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INFLUENCE OF THINNING ON BRANCH DIAMETER DISTRIBUTIONS AND BRANCH GROWTH

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EXECUTIVE SUMMARY

To understand the influence of thinning on branch diameter growth, two separate analyses have been carried out.

The first analysis examined branch diameter growth for 81 individual branches formed 2 - 5 years prior to thinning. The response of branch diameter growth to thinning was classified into four groups:

little or no growth after thinning
increased diameter growth in the 2nd year after thinning
increased diameter growth in the year after thinning
diameter growth continues with no obvious response to thinning

The larger younger branches on the more dominant trees were able to respond to thinning through increased diameter growth. Diameter growth continued with no obvious response on the largest and youngest branches on the most dominant trees.

The second analysis examined the branch diameter distribution for different sections of a tree stem. The stem sections were selected according to tree age in a stocking trial, and according to the time of thinning and the likely effects on branch diameter growth in a timing of thinning / stocking trial.

The diameter of the larger branches in the distribution did not change much with age when the nominal stocking remained constant, indicating that any changes observed in the thinning trial are likely to be due to the thinning. In the timing of thinning / stocking trial, the diameter of the larger branches in the distribution increased due to thinning on the larger-diameter trees but not the smaller-diameter trees.

The two sets of results are compatible. They will be used to develop a model to predict branch diameter increment from current branch diameter.

BRANCH DIAMETER DISTRIBUTIONS FOR STEM SECTIONS

INTRODUCTION

Within the branch growth model, functions have been developed to predict the maximum branch diameter in a cluster, and the diameter of the other branches in the cluster as a function of this maximum (Grace, 1996). However, there was a lot of variability in both the maximum branch diameter per cluster, and the relative diameter of branches within a cluster.

As a first step in examining the influence of thinning on branch diameter, it was decided to investigate the variability in branch diameter distribution for sections of the stem. These sections were chosen in relation to the time and the likely effect of thinning on branch diameter growth.

In this report, data from the timing of thinning and spacing trial (RO905) is analysed to determine whether thinning has affected branch diameter distribution in different sections of the stem.

As a comparison, data from the spacing trial (RO696) is analysed to determine whether distributions are likely to vary with age when the nominal stocking remains constant. Previous analyses (Grace, 1996) indicated that maximum branch diameter per cluster was unlikely to vary with age when the nominal stocking remained constant.

EXPERIMENT RO905 - TIMING OF THINNING AND SPACING TRIAL

METHODS

Experiment RO905 was planted in 1967 at a spacing of 1.8 m x 1.8 m (3086 stems/ha). Plots 20 m x 40 m were established in 1970 and a variety of thinning treatments applied in subsequent years. During summer 1996, 13 sample trees were chosen, based on tree DBH within selected treatments, and felled. These trees are listed Table 1. Further details on the selection process are given in Grace *et al.* (1996).

Table 1. 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	1976	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

Current branch diameter was measured for every branch in each cluster formed prior to and for at least three years after thinning. After that branch diameters were measured on alternate annual shoots. (see Grace *et al.* (1996) for further details).

For each tree, the stem was split into zones according to when the thinnings had taken place and whether it was considered that the branches would respond to thinning (see Table 2). The fact that branches were measured on alternate annual shoots formed more than three years after thinning is unlikely to have affected branch diameter distributions.

Table 2. Stem zones selected in order to investigate the influence of thinning on branch diameter distributions.

Trees	Zone	Years Formed	Rings in stem	Reason
1 -3	1	1969-1972	28-25	May be able to observe a response in branch diameter due to the thinning in 1974
	2	1973-1974	24-23	Year of thinning and previous year. Insufficient growth periods to observe a response in branch diameter due to thinning
	3	1975-1977	22-20	Unlikely to observe a response in branch diameter growth due to the second thinning in 1983
	4	1978-1981	19-16	May be able to observe a response in branch diameter due to the thinning in 1983
	5	1982-1983	15-14	Year of thinning and previous year. Insufficient growth periods to observe a response in branch diameter due to thinning
4-5	1	1969-1973	28-24	Unlikely to observe a response in branch diameter growth due to the thinning in 1979
	2	1974-1977	23-20	May be able to observe a response in branch diameter due to the thinning in 1979
	3	1978-1979	19-18	Year of thinning and previous year. Insufficient growth periods to observe a response in branch diameter due to thinning
	4	1980-1983	17-14	Years following thinning
6-9	1	1971-1974	26-23	May be able to observe a response in branch diameter due to the thinning in 1976
	2	1975-1976	22-21	Year of thinning and previous year. Insufficient growth periods to observe a response in branch diameter due to thinning
	3	1977-1983	20-14	Years following thinning
10-13	1	1969-1972	28-25	May be able to observe a response in branch diameter due to the thinning in 1974
	2	1973-1974	24-23	Year of thinning and previous year. Insufficient growth periods to observe a response in branch diameter due to thinning
	3	1975-1983	22-14	Years following thinning

For each section of the stem, the branch were ranked in order of diameter and their relative position in the distribution calculated. Branch diameter was then plotted against relative position in the distribution (see Fig 1.)

In order to test whether thinning had influenced the branch diameter distribution for each tree, the branches were grouped into classes according to diameter and tested to see whether there was any association between diameter distribution and stem zone using the chi-square test. The number of branches in each zone was variable due to the length of the stem zone, and number of branches in a cluster. The number of branches varied between 25 and 172.

Initially the data was split into 2 cm branch diameter classes. However, the chi-square test is not accurate for small numbers of observations in the classes. The analyses was repeated with the data split into 3 classes:

Class1:	2 cm or less
Class2:	2 cm to 4 cm
Class3:	greater than 4 cm

This split was satisfactory for most trees.

From examining the plots in Figure 1, further analyses were carried out to determine which zones were significantly different.

Another point of interest is whether the timing of thinning has any influence on the branch diameter distribution after thinning. In order to investigate this point, branch diameter distributions from comparable trees (ie. same position within DBH distribution and same nominal stocking) but different time of thinning were compared using the chi- square test.

RESULTS

Effect of thinning within a tree

The results of the chi-square tests are summarised by thinning treatment in Tables 3-6.

Table 3. Two thinnings: 1974 and 1983.

Tree	DBH (cm)	Result
1	65.8	The chi-square test indicated that the branch diameter distribution in zone 1 was significantly different from the other zones. The difference between zone 1 and the other zones is the absence of many branches over 24 mm (Figure 1a). The response to the first thinning is an increase in the proportion of larger diameter branches present (zones 2 and 3) There does not appear to be an additional response to the second thinning (zones 4 and 5). One reason that the second thinning had little influence on the branch diameter distribution is that there was little change in the stocking (300 to 200 stems/ha) compared to the first thinning (3086 to 300 stems/ha).
2	51.0	The chi-square test indicated that there were significant differences in the branch diameter distributions. The branch diameter distribution in zone 1 is different from the branch diameter distributions formed immediately prior to and after the first thinning (zones 2 and 3) which are not significantly different from each other (Fig. 1b). It appears that the branches in zone 4 have been able to respond to the second thinning. At the second thinning the plot was thinned from 400 to 200 stems/ha. Zone 4 has more larger diameter branches than zone 5. There is no obvious reason for this difference.
3	42.5	The initial chi-square calculation indicated that class 3 was too small. When class 2 and 3 were combined there was no significance difference in the distribution between zones (Fig. 1c). This indicates that this tree was not able to respond to the thinnings.

Table 4. 1 thinning in 1979

Tree	DBH (cm)	Result
4	66.4	The initial chi-square test indicated that there were significant differences in the branch diameter distribution between zones. As there were only a few branches greater than 40 mm in zones 1-3 (Figure 1d), classes 2 and 3 were combined. A chi-square test using just two classes, indicated that there were no significant difference between the branch diameter distributions between zones 1, 2 and 3. After thinning (zone 4), there is an increase in the proportion of branches greater than 2 cm in diameter.
5	53.5	The initial chi-square test indicated that there were significant differences between zones. The distributions in zones 2 and 3 were not significantly different from each other. Overall, the response to thinning is not substantial (Figure 1e). In zone 4 (formed after thinning), there was a higher proportion of branches less than 1 cm in diameter.

Table 5. 1 thinning in 1976

Tree	DBH (cm)	Result
6	63.8	The chi-square test indicated that there were significant differences in the branch diameter distribution between zones. There is an obvious response to the thinning in that the number of larger diameter branches increases from zone 1 through to zone 3 (Figure 1f).
7	54.8	The initial chi-square test indicated that there were significant differences in the branch diameter distribution between zones. However zones 1 and 2 were not significantly different. Again there was a higher proportion of smaller branches in zone 3 (formed after thinning) (Figure 1g).
8	46.6	Due to the small number of branches above 4 cm in diameter, classes 2 and 3 needed to be combined for the chi-square test to be valid. With just two classes there was no significant difference in the branch diameter distribution between zones. However, there appears to be a change in branch diameter distribution in zone 3 (Figure 1h) with more larger diameter branches present.
9	33.8	There was no significant differences in branch diameter distribution between the three zones (Fig. 1i).

Table 6. 1 thinning in 1974

Tree	DBH (cm)	Result
10	61.1	The initial chi-square test indicated that there were significant differences in branch diameter distribution between the zones. The number of larger diameter branches increases from zone 1 through to zone 3 (Fig. 1j). Again there is also a higher proportion of branches with small diameters in zone 3.
11	54.4	The initial chi-square test indicated that there were significant differences in the branch diameter between the zones. The number of larger diameter branches increases from zone 1 through to zone 3 (Fig. 1k).
12	43.3	The initial chi-square test indicated that there were significant differences in the branch diameter between the zones. The main difference appears to be in the proportion of smaller diameter branches (Fig. 1l).
13	33.8	Due to the small number of branches above 4 cm in diameter, classes 2 and 3 needed to be combined. The chi-square test indicated that the were significant differences in the branch diameter distributions between zones. However the differences are minor compared to the larger trees (Fig. 1m).

Effect of time of thinning

For each group of trees, comparisons were made across the zone that might respond to thinning and the zone formed after thinning. There was a different result for each group of trees making it difficult to draw any conclusion about the influence of timing of thinning on branch diameter distribution (Table 7).

Table 7. Comparison of branch diameter distributions across time of thinning

Trees and zones compared	Chi-square test significant
Tree 4, zone 2; Tree 6, zone 1; Tree 10, zone 1	Yes
Tree 4, zone 4; Tree 6, zone 3; Tree 10, zone 3	No
Tree 5, zone 2; Tree 7, zone 1; Tree 11, zone 1	No
Tree 5, zone 4;, Tree 7, zone 3; Tree 11, zone 3	Yes
Tree 8 , zone 1; tree 12, zone 1	Yes
Tree 8, zone 3; tree 12, zone 3	Yes
Tree 9, zone 1; tree 13, zone 1	No
Tree 9, zone 3; tree 13, zone 3	No

DISCUSSION

The sample trees from each timing of thinning were chosen based on an index of growing spacing (Grace *et al.*, 1996) which was found to be correlated with the average (over all clusters which had stopped growing) maximum branch diameter per cluster (Grace. 1996). For this reason, and to keep the sample size manageable, trees with similar growing space index at different nominal stockings were not sampled.

For the trees 10 and 11 (thinned once in 1974 to 200 stems/ha) the proportion of larger diameter branches increases from the zone 1 (where branches may respond to the thinning) through to zone 3 (where the branches have grown since the thinning).

The same pattern also shows for trees 6 and 7 (thinned once in 1976 to 200 stems/ha).

However the same pattern is not so obvious for trees 4 and 5 which were thinned once in 1979 to 200 stems/ha. A change in branch diameter distribution is most obvious in zone 4 (where the branches have grown since the thinning).

For the trees 12 and 13 (thinned to 400 stems/ha in 1974) and trees 8 and 9 (thinned to 400 stems/ha in 1976) there is little sign of a big response to thinning.

These trees were smaller than the trees thinned to 200 stems/ha. It is possible that the increase in growing space was too small to allow a substantial increase in branch diameter growth. Also stocking has little influence on the diameter of the larger branches in a cluster above about 500 stem/ha (see Figs. 2 and 3 (Grace, 1989)).

Trees 1- 3 received two thinnings. For tree 1 there is a response to the first thinning but not the second. It is thought that the small change in stocking between the first and second thinning (300 to 200 stems/ha) may be the reason for no response to the second thinning. Tree 2 appears to have responded to both. For this tree the second thinning was heavier (400 to 200 stems/ha). Tree 3 did not respond to either thinning to any great extend. This may be due to the smaller tree size.

It was not possible to draw any conclusions about whether timing of thinning influenced the branch diameter growth (Table 7).

The reason for the higher proportion of smaller branches noted in the higher zones on several trees is not known. Possible reasons for this phenomenon will be looked for when examining the data on number of branches per cluster and relative branch distribution within a cluster.

EXPERIMENT RO696 - SPACING TRIAL

METHODS

This spacing trial was established in a naturally regenerated stand in 1972. The plots were thinned to their nominal stocking at the time of establishment. Trees were also pruned to 6.1 m. It is considered that all branches remaining on the trees should have been formed when the plots were at their nominal stocking.

Twelve trees were sampled from this experiment (see Table 8).

Table 8. Nominal stocking and DBH at time of thinning

Tree Number	DBH (cm)	Stems/ha
18	60.3	200
21	50.8	200
30	37.4	200
33	57.8	400
35	46.1	400
39	31.6	400
71	65.0	600
76	43.4	600
79	30.0	600
56	50.0	800
63	39.5	800
7	29.8	800

For each tree, two zones of the stem have been selected. The first zone contains clusters with 20 to 17 growth rings. The second zone contains clusters with 16 to 13 growth rings. All the branches would have stopped growing in diameter. As the observed decrease in branch diameter after branches have stopped growing is generally only a few mm, it is considered that any major changes in distribution would be a result of age influencing the branch diameter distribution. The data from tree 7 was not considered as it was difficult to count the rings on this tree due to its small size and it is uncertain whether the recorded data is accurate.

For each section of the stem, the branch were ranked in order of diameter and their relative position in the distribution calculated. Branch diameter was then plotted against relative position in the distribution (see Fig 2).

In order to test whether age had influenced the branch diameter distribution for each tree, the branches were grouped into classes according to diameter and tested to see whether there was any association between diameter distribution and stem section using the chi-square test. The number of branches in a zone varied between 40 and 107.

Initially the data was split into 2 cm branch diameter classes. However, the chi-square test is not accurate for small number of observations in the classes. The analyses was repeated with the data split into 3 classes:

Class1:	2 cm or less
Class2:	2 cm to 4 cm
Class3:	greater than 4 cm

RESULTS

For most trees there is no significant difference between the two zones using a chi-square test (Table 9 and Figure 2).

Table 9. Results of Chi-square test on branch diameter distributions

Tree Number	DBH (cm)	Stems/ha	Significant difference between two zones
18	60.3	200	No
21	50.8	200	No
30	37.4	200	No
33	57.8	400	Yes
35	46.1	400	No
39	31.6	400	No
71	65.0	600	Yes
76	43.4	600	Yes
79	30.0	600	Yes
56	50.0	800	Yes
63	39.5	800	No

The differences for the trees with significant differences between zones are described below (Table 10).

Table 10. Comments on variation in branch diameter distribution

Tree	Result
33	There is a greater proportion of smaller branches in zone 2. However at the top end of the distribution the differences are small (Fig. 2d).
71	Zone 2 has proportionally more small branches than Zone 1. At the top end of the distribution the branches tend to be slightly larger than in zone 1 (Fig. 2i)
76	The branches in zone 2 tend to be smaller than in Zone 1. At the top end of the distribution there is little difference in branch diameter between the two zones (Fig. 2j).
79	The branches in zone 2 tend to be smaller than in Zone 1. At the top end of the distribution there is little difference in branch diameter between the two zones (Fig. 2k).
56	While the chi-square test indicated a significant relationship (p=0.06), the two lines are similar (Fig. 2g).

DISCUSSION

For the trees in RO696, where there are significant differences in the branch diameter distributions (Fig. 2), the differences occur in the middle of the distribution. The main reason appears to be a greater proportion of branches with small diameters. At the top end of the distribution the branch diameter tend to be similar. This is in contrast to the trees in RO905 where there were obvious changes in the diameter of the larger branches (Fig. 1).

The reason for the greater proportion of branches with small diameters is not known. One possibility is that the smallest branches were missed lower in the tree. This seems unlikely as care was taken in counting the branches; and the number of branches in a cluster (in Experiment RO696) was not significantly correlated with the number of stem growth rings below the cluster (Lundgren and Grace, 1996).

SUMMARY

The results outlined in this report suggest that the diameter of the larger branches in the distribution do not change much as a result of age when stocking is constant (from Experiment RO696), but that they may change as a result of thinning (Experiment RO905).

The change in branch diameter distribution with thinning is most obvious on the larger trees. On some of the smaller trees there was little or no response to the thinning. It was not possible to determine whether timing of thinning had any influence on branch diameter distribution.

The minor changes in branch diameter distribution with age may be due to changes in the competitive status of the trees and mortality of smaller trees. This is likely as a change in distribution with age tended to occur at the higher stockings.

The observation that there are more smaller diameter branches higher in the trees will be investigated in future analyses.

REFERENCES

Grace, J.C. 1989: Branch size prediction for radiata pine. Stand Management Co-operative Report No. 18.

Grace, J.C. 1996: Diameter of branches within a cluster in experiment RO696. Stand Growth Modelling Co-operative Report No. 50.

Grace, J.C. ; Lundgren, C.; Blundell, W. 1996: Branching characteristics of radiata pine in Experiment RO905: Data Collection. Stand Growth Modelling Co-operative Report No. 52.

Lundgren, C.; Grace, J.C. 1996: Modelling stem cone occurrence, number of branches in a cluster and cluster depth in radiata pine: Progress to January 1996. Stand Growth Modelling Co-operative Report No. 48.

Figure 1. Branch diameter versus relative position in branch diameter distribution for different sections of the stem for trees from Experiment RO905 as outlined in Table 2.

a. Tree 1
b. Tree 2
c. Tree 3
d. Tree 4
e. Tree 5
f. Tree 6
g. Tree 7
h. Tree 8
i. Tree 9
j. Tree 10
k. Tree 11
l. Tree 12
m. Tree 13

Figure 2. Branch diameter versus relative position in branch diameter distribution for different sections of the stem for trees from Experiment RO696.

a. Tree 18
b. Tree 21
c. Tree 30
d. Tree 33
e. Tree 35
f. Tree 39
g. Tree 56
h. Tree 63
i. Tree 71
j. Tree 76
k. Tree 79

Figure 1a

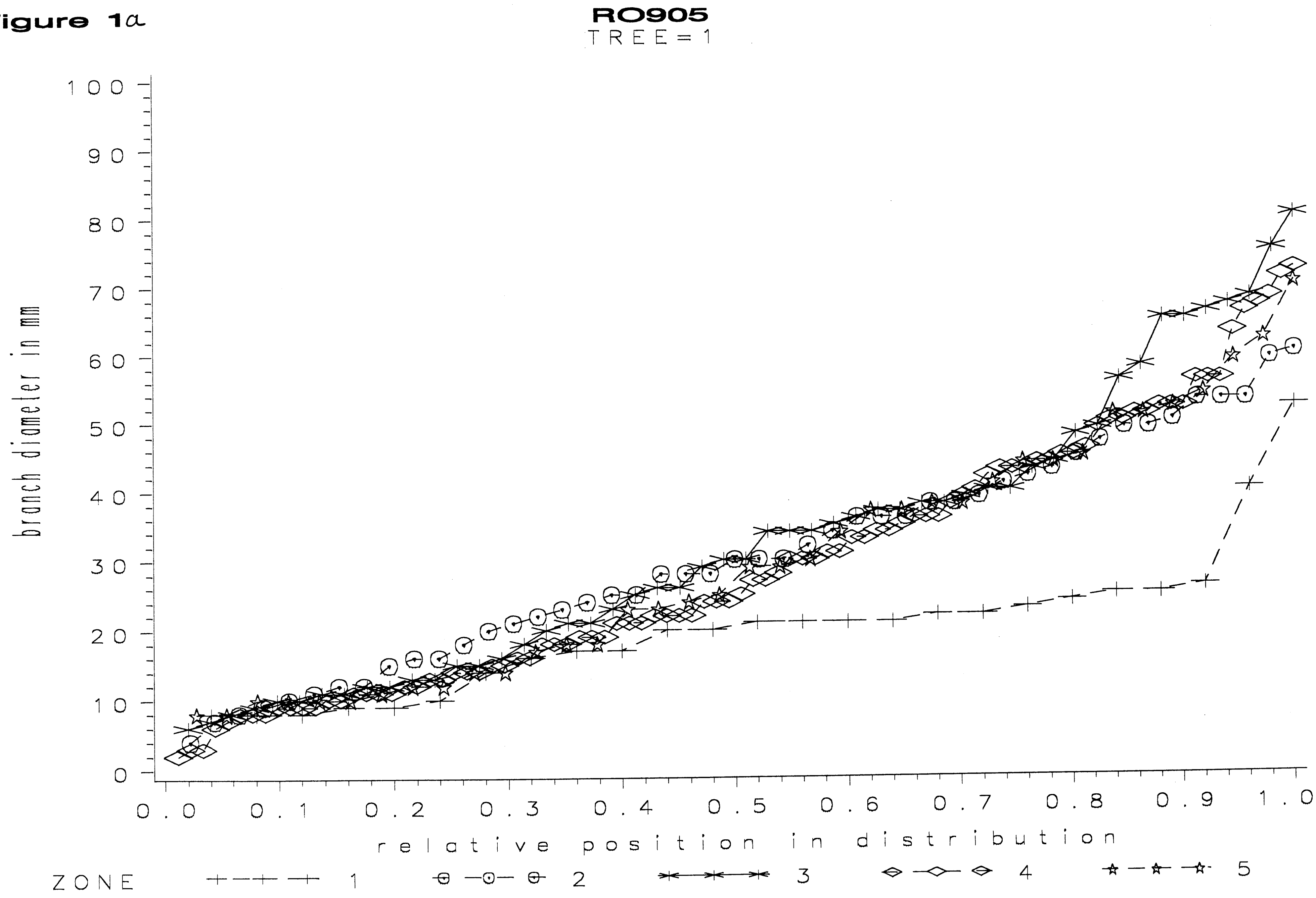

RO905
TREE=1
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3
4
5

Figure 1b

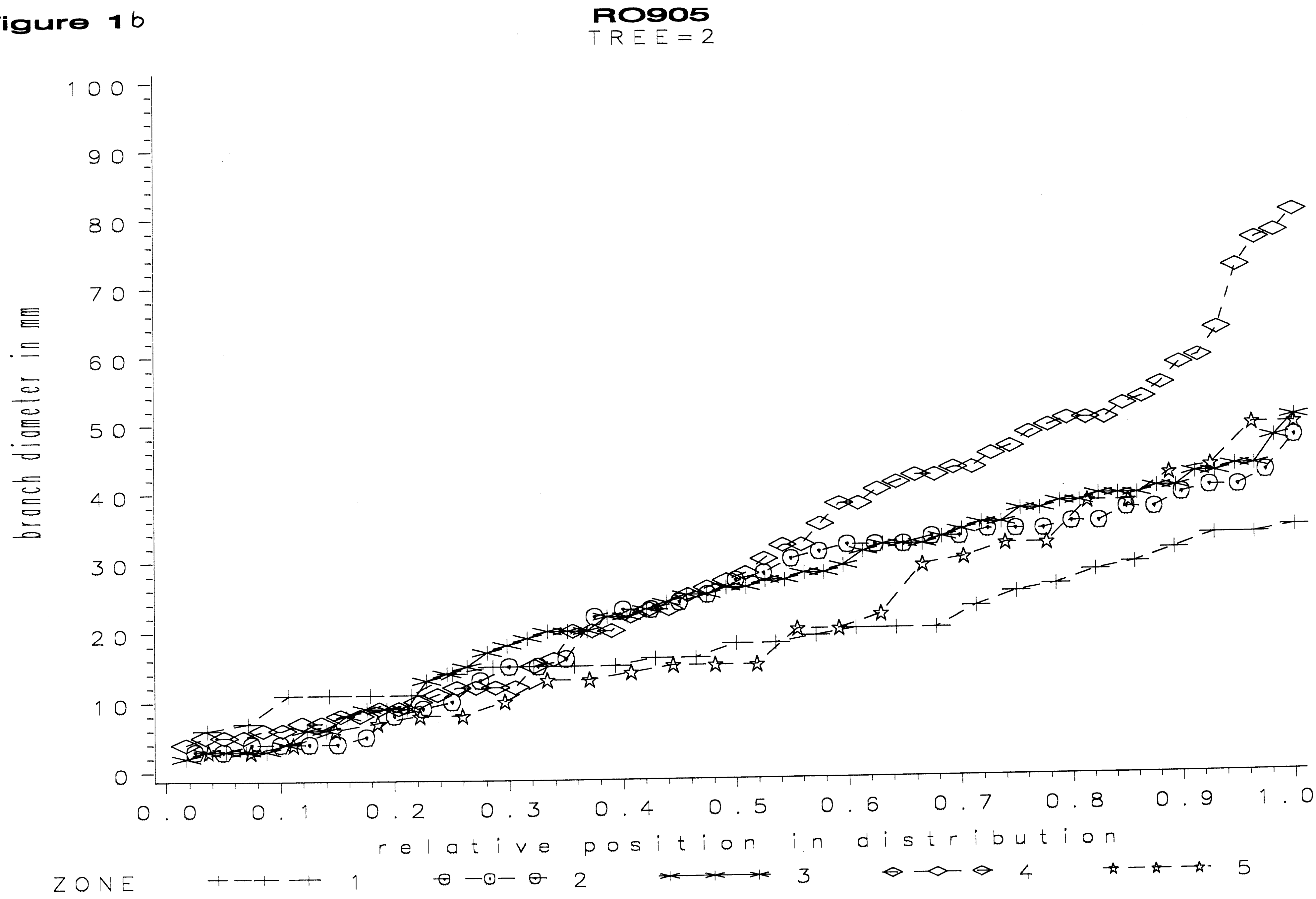

RO905
TREE=2
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3
4
5

Figure 1c

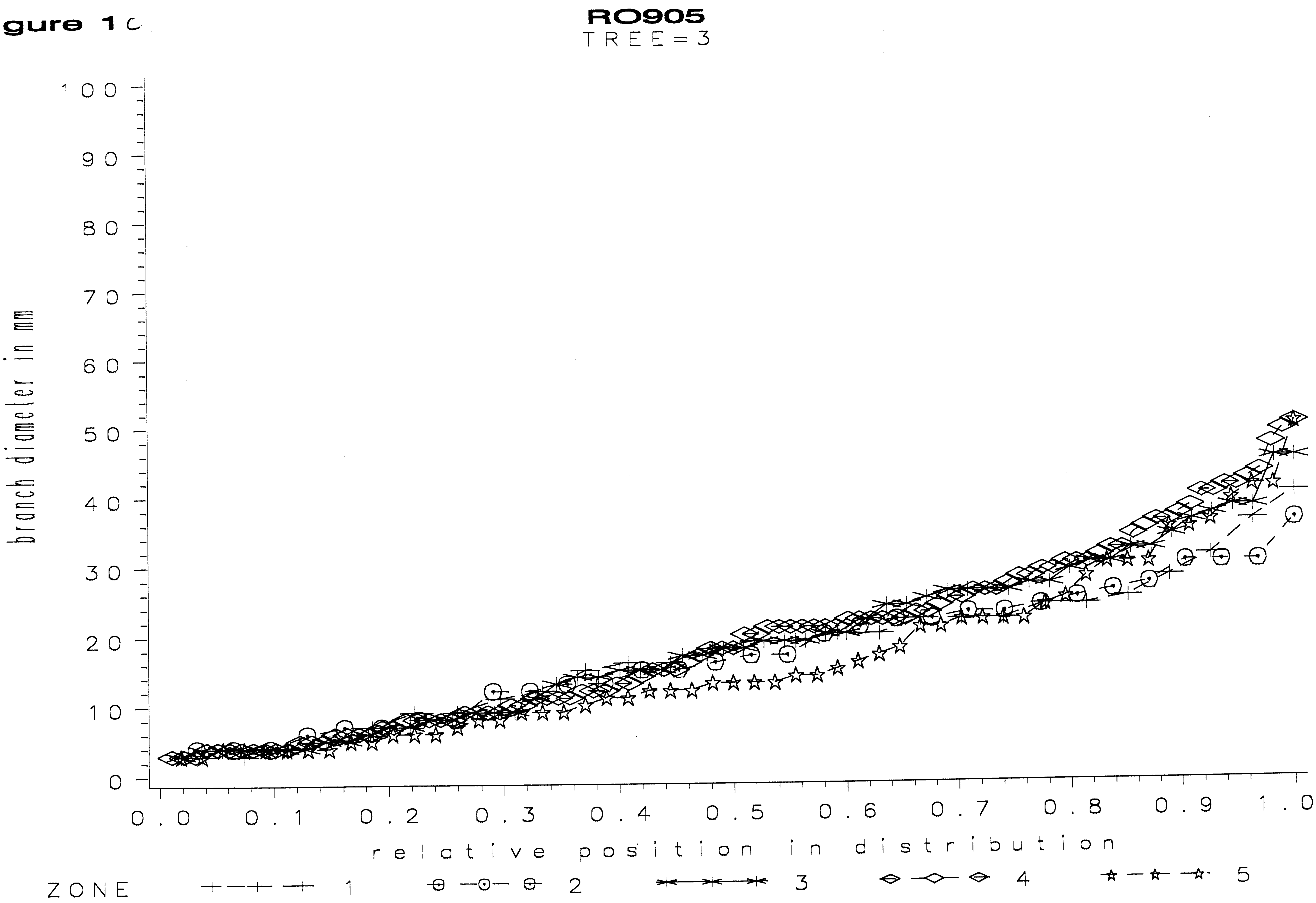

RO905
TREE=3
branch diameter in mm
0
10
20
30
40
50
60
70
80
90
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3
4
5

Figure 1d

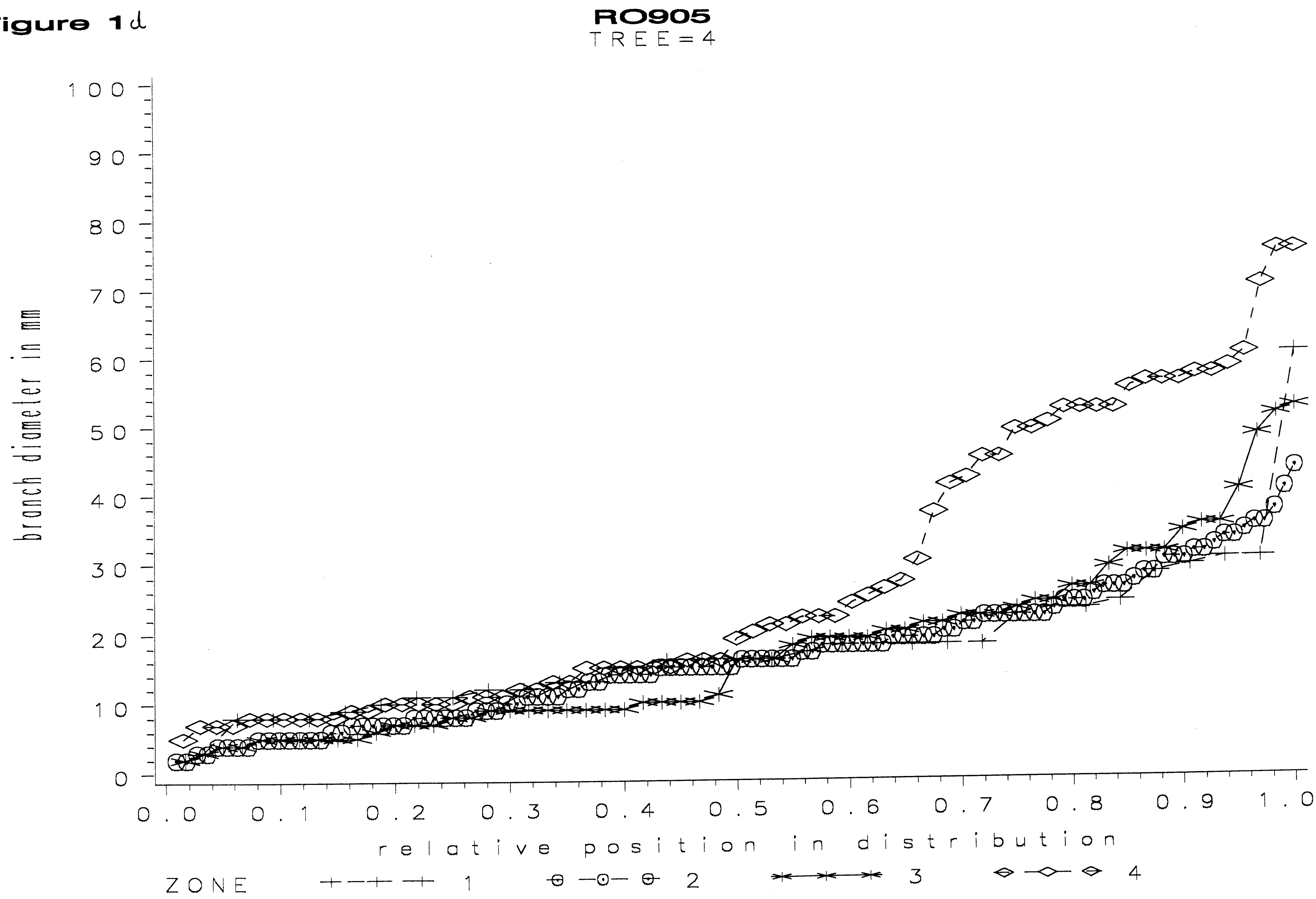

RO905
TREE=4
100
90
80
70
60
50
40
30
20
10
0
branch diameter in mm
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3
4

Figure 1e

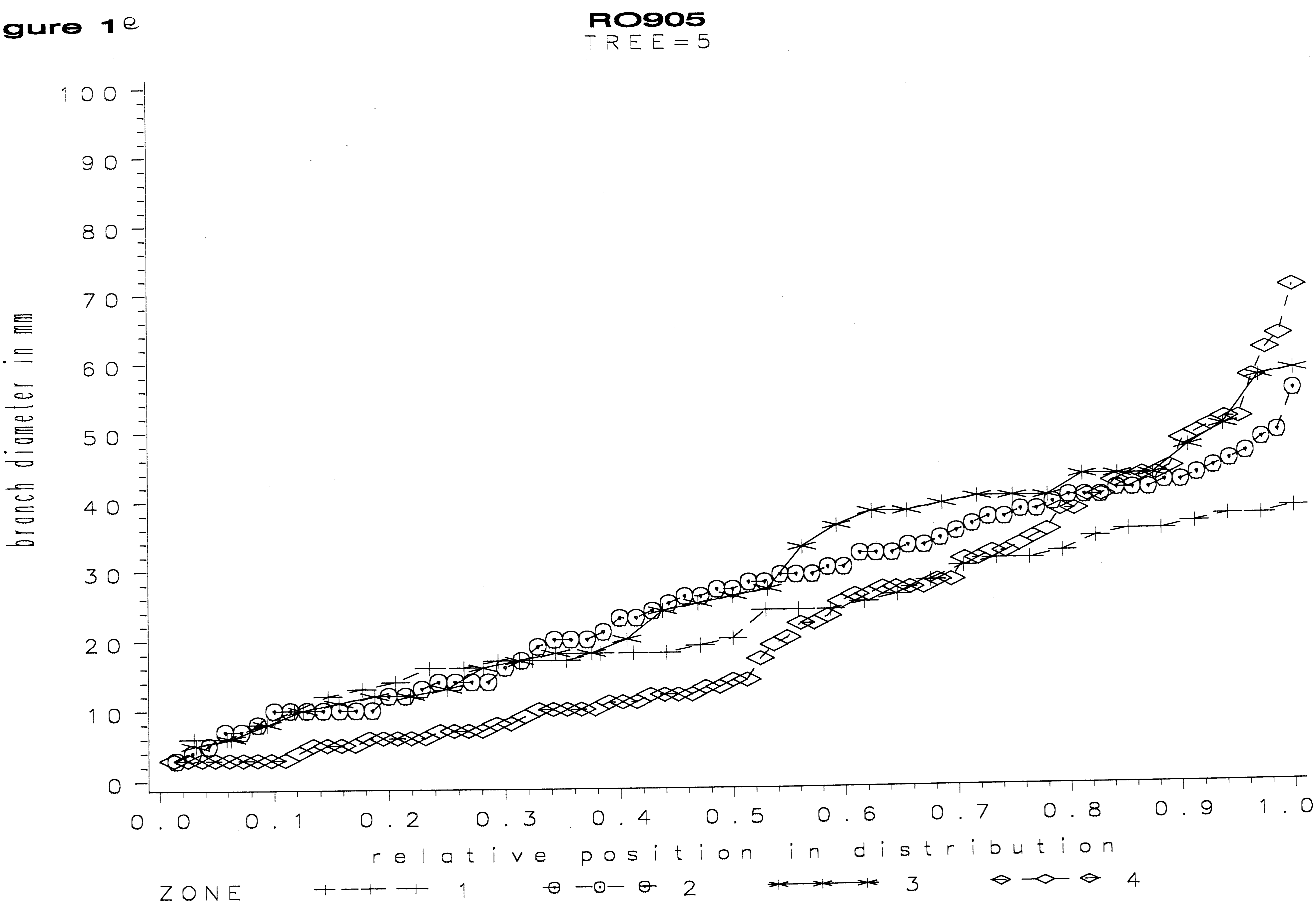
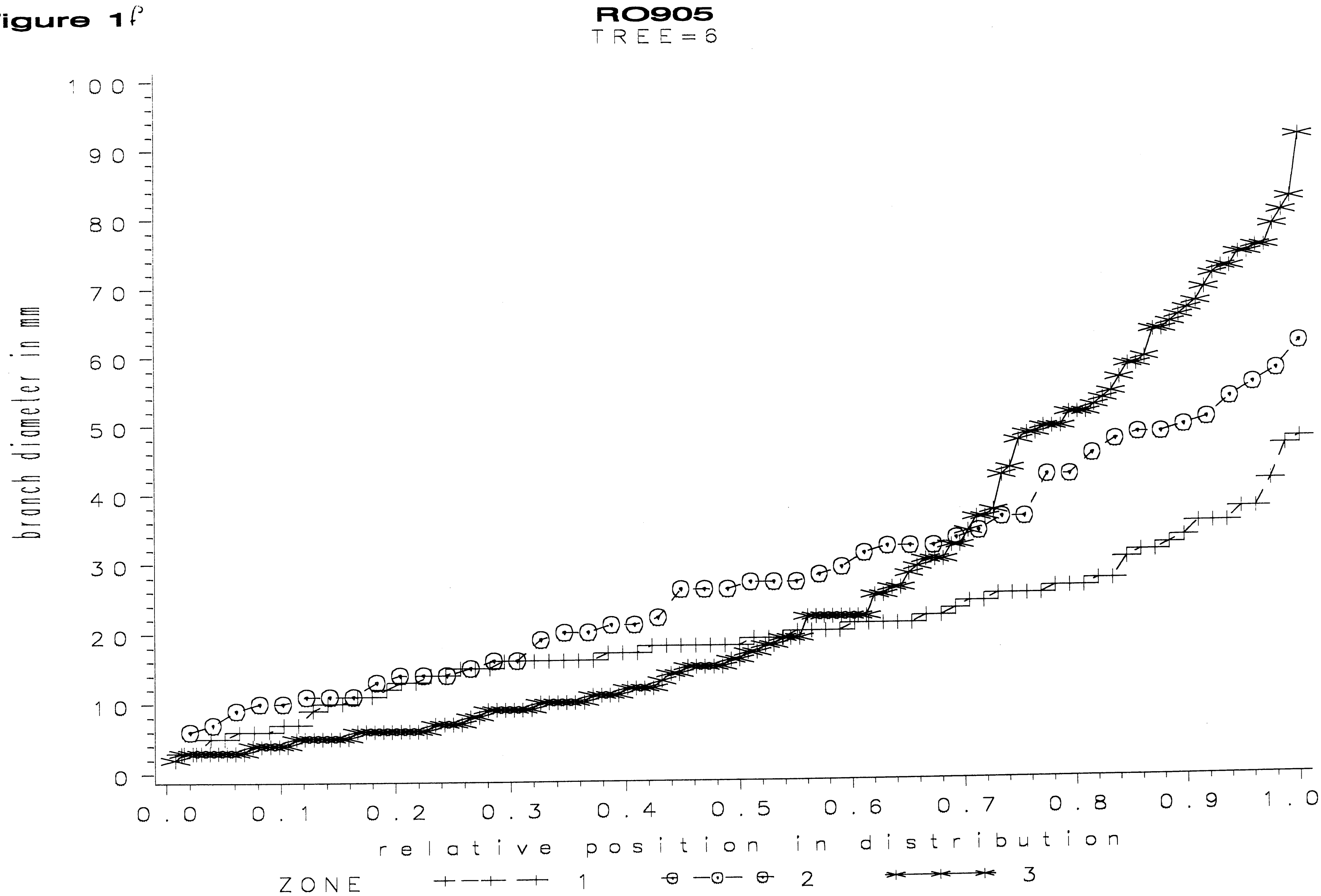
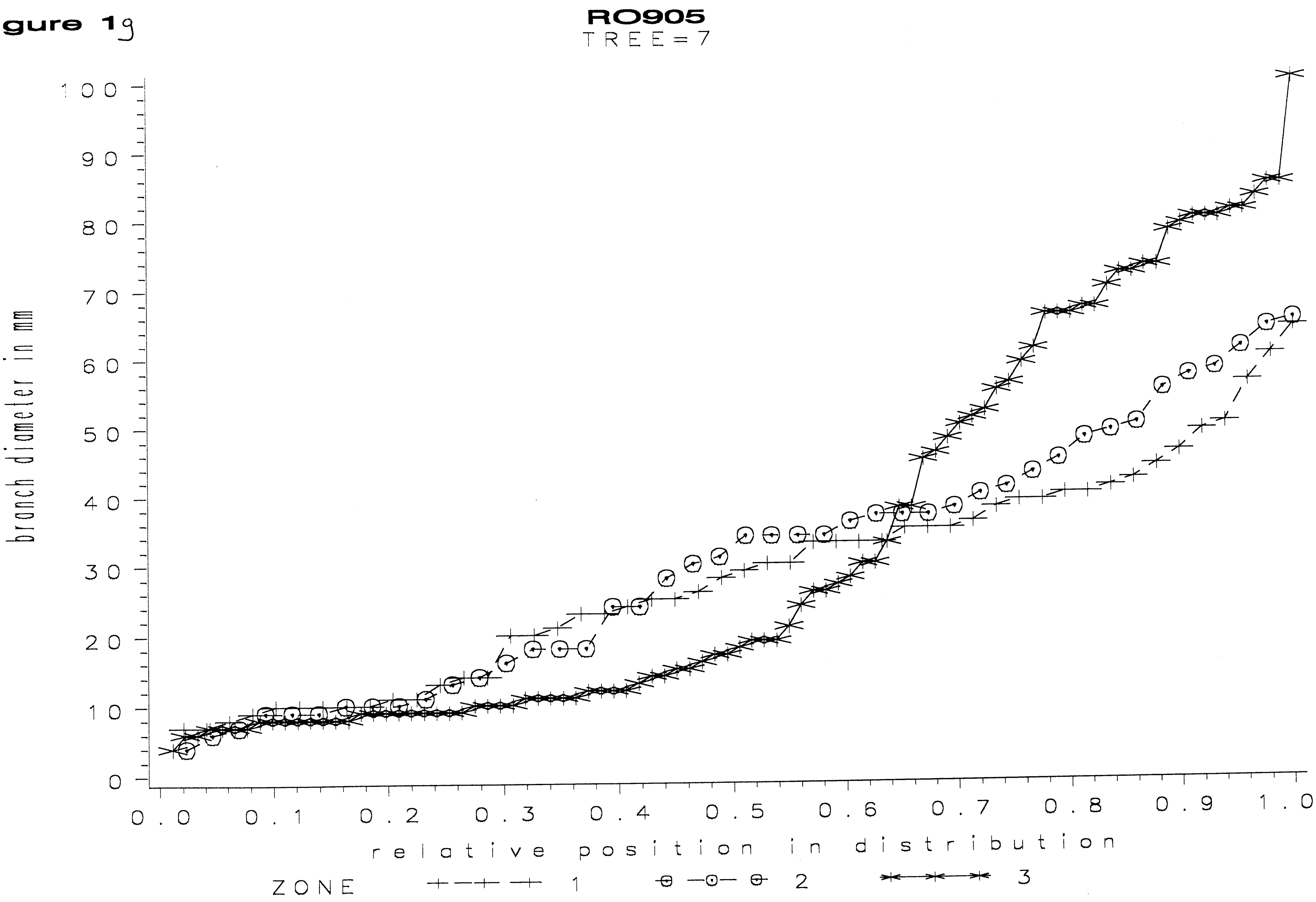

RO905
TREE=5
branch diameter in mm
0
10
20
30
40
50
60
70
80
90
100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3
4

Figure 1ᶠ



RO905
TREE=6
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1g



RO905
TREE=7
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1h

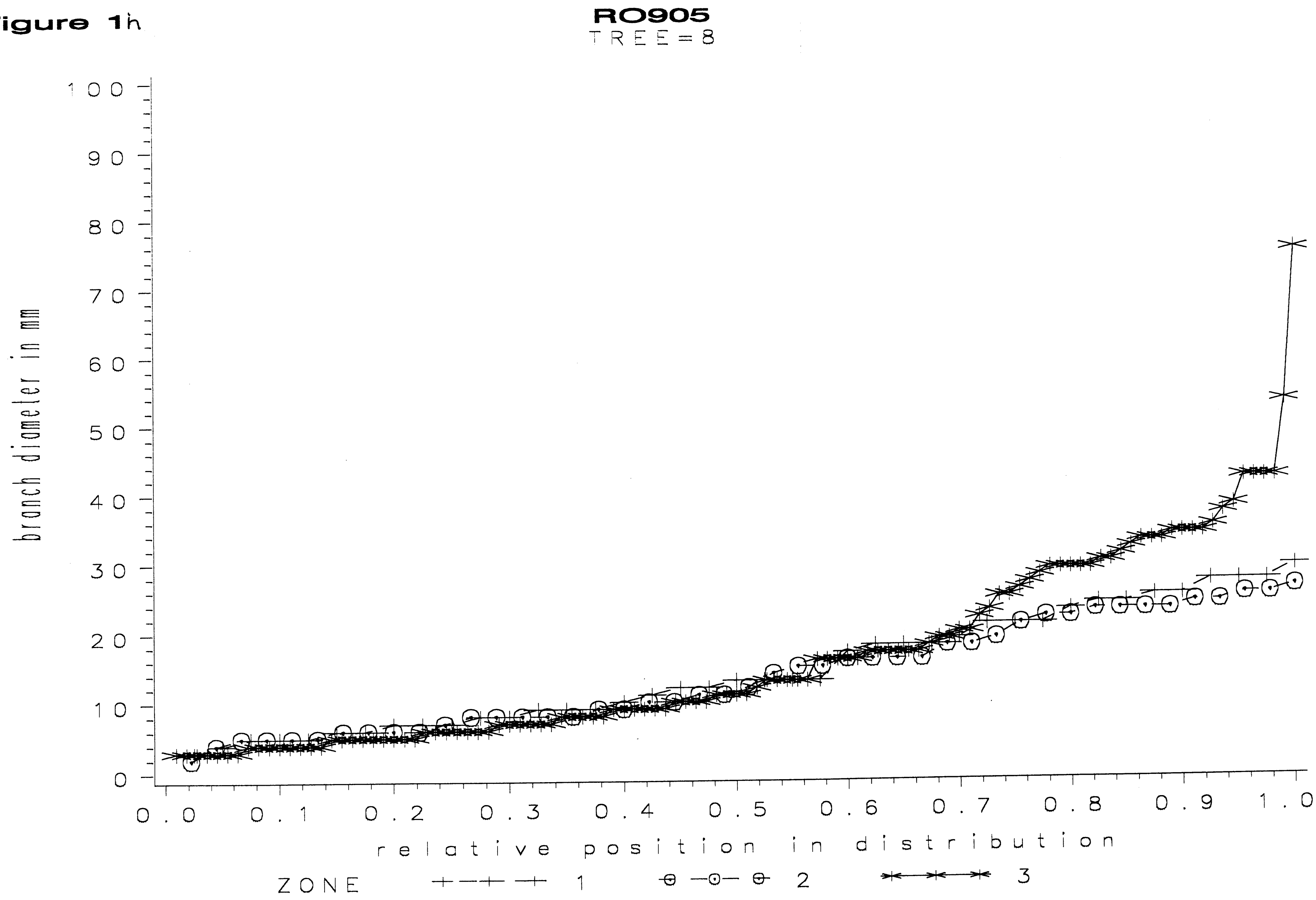

RO905
TREE=8
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1i

RO905

TREE=9

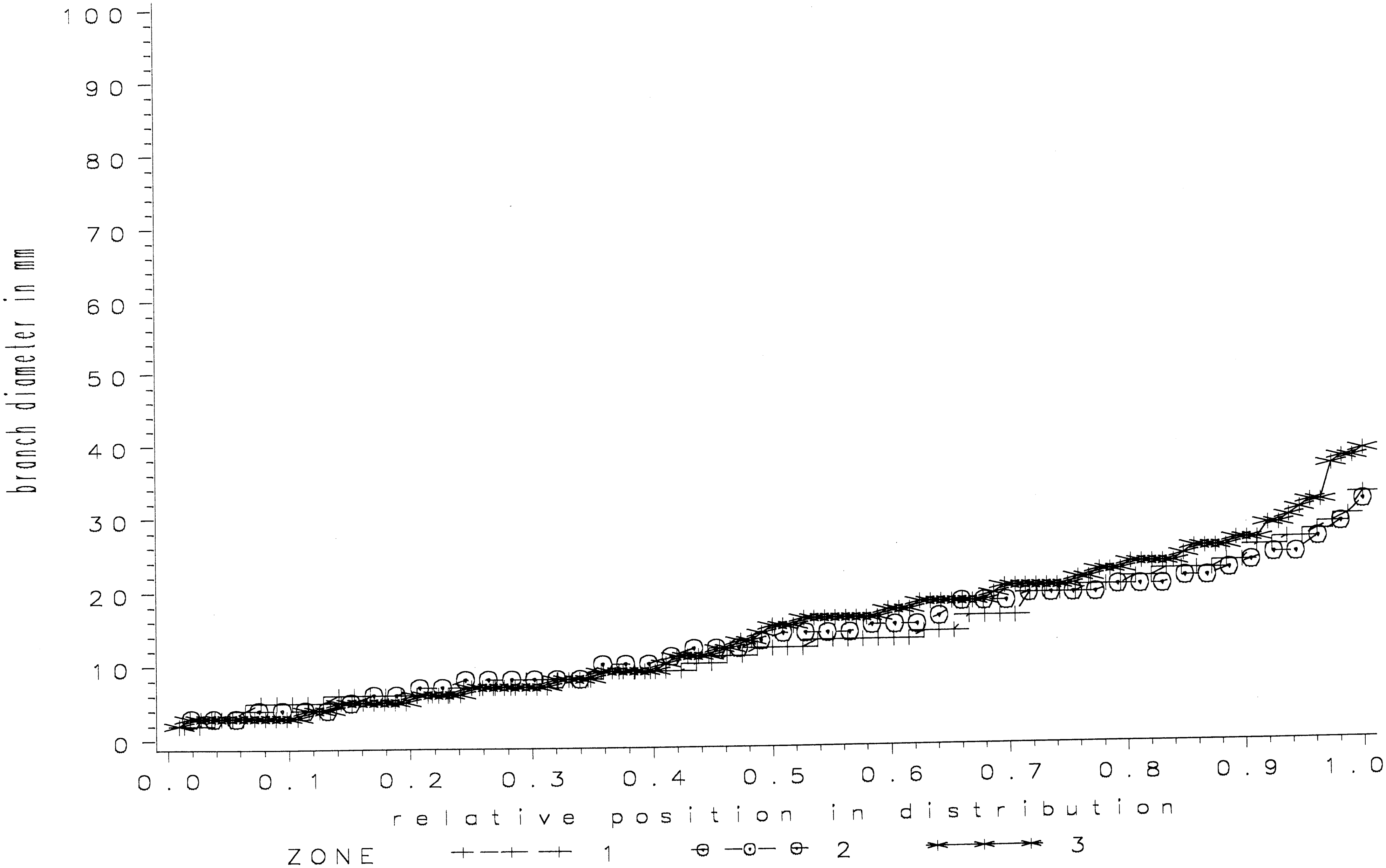


Figure 1j

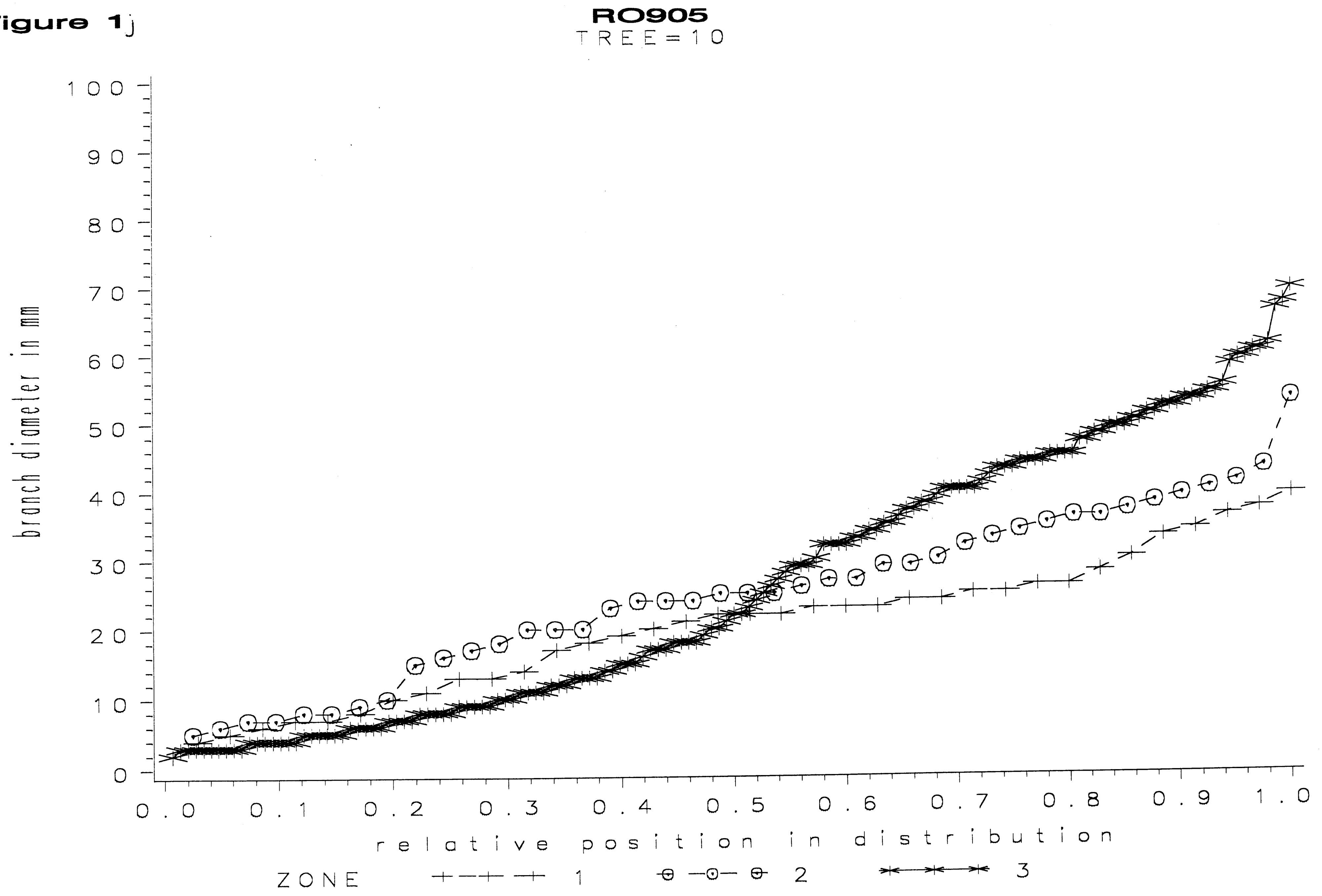

RO905
TREE=10
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1K

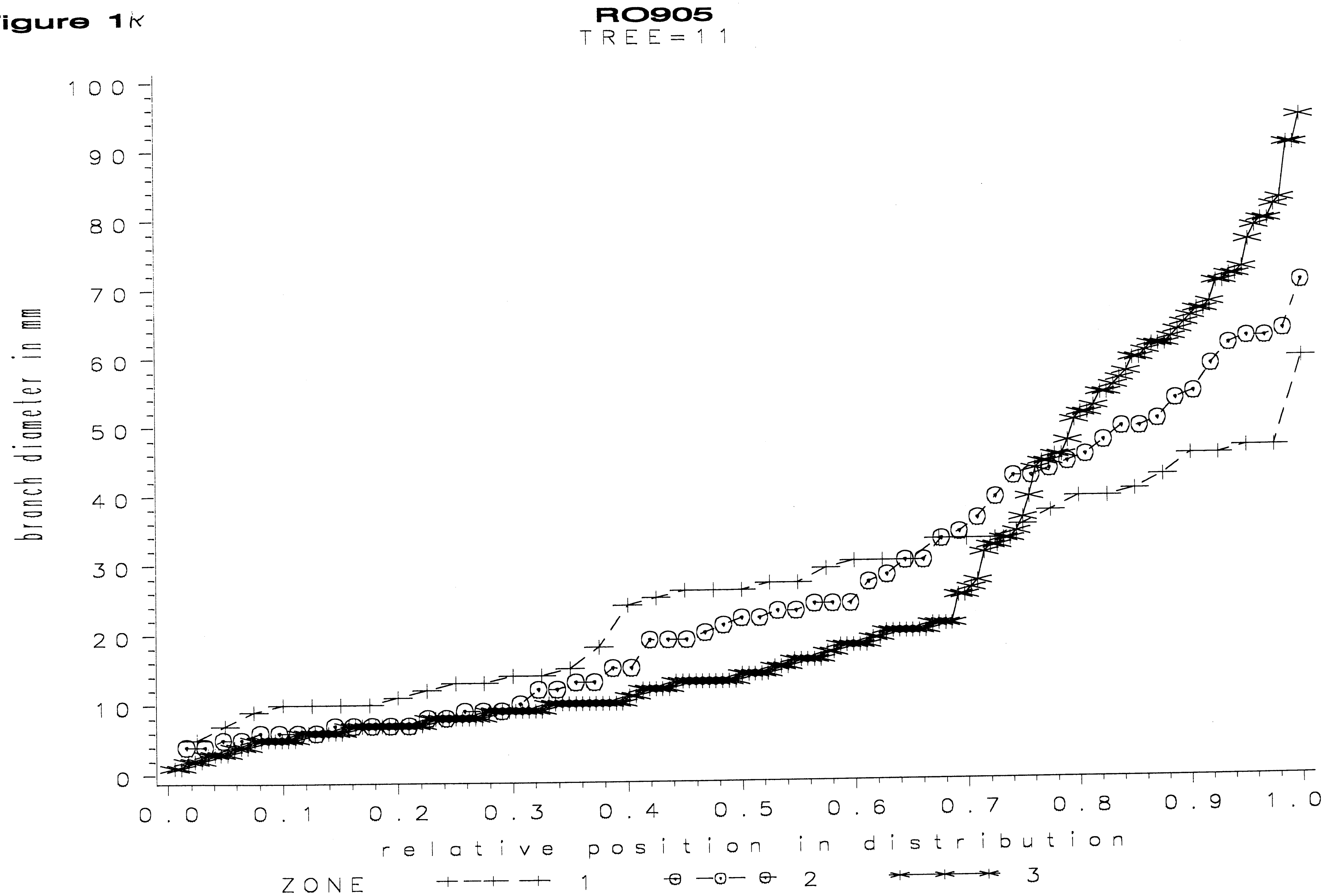

RO905
TREE=11
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1l

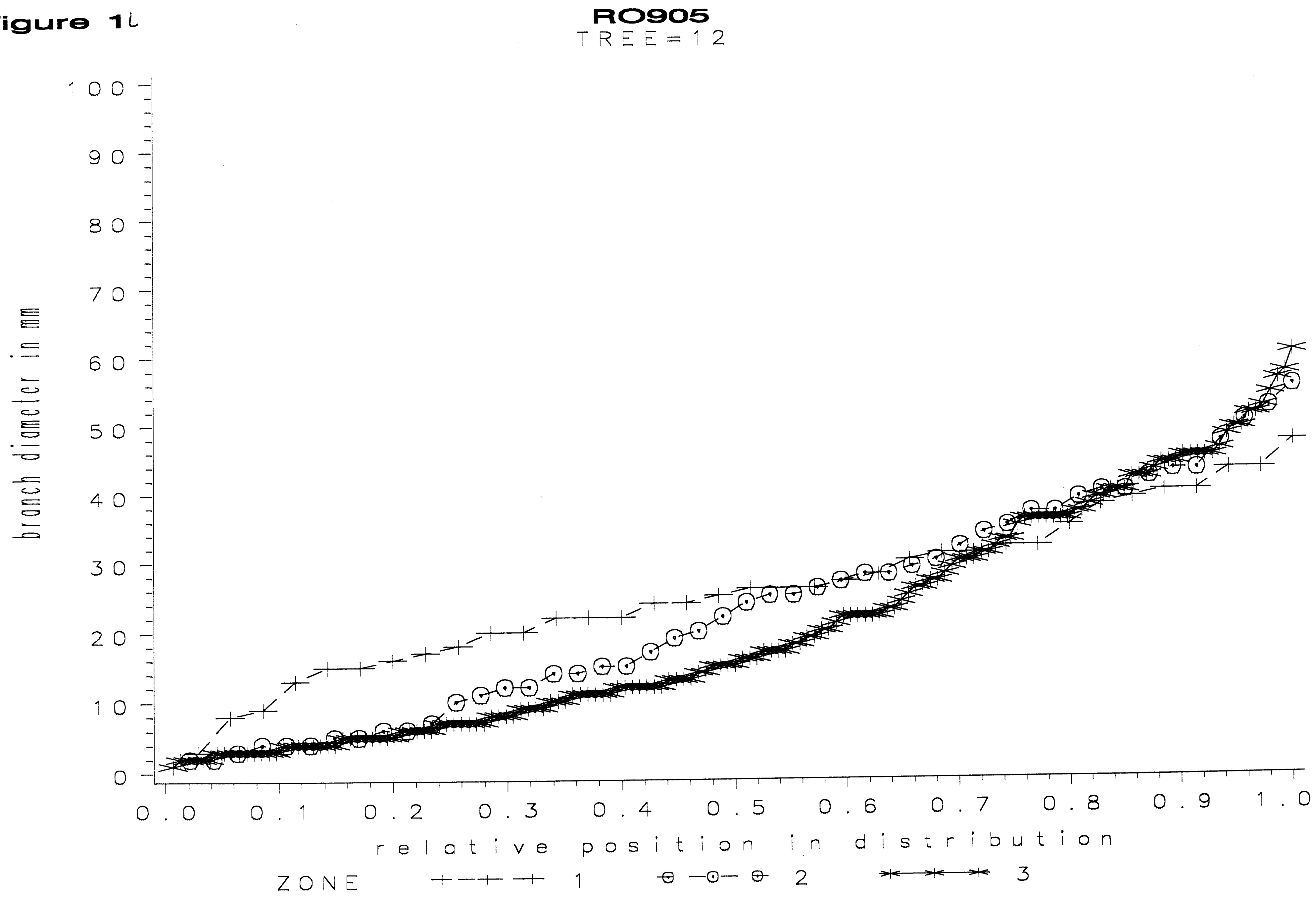

RO905
TREE=12
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 1m

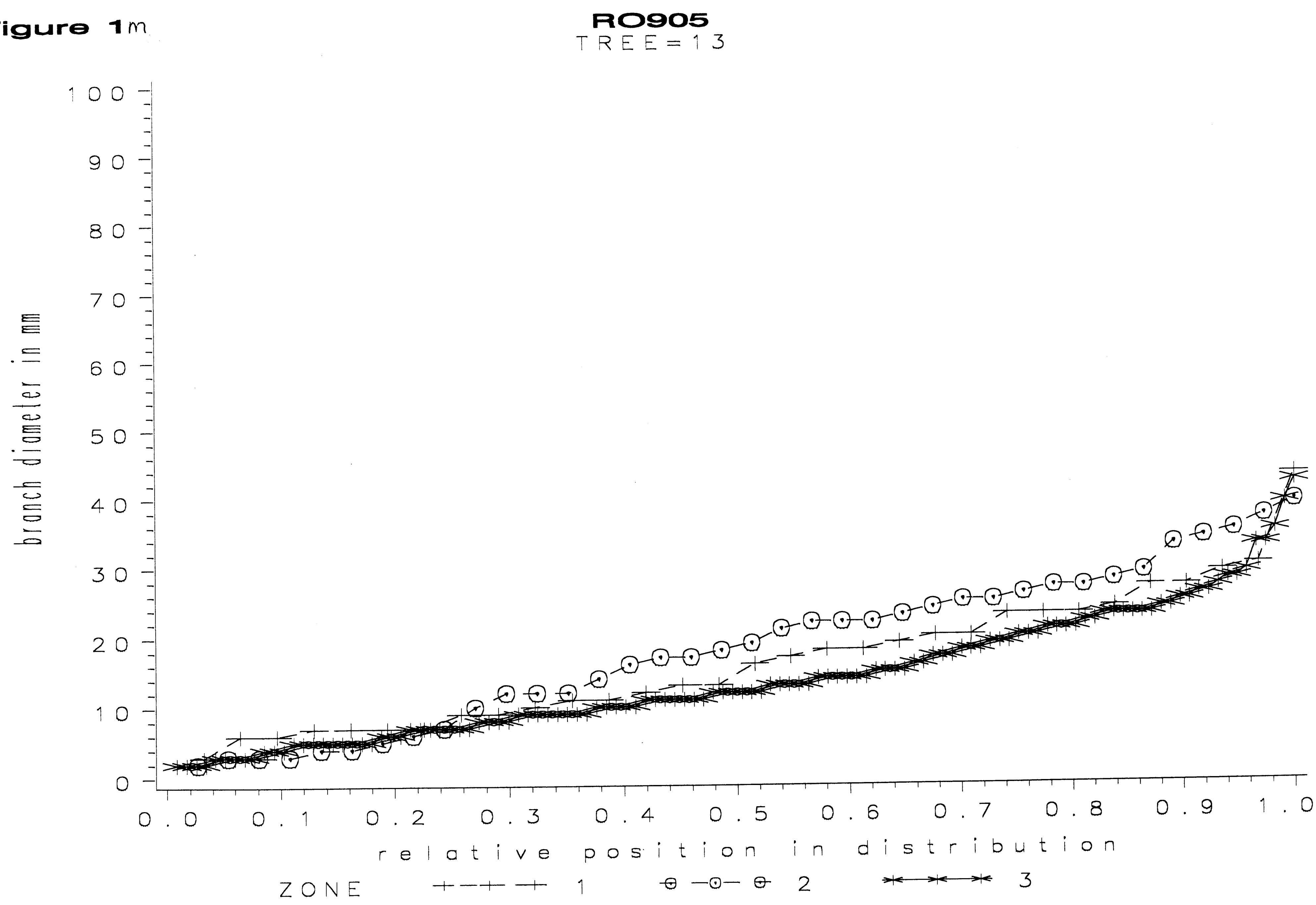

RO905
TREE=13
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2
3

Figure 2a

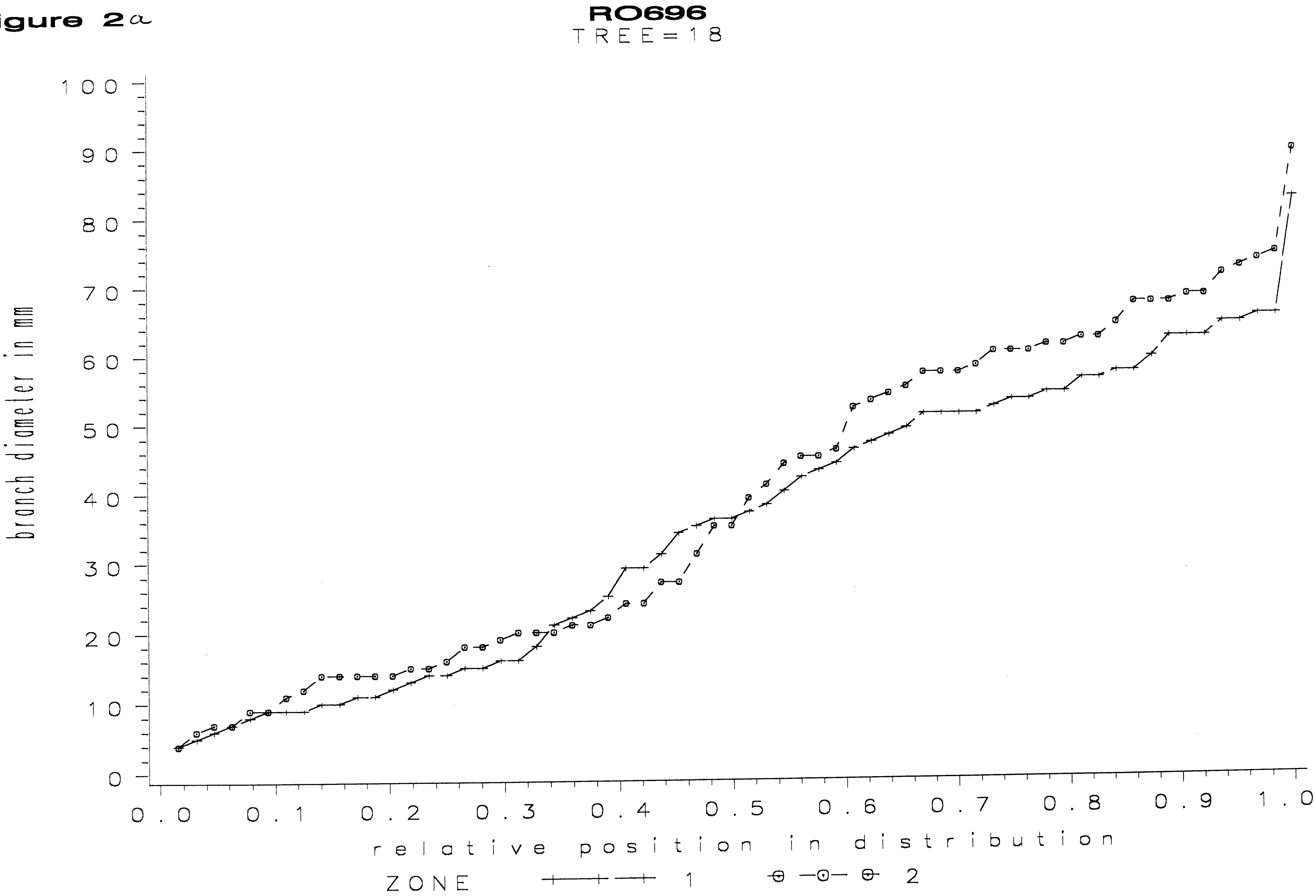

RO696
TREE=18
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2b

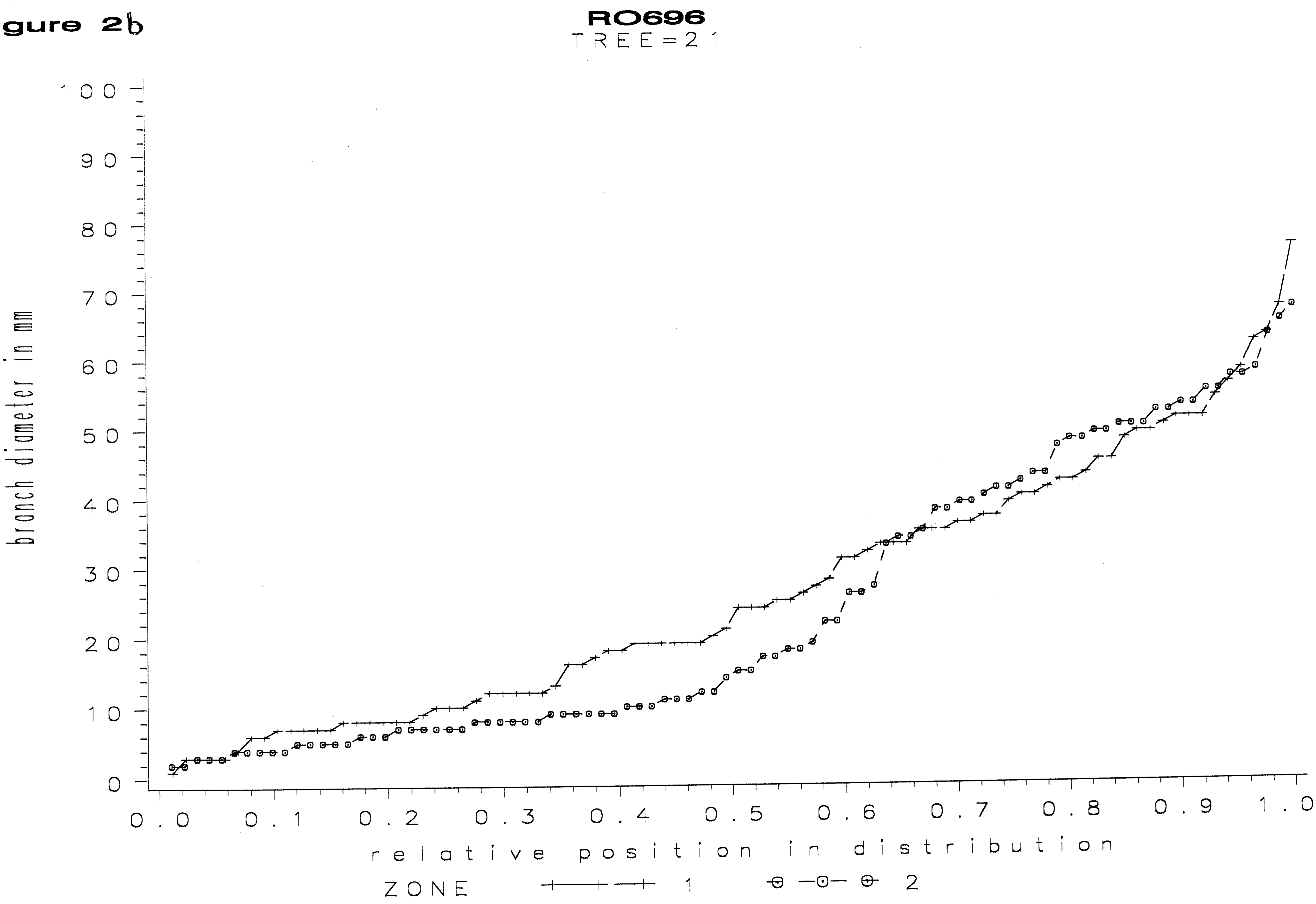

RO696
TREE=21
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2c

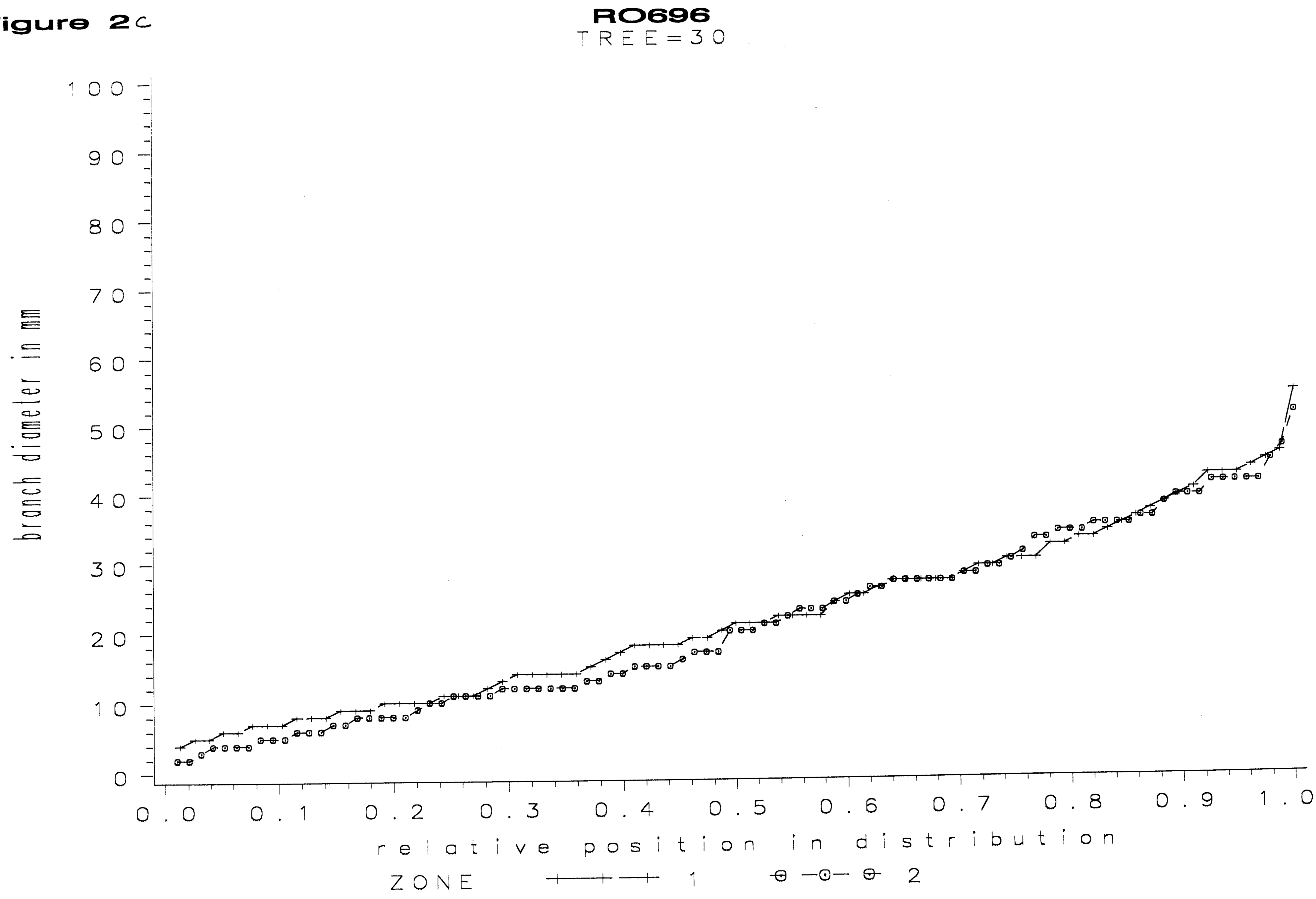

RO696
TREE=30
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2d

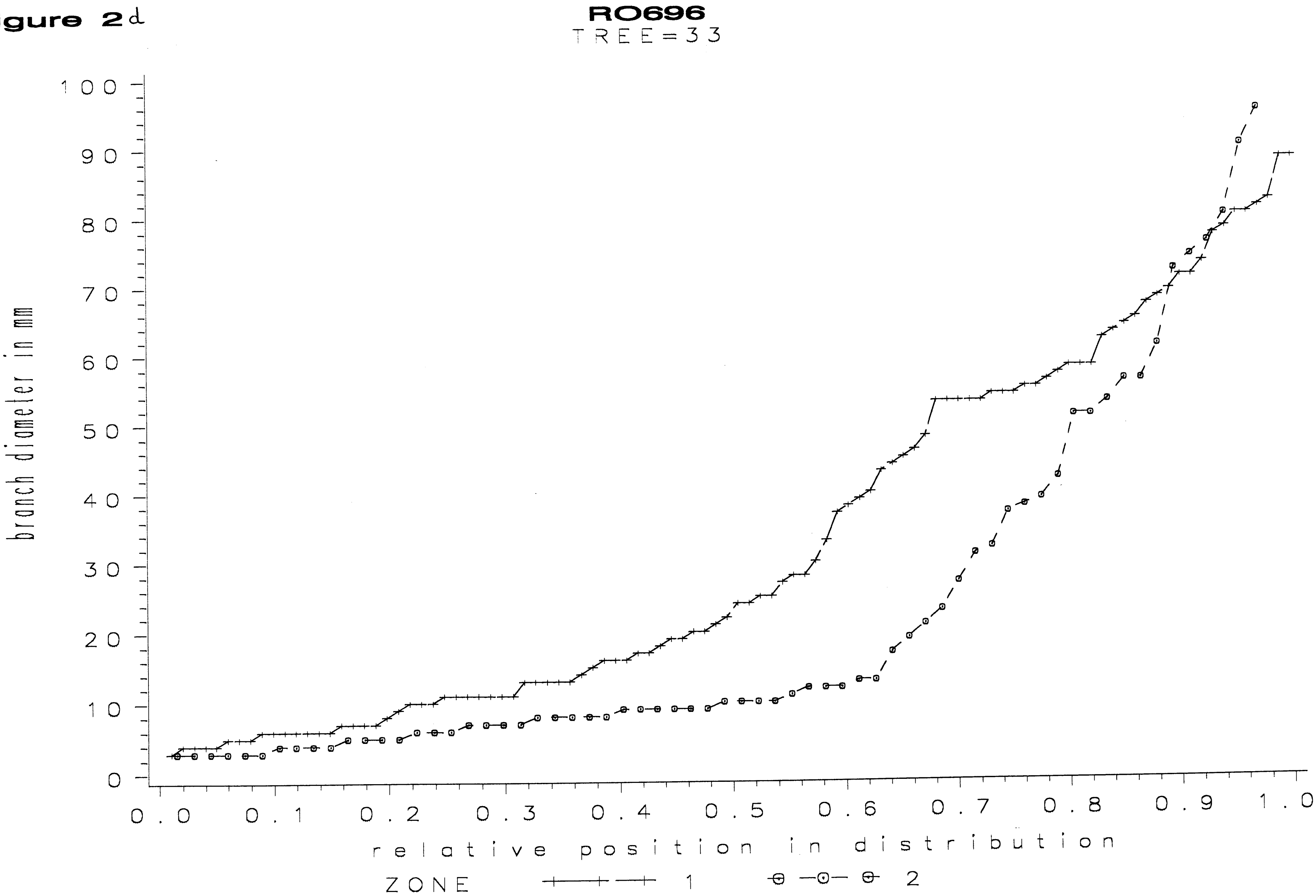

RO696
TREE=33
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2e

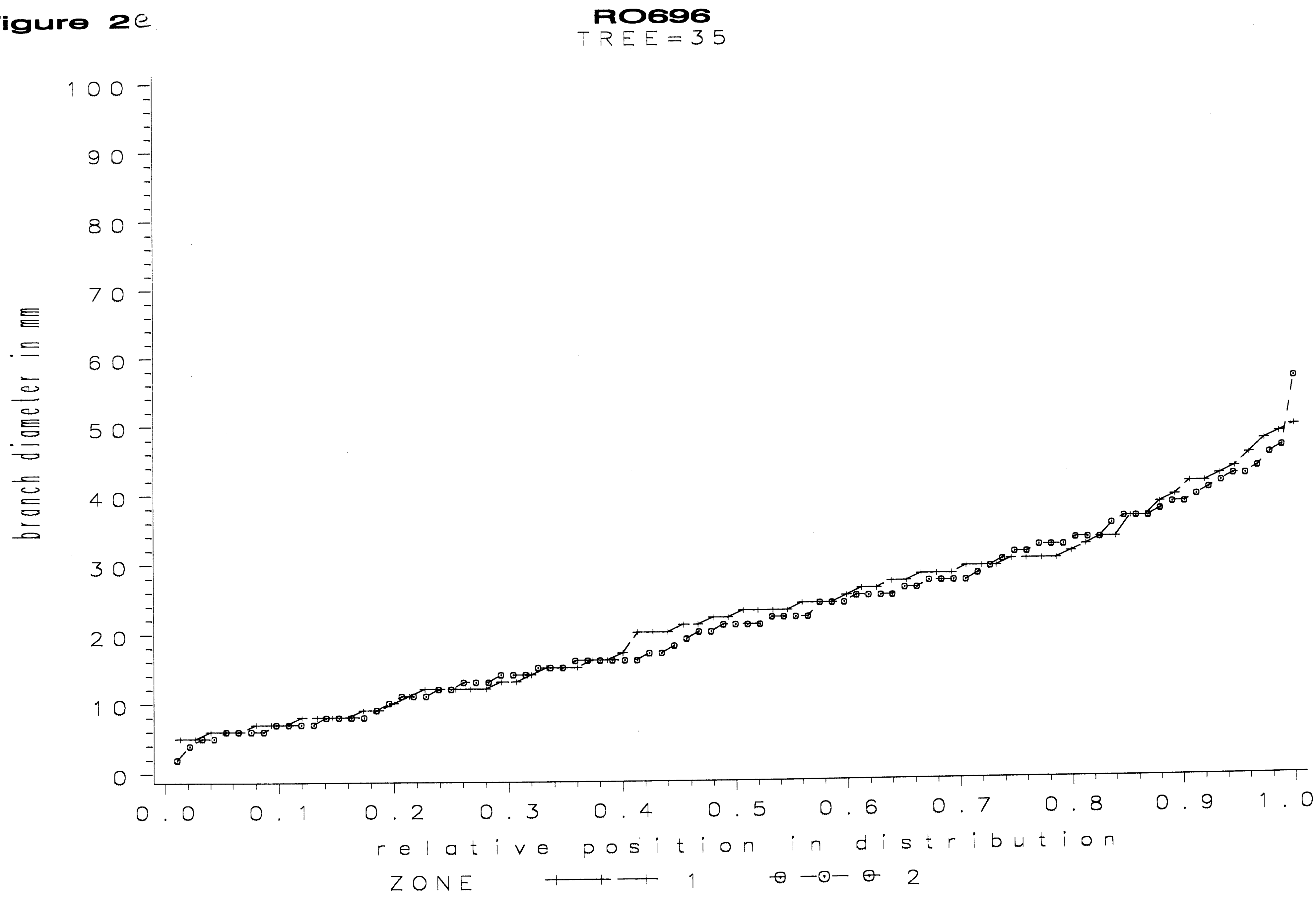

RO696
TREE=35
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2f

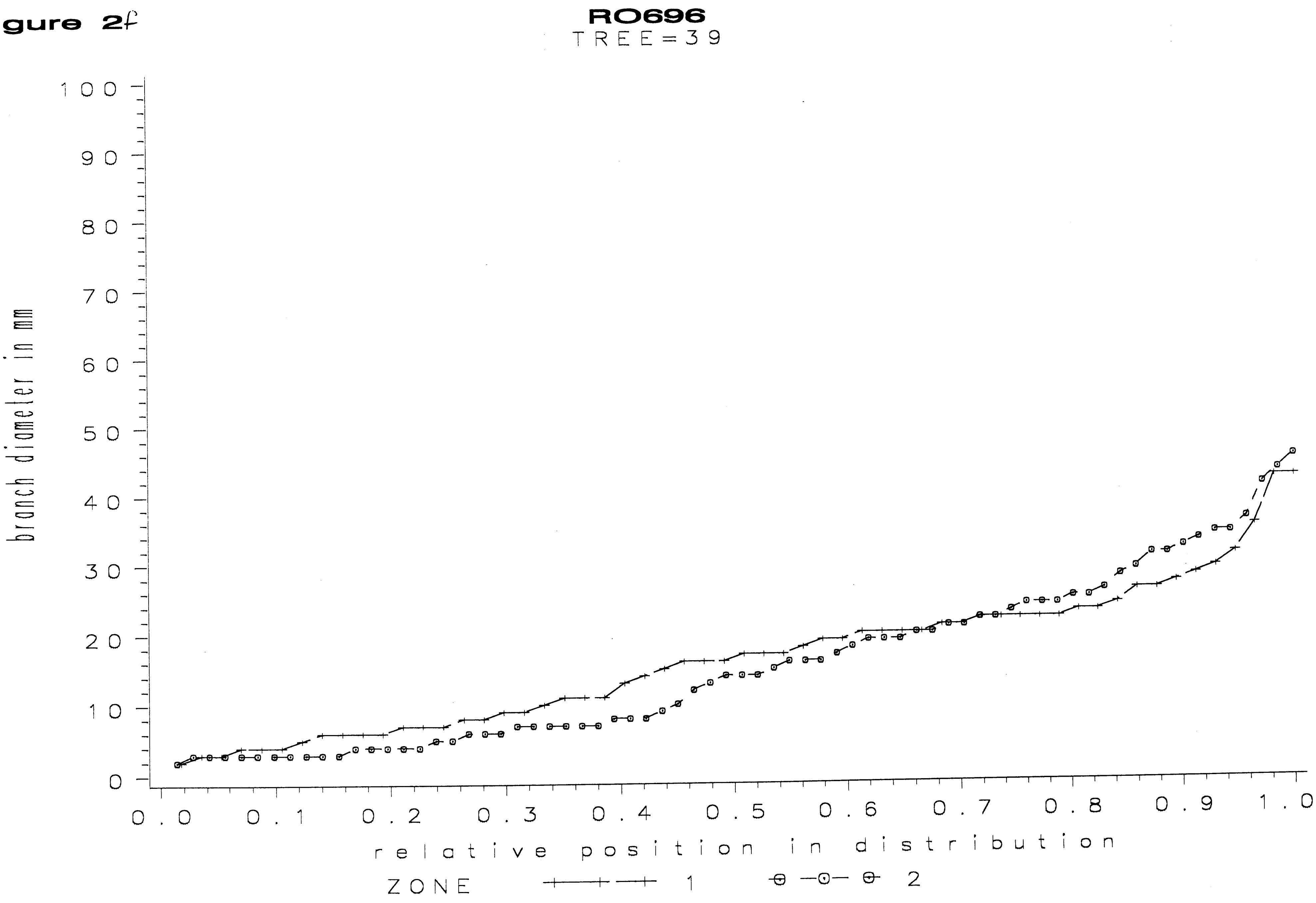

RO696
TREE=39
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 29

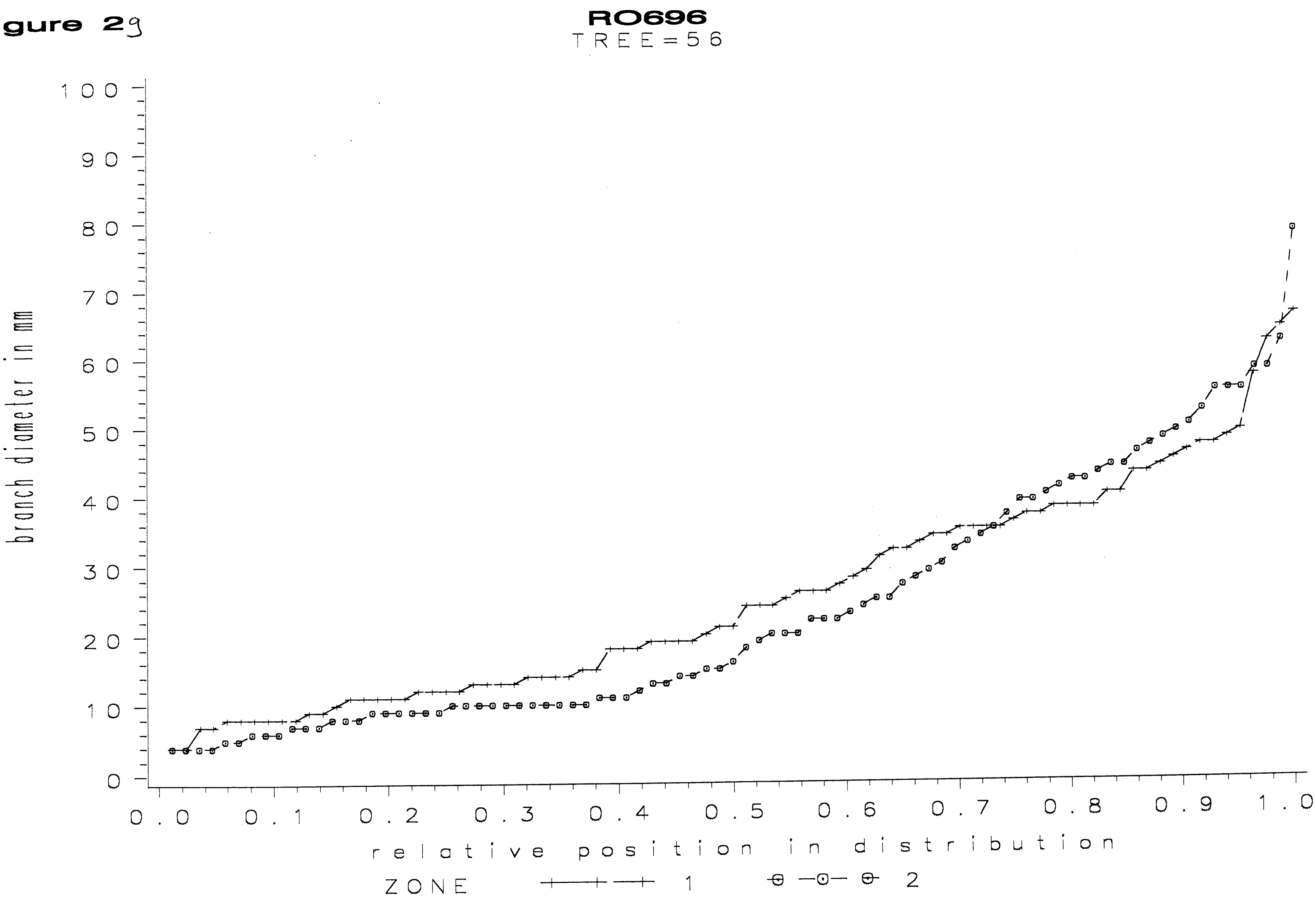

RO696
TREE=56
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2h

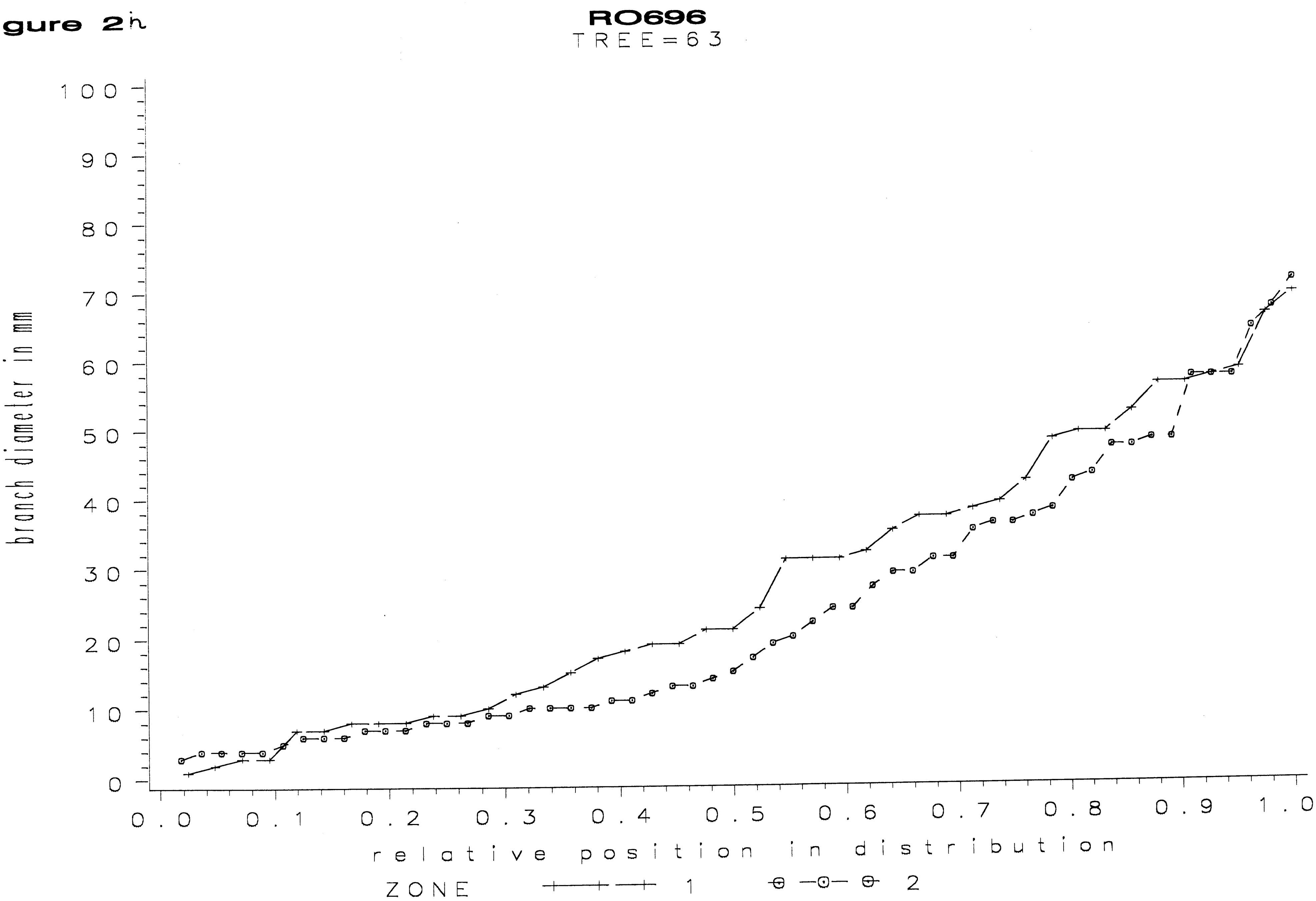

RO696
TREE=63
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2i

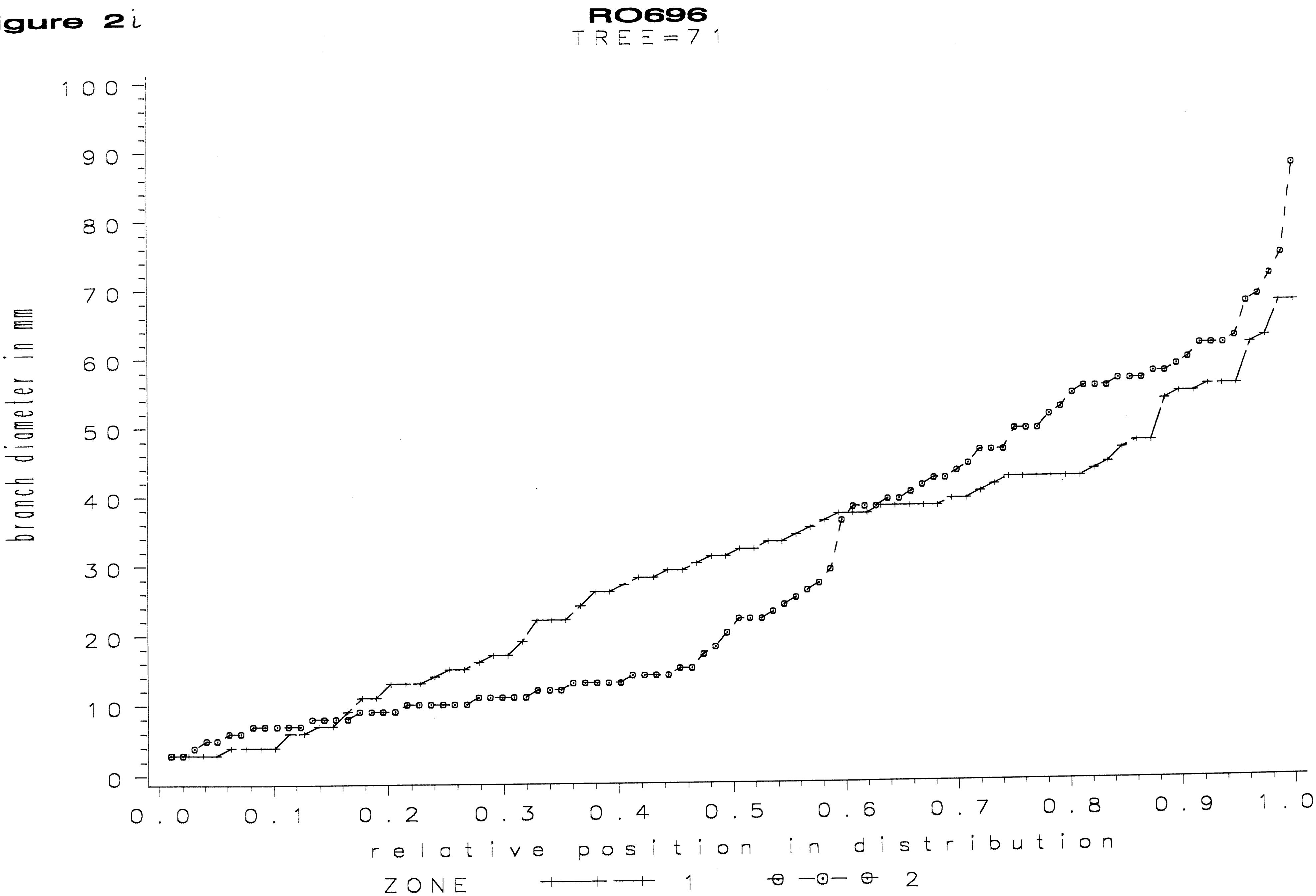

RO696
TREE=71
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

Figure 2j

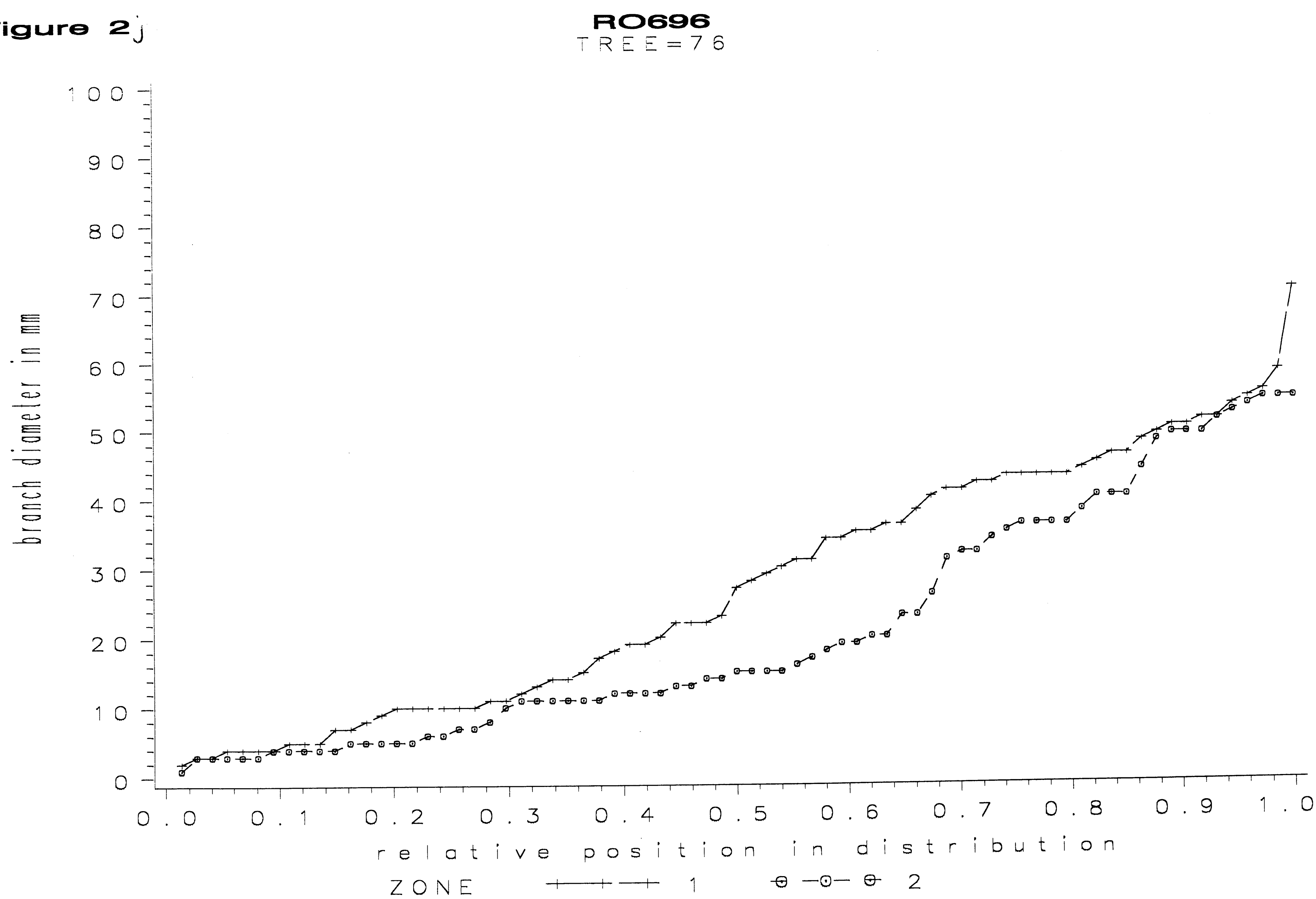
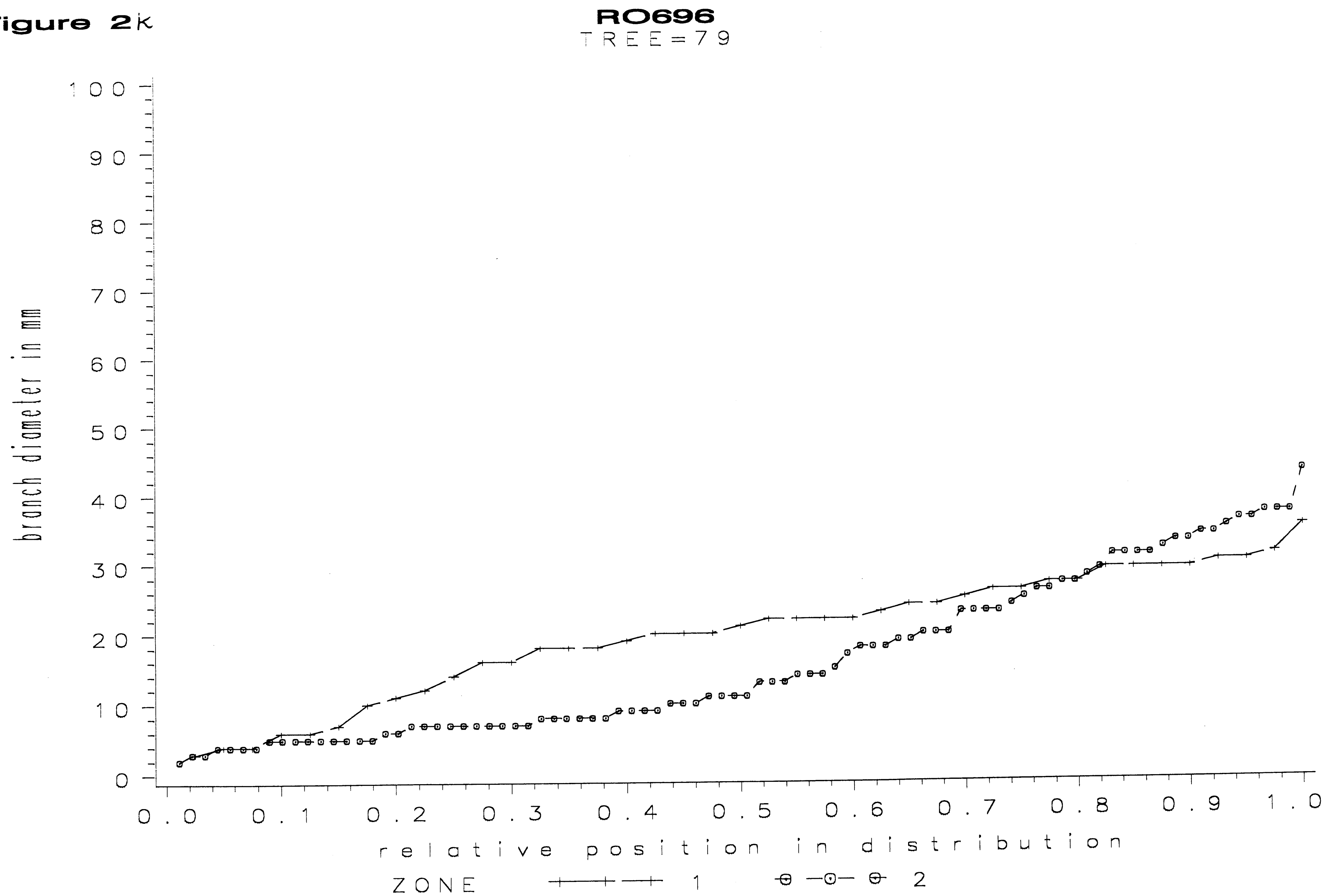

RO696
TREE=76
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE 1 2

Figure 2k



RO696
TREE=79
branch diameter in mm
100
90
80
70
60
50
40
30
20
10
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
relative position in distribution
ZONE
1
2

BRANCH GROWTH RESPONSE TO A THINNING

INTRODUCTION

Experiment RO905 was planted in 1967 at a spacing of 1.8 m x 1.8 m (3086 stems/ha). Plots 20 m x 40 m were established in 1970 and a variety of thinning treatments applied in subsequent years. During summer 1996, 13 sample trees were felled from a range of these treatments as outlined in Table 1.

Table 1. 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	1976	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

Data relating to the branching characteristics of these trees were collected to be used in developing the branch growth model (see Grace *et al.* (1996) for further details).

The objective of this study is to determine for which branches, branch diameter growth can increase after a thinning when growth has been decreasing prior to thinning. Development of an equation to predict branch diameter increment will be the subject of a future study.

A change in branch diameter growth after a thinning is likely to occur if the branch was still alive at the time of thinning, and if it received extra solar radiant energy after thinning enabling it to grow more vigorously. Easily measured variables that may be useful in predicting the influence of thinning on branch diameter growth are therefore:

* Branch diameter and branch age at the time of thinning (together these variables are likely to indicate whether the branch is still alive).

*	Stems/ha before and after thinning (together these variables give an indication of the average change in growing space).

*	Tree age at time of thinning (if response to thinning depends on tree age).

*	Tree size, or relative tree size at the time of thinning (as Grace (1997) found that branch diameter distributions for stem sections formed before and after thinning were different on larger trees but varied little on smaller trees).

METHODS

Sample branches were selected from clusters formed 2 - 5 years prior to thinning. Branches more than 5 years old are unlikely to respond (Grace, 1996). These branches were cut open and planed to expose the branch pith. Branch diameter was measured for each year that the stem had grown (see Grace *et al.* (1996) for further details). Data were available for 81 sample branches and these data were used to examine whether branch diameter growth can increase after a thinning when growth has been decreasing prior to thinning.

For a branch to show a decrease in branch diameter growth prior to a thinning and an increase in branch diameter growth after the thinning, there needs to be at least 3 growth rings present at the time of thinning (assuming that the edge of the wood is counted as a ring). This gives a minimum of two consecutive annual increments to observe whether branch growth is slowing down prior to thinning. The increment between the pith and 1st growth ring is not necessarily an annual increment and has not been considered.

The sample branches were divided into groups according to the number of branch growth rings present at the time of thinning. Independently they were also split into "classes" according to the time of thinning and nominal stocking after thinning (see Tables 1 and 2).

Table 2. Labels used on graphs for different classes of sample branches

Class Label	Sample Branches on:	May Respond to thinning in:
12	trees 1-3;	1974
22	trees 1-3;	1983
792	trees 4 and 5	1979
762	trees 6 and 7	1976
764	trees 8 and 9	1976
742	trees 10 and 11	1974
744	trees 12 and 13	1974

For each sample branch, annual growth increments were calculated and plotted against initial age. These were examined and coded according to their response to the thinning (see Table 3).

Table 3. Codes for response to thinning.

Code	Response to thinning
0	Little or no growth after thinning
1	Response starts in second year after thinning.
2	Response starts in year after thinning
3	Growth continues with no obvious response to thinning

It is considered that these codes are a logical progression for representing the ability of a branch to increase in diameter following a thinning. For branches coded 3, it is not possible to tell whether or not the increment declined more slowly as a result of the thinning. For each of these response codes, a graph for an individual branch is shown in Fig. 1 as an example.

All branches, except those in class 22, were thinned from a common initial stocking of 3086 stems/ha. In coding the responses, it was noticed that many of the branches in class 22 (initially at 300 or 400 stems/ha) were being coded as 3.

Initial plots of the data did not reveal any obvious relationships between the response code and independent variables. In order to gain an idea of the variables influencing the response code, the SAS procedure PROC RSQUARE was used to determine which subsets of independent variables best predicted the response code using linear regression. PROC RSQUARE was run for:

(a) the whole dataset
(b) excluding branches in class 22

The following variables were considered initially:

BDIAM	branch diameter at time of thinning
THINAGE	branch age at time of thinning
TREEAGE	tree age at time of thinning
ISPH	stems/ha before thinning
ATSPH	stems/ha after thinning
IGS	increase in growing space: $(100/\sqrt{ATSH} - 100/\sqrt{ISPH}) / (100/\sqrt{ISPH})$

PROC RSQUARE was run a second time including the most appropriate variables from above, and allowing it to add one more variable from the following list:

RDMAX	tree diameter / maximum diameter in plot (at time of thinning)
RDMEAN	tree diameter / mean diameter in plot (at time of thinning)
RBAMAX	tree basal area / maximum basal area in plot (at time of thinning)
RBAMEAN	tree basal area / mean basal area in plot (at time of thinning)

Each of these variables is a measure of the relative size of the tree at the time of thinning.

Once the likely model had been selected, The SAS procedure, PROC REG, was run to determine the coefficients of the regression model. This regression model was then used to produce a table of response codes for different inputs.

RESULTS

Fig. 1 shows branch diameter increment versus age for four branches with different response codes. The absence of a bar at any age indicates that no growth occurred. Figure 1a shows a branch which does not respond to thinning and does not grow after thinning . Figures 1b shows a branch which responds in the year following thinning, ie. the increments in the year of thinning are no greater than the previous year, but are larger in the year following thinning. Figure 1c shows a branch which responds in the year of thinning, ie the increment is larger in the year of thinning than in the previous year. Figure 1d shows a branch which has a response code of 3. These branches were coded as 3 because there were reasonable increments after thinning even though the increments did not increase relative to the year prior to thinning.

The results of the PROC RSQUARE analysis are shown in Table 4.

Table 4. Variables giving highest R-square from first run of PROC RSQUARE.

Number of variables in regression	Variables included using all data	R-square using all data	Variables included excluding class 22	R-square excluding class 22
1	BDIAM	0.15	THINAGE	0.08
2	BDIAM THINAGE	0.22	BDIAM THINAGE	0.13
3	BDIAM THINAGE ISPH	0.26	BDIAM THINAGE ATSPH	0.13
4	BDIAM THINAGE ATSPH IGS	0.26	BDIAM THINAGE ATSPH TREEAGE	0.13
5	BDIAM THINAGE ISPH IGS ATSPH	0.28		
6	BDIAM THINAGE TREEAGE ISPH ATSPH IGS	0.28		

When all data are considered, the most appropriate variables to be included in a regression model appear to be BDIAM, THINAGE, ISPH, ATSPH and IGS. Adding further variables does not improve the model (Table 4).

When class 22 is excluded, the most appropriate variables to include in a regression model appear to be BDIAM and THINAGE (Table 4). ISPH is not included as there was no variation in the initial stocking.

It seems reasonable that the ability of a branch to respond to a thinning should depend on its diameter and age at the time of thinning. It is possible that stocking and growing space variables were significant, when using the complete dataset, as CLASS 22:

was at a different initial stocking from the rest of the classes,
the change in growing space was much less than for the rest of the classes,
it was noticed that the response code for many observations in this class was 3.

When the variables indicating the relative size of the tree were included and PROC RSQUARE run (Table 5), the following results were obtained when one of the variables representing relative tree size was included in the regression:

* with 3 or less independent variable, there was essentially no difference between RBAMAX and RDMAX in usefulness (the difference in R-square was less than 0.005), but they were clearly more appropriate than RBAMEAN and RDMEAN;

* with 4 or more independent variables, there was no difference in the value of R-square (to 2 decimal places) between the four variables representing relative tree size.

Comparing the results in Table 5 with those in Table 4 it is clear that the relative size of the tree at the time of thinning is likely to affect the ability of a branch to respond to thinning.

For the whole dataset, there was little increase in R-square with 4 or more, rather than 3 independent variables.

Table 5. Variables giving highest R-square from second run of PROC RQSUARE.

Number of variables in regression	Variables included using all data	R-square using all data	Variables included excluding class 22	R-square excluding class 22
1	RBAMAX	0.16	THINAGE	0.08
2	BDIAM RBAMAX	0.22	BDIAM THINAGE	0.13
3	BDIAM THINAGE RBAMAX	0.30	BDIAM THINAGE RDMAX	0.17
4	BDIAM THINAGE IGS RBAMEAN	0.31		
5	BDIAM THINAGE ISPH IGS RBAMEAN	0.31		
6	BDIAM THINAGE ISPH ATSPH IGS RBAMEAN	0.31		

With three independent variables, BDIAM, THINAGE and one of RDMAX or RBAMAX are the most suitable variables for predicting the likely response to a thinning for the whole dataset or excluding class 22. Given that RDMAX would be slightly easier to calculate in the field, it was decided to use this variable in preference to RBAMAX.

PROC REG was run for the whole dataset using BDIAM, THINAGE, and RDMAX as independent variables. It was found that the parameter estimates for the intercept was not significant.

As all four variables representing relative tree size appeared equally appropriate, PROC REG was also run for the whole dataset using BDIAM, THINAGE, IGS and RDMAX to determine whether IGS should be included in the regression model. The estimated coefficient for IGS was not significantly different from zero, indicating that the change in growing space was not useful in predicting the response to thinning.

The regression model developed for predicting response codes was therefore:

$$\text{Response code} = 0.046\ \text{BDIAM} - 0.38\ \text{THINAGE} + 2.30\ \text{RDMAX} \quad (1)$$

The predicted response codes for different initial values of BDIAM, THINAGE and RDMAX are shown in Table 6. A predicted response codes have been rounded to the nearest integer. A predicted response code of less than zero was assumed to be zero. Similarly, a predicted response code of greater than 3 should be assumed to be 3.

Table 6. Predicted response codes using Equation 1.

Branch diameter 10 mm at time of thinning

Branch age at time of thinning	3 years	6 years	9 years
RDMAX at time of thinning			
0.25	0	0	0
0.50	0	0	0
0.75	1	0	0
1.0	2	0	0

Branch diameter 30 mm at time of thinning

Branch age at time of thinning	3 years	6 years	9 years
RDMAX at time of thinning			
0.25	1	0	0
0.50	1	0	0
0.75	2	1	0
1.0	3	1	0

Branch diameter 50 mm at time of thinning

Branch age at time of thinning	3 years	6 years	9 years
RDMAX at time of thinning			
0.25	2	1	0
0.50	2	1	0
0.75	3	2	1
1.0	3	2	1

DISCUSSION

The number of sample branches for which data were available was smaller than planned. Firstly, the access pruning had removed branches which might have responded to the thinning in 1974. Secondly, some samples could not be measured due to the branch pith being missed in planing (see Grace *et al.*, 1996).

From Figure 1, it is clear that some branches are responding to the thinning.

The analyses using PROC RSQUARE and PROC REG indicate that branch diameter and branch age at time of thinning, together with relative tree size at the time of thinning are the variables most likely to influence the branches ability to respond to the thinning. These variables, and the results in Table 6 seem logical. Branches which are most likely to respond to thinning are the younger and larger branches on the more dominant trees. It must be remembered that Eqn. 1 has only been derived from a few trees on 1 site, and is therefore only a preliminary result. Eqn. 1 will not predict the diameter increment in response to thinning, but its derivation is useful in that it shows which branches are likely to respond to thinning.

Tree age at time of thinning did not have a major influence on the response code. There were 3 (excluding class 22) or 4 (including class 22) different ages of thinning in this dataset, and should have been sufficient to determine whether tree age was important.

Stocking before and after thinning, and change in growing space did not influence the response code for this dataset. Apart from Class 22, all trees were at the same initial stocking. It is possible that there is no additional effect of initial stocking over and above its influence on branch diameter distribution at time of thinning. However, it is also possible that there was insufficient variation in initial stocking to observe any trends. The stocking after thinning was either 200, 300 or 400 stems/ha. It is possible that there was insufficient variation in stocking after thinning to observe a response. One might expect the change in growing space to influence the ability of a branch to respond to a thinning. However the increase in growing space (IGS) was not useful for predicting the response code for this dataset, perhaps because there was little variation in IGS.

The percentage of the variation explained by Eqn.1 is not high and it is likely that there are other variables influencing a branches ability to respond to a thinning.

FUTURE RESEARCH

The next phase is to determine a methodology for predicting branch diameter increment which incorporates a response to thinning.

The lack of an unthinned plot makes it difficult to determine how much the branches would have grown if there had been no thinning. A new trial(s) should be established with a wider range of initial and final stockings and an unthinned control.

An alternative approach to choosing the sample branches should be considered. The proposed approach is to mark pairs of sample branches of the same diameter on trees of the same DBH in plots that are to be thinned and left unthinned. These branches could then be destructively sampled several years later and the growth compared. Care would be needed to make certain that the pairs of branches were of the same age, but this approach should enable the response to thinning to be more precisely quantified.

ACKNOWLEDGMENTS

Thanks to A. Gordon and D. Pont for commenting on earlier drafts of this report.

REFERENCES

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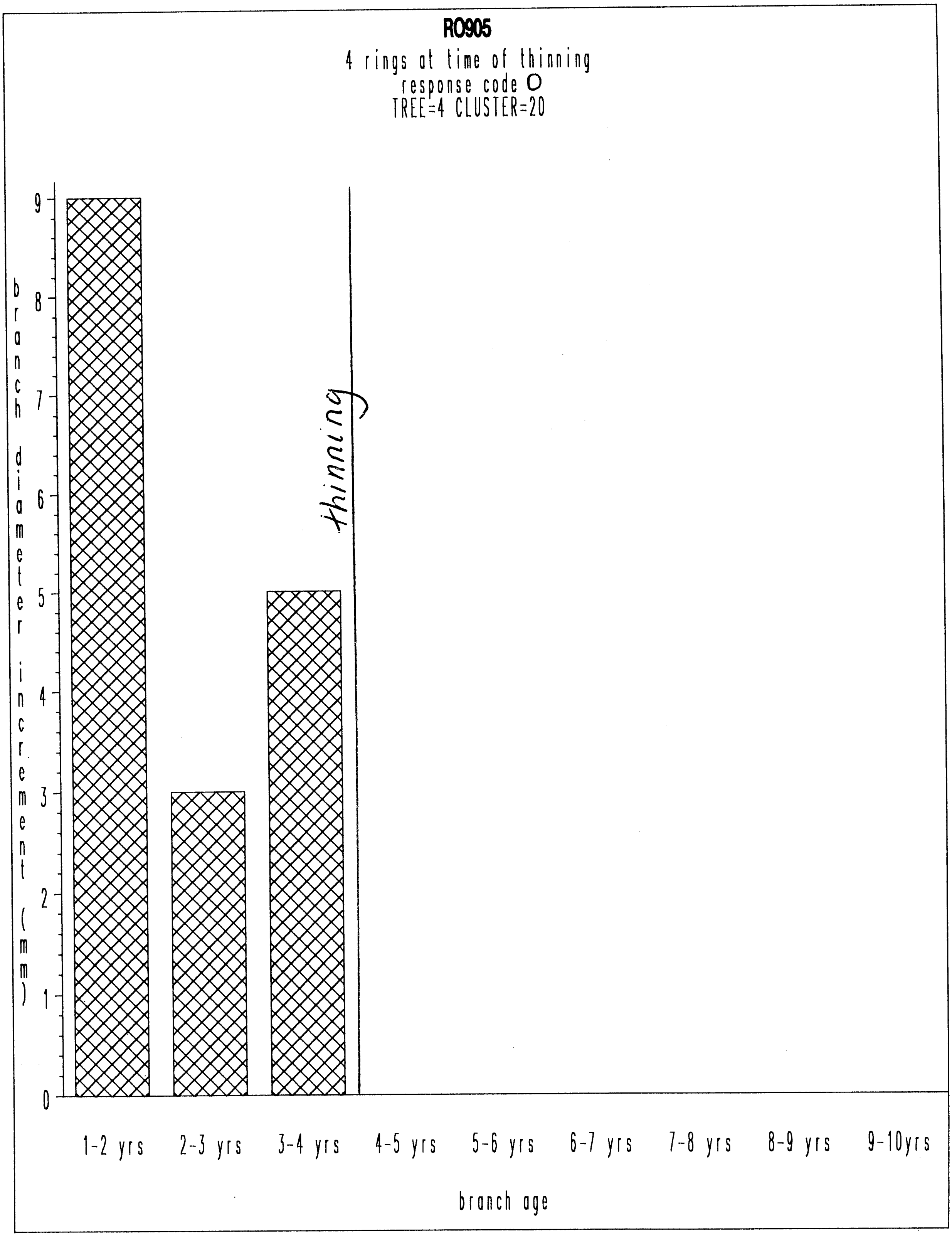
Grace, J.C. 1977: Branch diameter distributions for stem sections. Project Record No. (unpublished).

Grace, J.C. ; Lundgren, C.; Blundell, W. 1996: Branching characteristics of radiata pine in Experiment RO905: Data Collection. Stand Growth Modelling Co-operative Report No. 52 (unpublished).

Figure 1. Branch diameter increment versus age at the beginning of the period.

a. Tree 4, Cluster 20: Response code, 0.
b. Tree 5, Cluster 20: Response code, 1.
c. Tree 5, Cluster 11: Response code, 2.
d. Tree 1, Cluster 31: Response code, 3.

Figure 1a



RO905
4 rings at time of thinning
response code O
TREE=4 CLUSTER=20
branch diameter increment (mm)
0
1
2
3
4
5
6
7
8
9
thinning
1-2 yrs
2-3 yrs
3-4 yrs
4-5 yrs
5-6 yrs
6-7 yrs
7-8 yrs
8-9 yrs
9-10yrs
branch age

Figure 1b

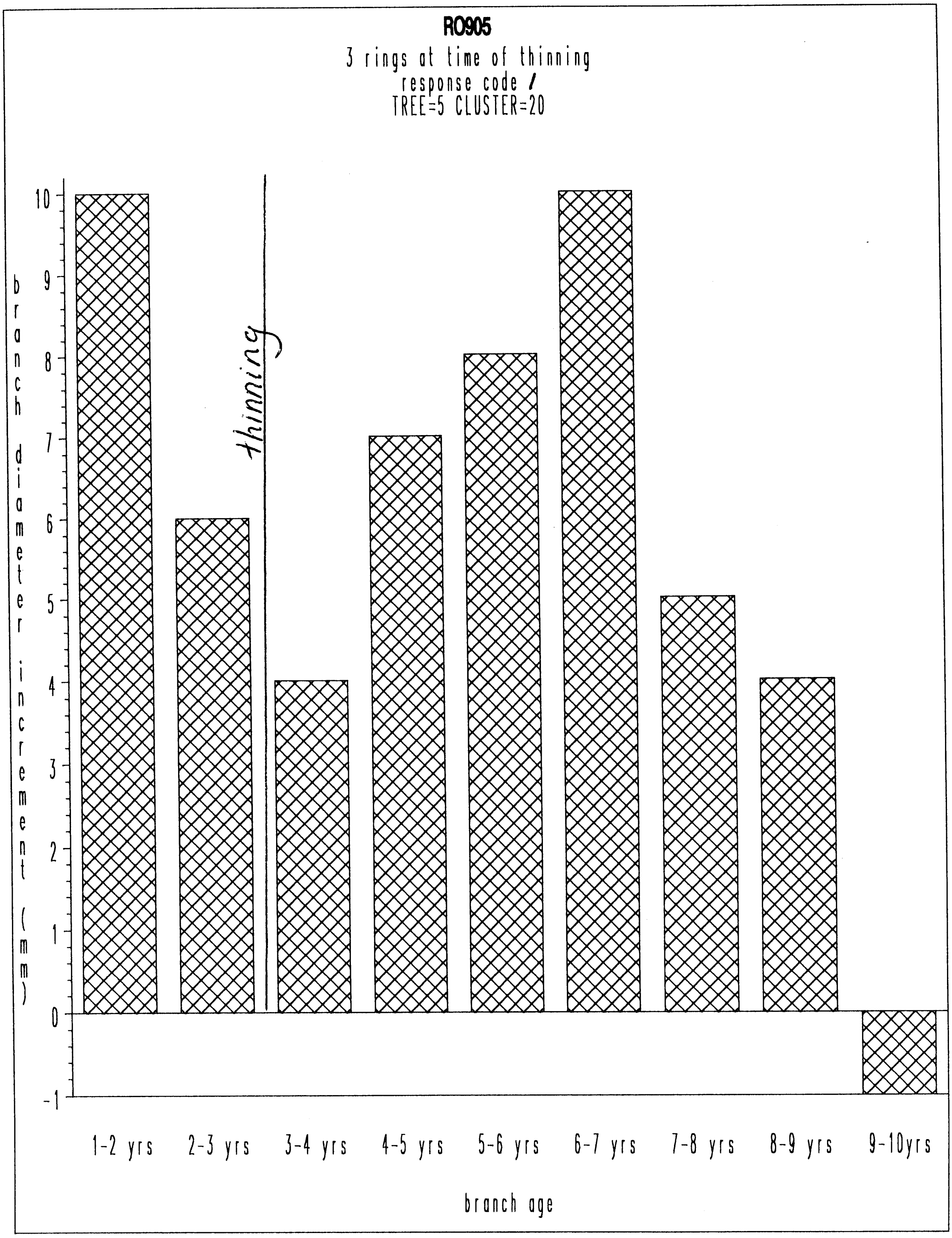

RO905
3 rings at time of thinning
response code 1
TREE=5 CLUSTER=20
thinning
branch diameter increment (mm)
10
9
8
7
6
5
4
3
2
1
0
-1
1-2 yrs
2-3 yrs
3-4 yrs
4-5 yrs
5-6 yrs
6-7 yrs
7-8 yrs
8-9 yrs
9-10yrs
branch age

Figure 1c.

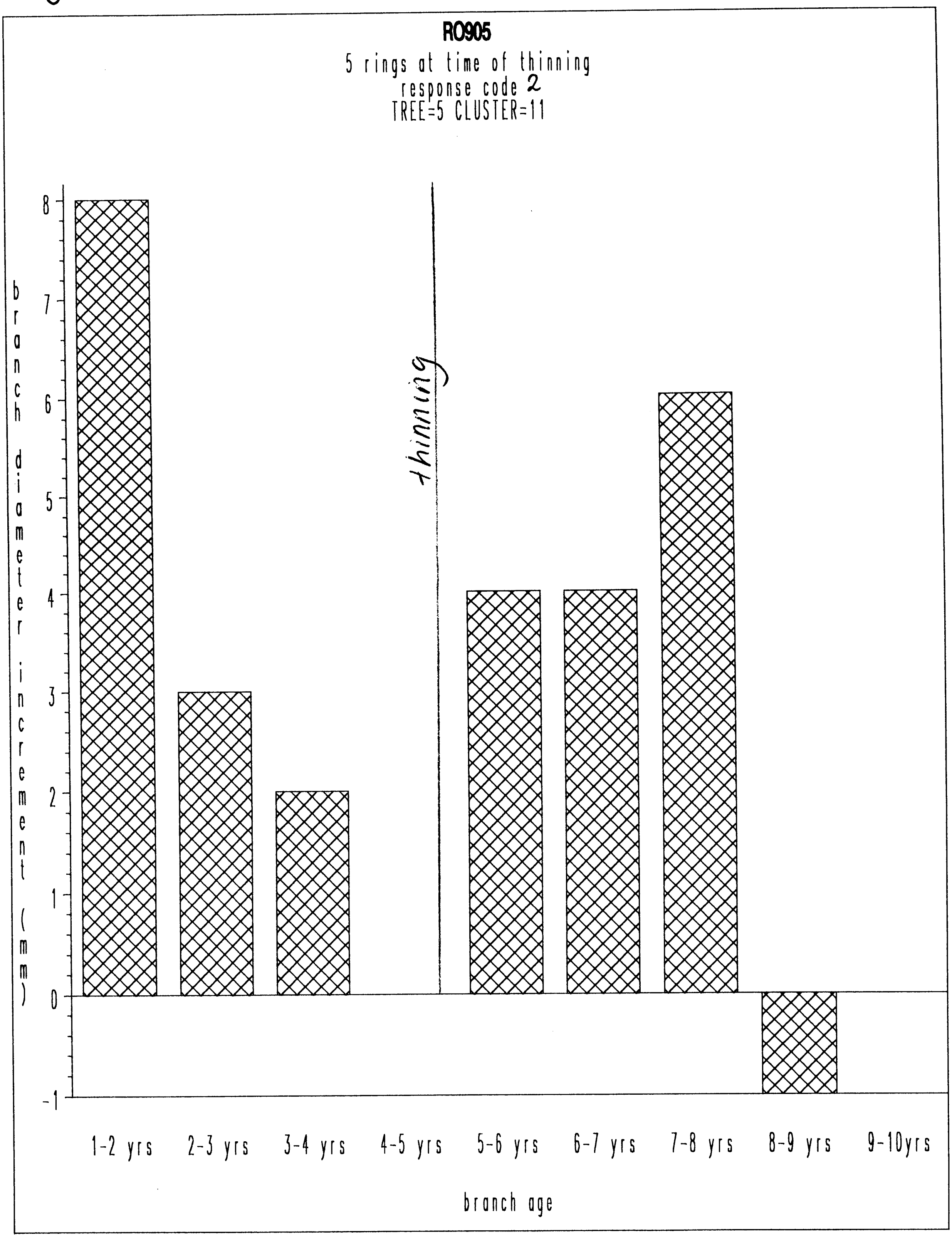
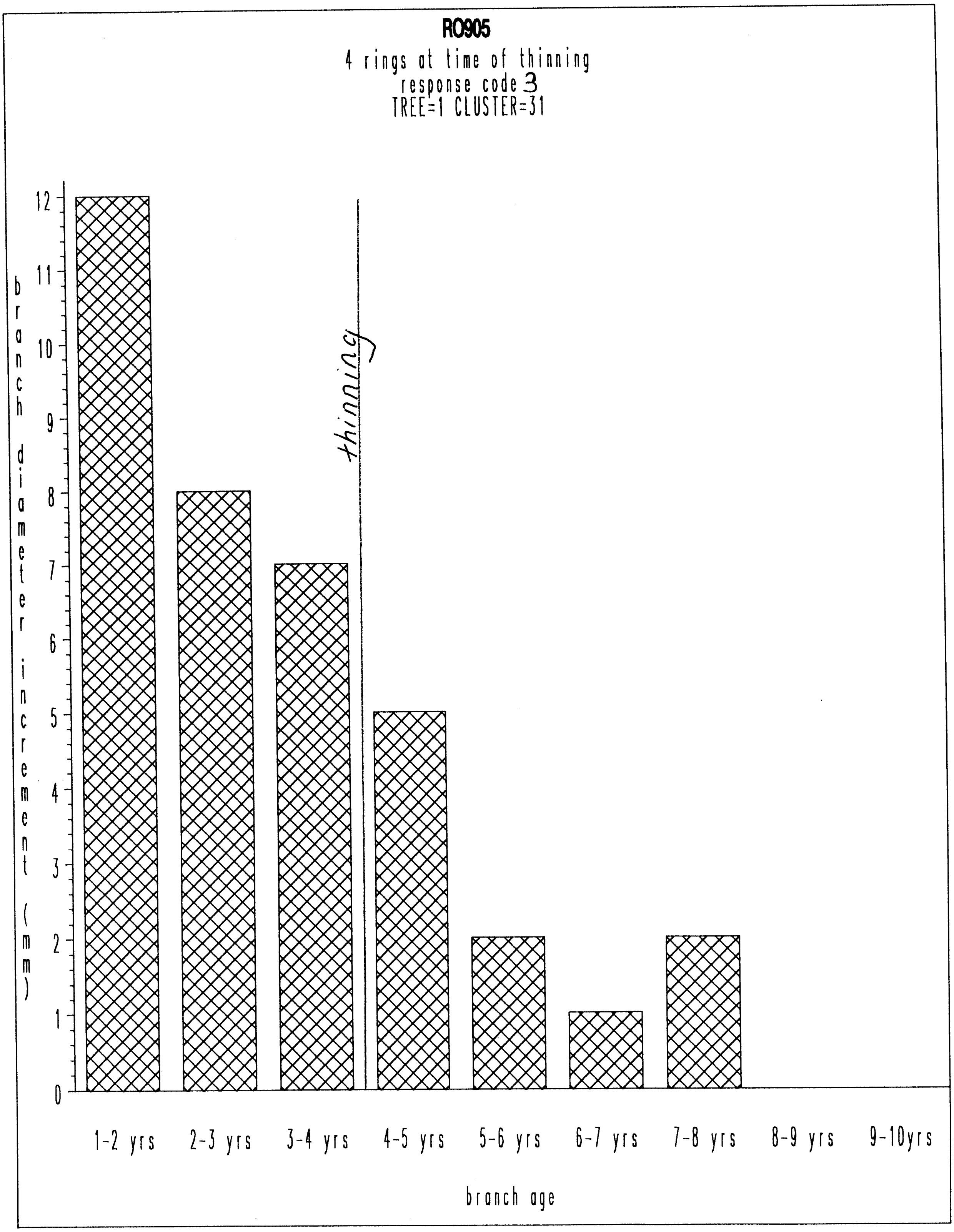

RO905
5 rings at time of thinning
response code 2
TREE=5 CLUSTER=11
branch diameter increment (mm)
8
7
6
5
4
3
2
1
0
-1
thinning
1-2 yrs
2-3 yrs
3-4 yrs
4-5 yrs
5-6 yrs
6-7 yrs
7-8 yrs
8-9 yrs
9-10yrs
branch age

Figure 1d.


RO905
4 rings at time of thinning
response code 3
TREE=1 CLUSTER=31
branch diameter increment (mm)
0
1
2
3
4
5
6
7
8
9
10
11
12
thinning
1-2 yrs
2-3 yrs
3-4 yrs
4-5 yrs
5-6 yrs
6-7 yrs
7-8 yrs
8-9 yrs
9-10yrs
branch age