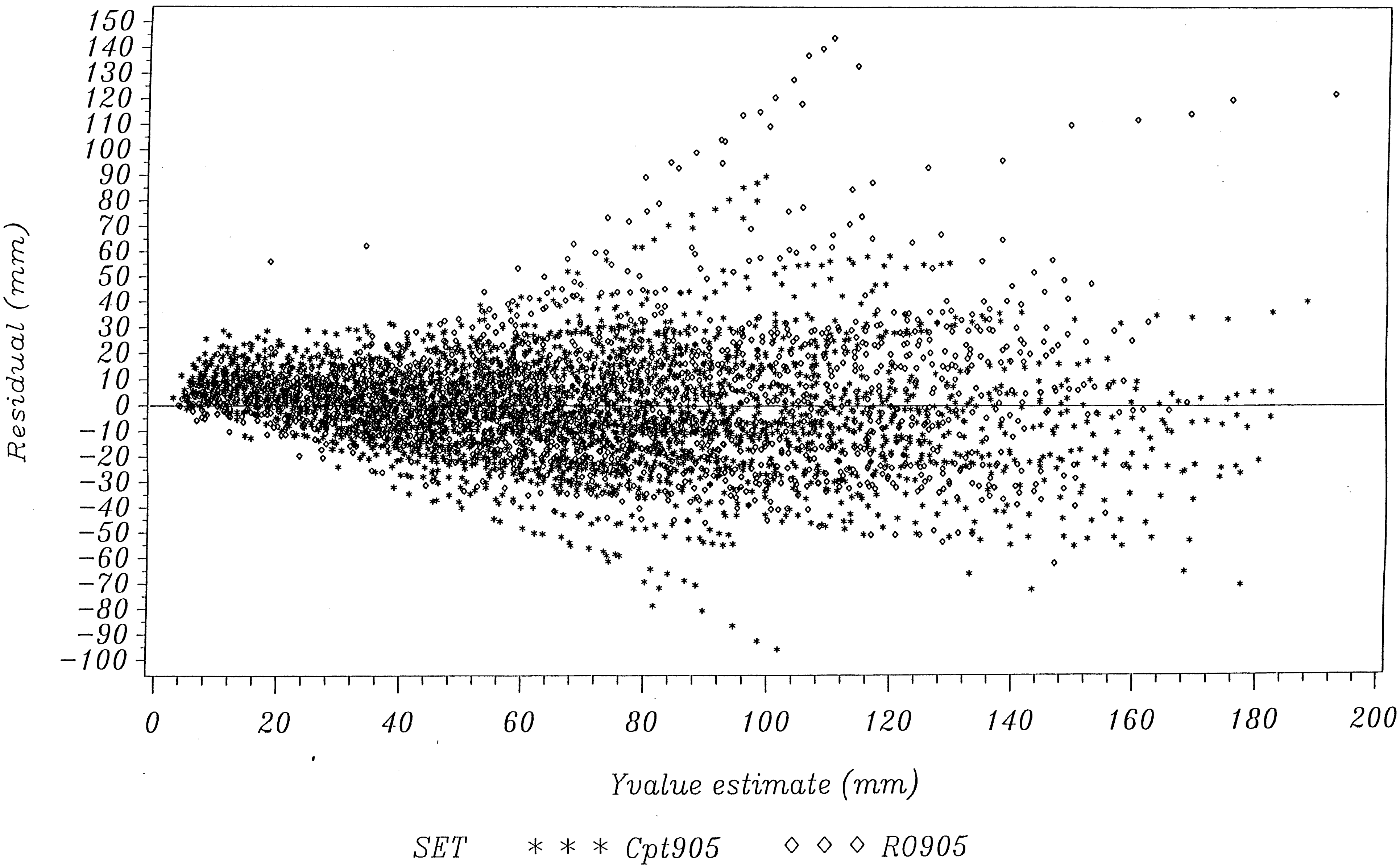


Figure 18. Residual vs Stem Radius

Combined data

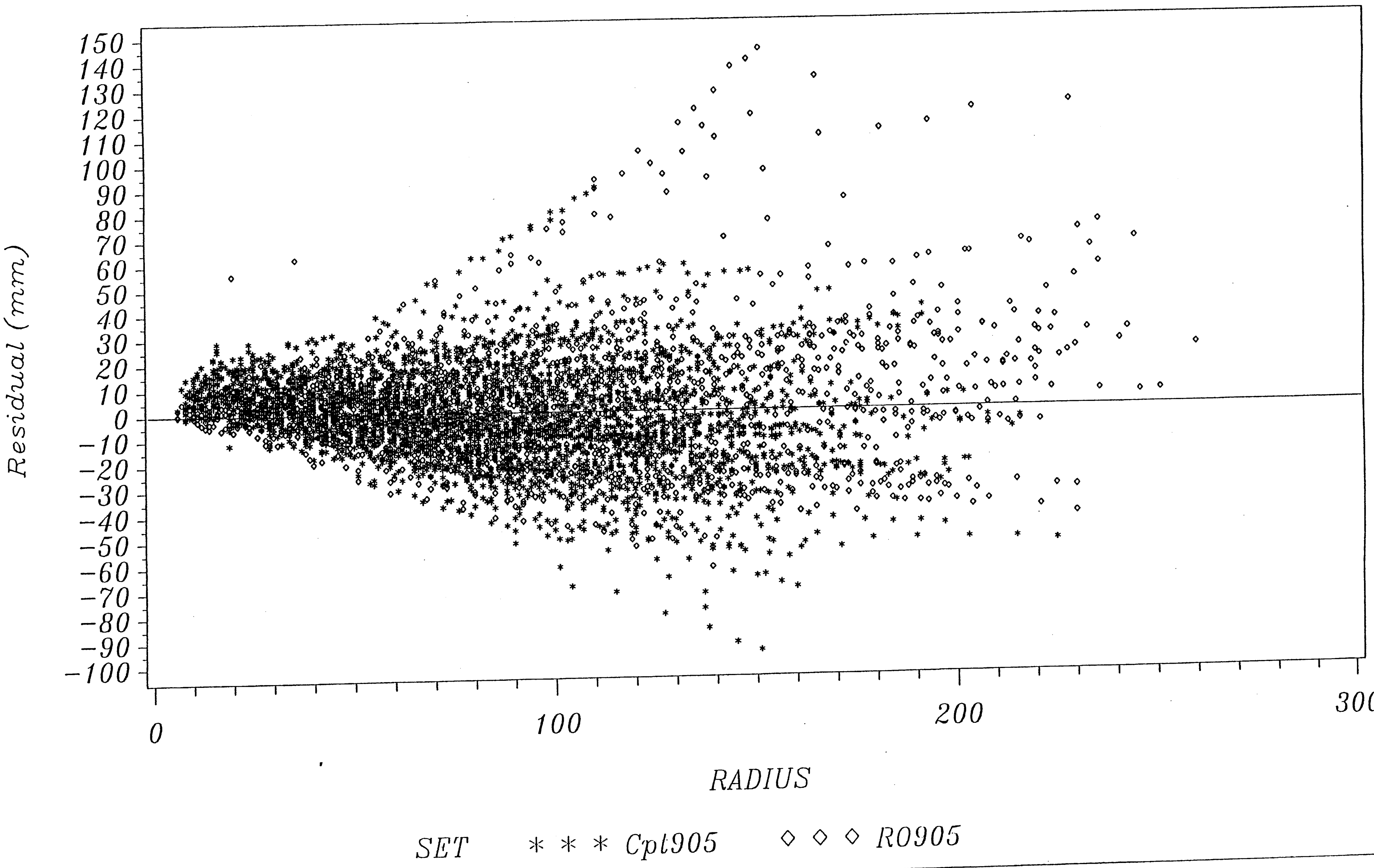


Figure 19. Residual vs Branch Diameter

Combined data

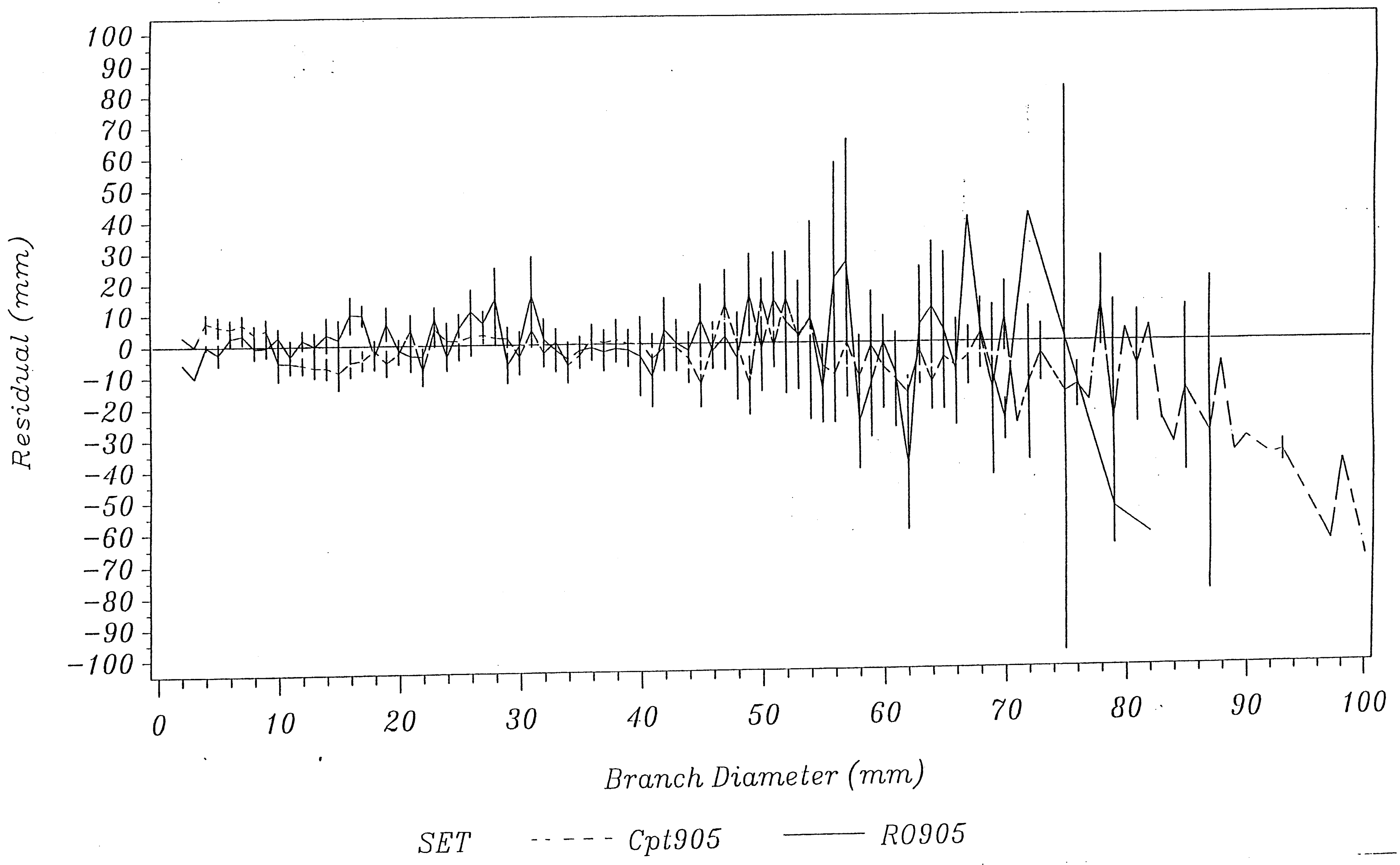


Figure 20. Residual vs Maximum Branch Diameter

Combined data

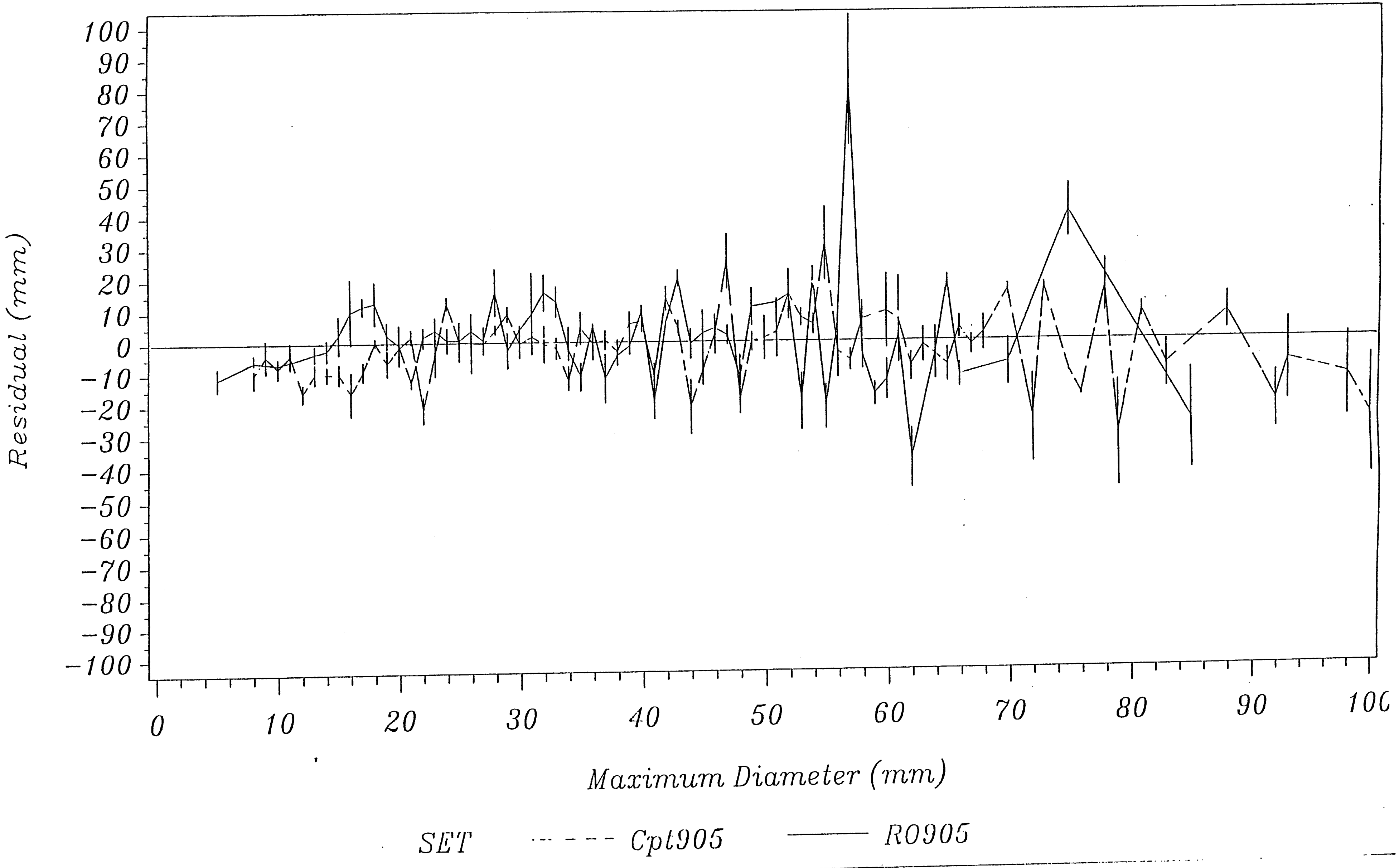


Figure 21. Residual vs Branch Age
Combined data