AZIMUTH ANGLE OF THE LARGEST BRANCH IN A CLUSTER

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EXECUTIVE SUMMARY

The azimuth angle of the largest branch in a cluster is highly variable, but tends to avoid southerly directions. Consequently, the observed distribution is statistically non-uniform. The mean direction appears to be determined by availability of light. The angle between the largest branch in adjacent clusters is random. The diameter of the largest branch is generally not correlated with azimuth angle.

In the branch model it is suggested that the azimuth angle of the largest branch in a cluster is determined by selecting a random angle from a von Mises distribution. The diameter of the largest branch can be determined independently from its azimuth angle.

Further research to understand the influence of site factors, such as slope and aspect, is suggested.

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INTRODUCTION

On young radiata pine shoots, it has been observed that branches are initiated in a spiral sequence. Several sequences have been observed. In the most common sequence, there is an angle of 137.5° between successive branches. Also branch diameter tends to increase with increasing height in the sequence. This spiral arrangement leads to the visually observed patterns of branches within a cluster, the larger branches are distributed around the circumference and are separated by smaller branches (Pont, 1999). Doruska and Burkhart (1994) found that loblolly pine branches were uniformly distributed around the stem. Though, not mentioned by the authors, the observed pattern is likely to have been due to the underlying phyllotaxy. Rouvinen and Kuuluvainen (1997) suggest that initial morphological patterns may be modified by future growth so that the crown adapts to the local growing environment. In situations of minimal competition, Scots pine crowns in the northern hemisphere were found to be asymmetric and longer towards the south (Skatter and Kuncera, 1998). Local competition also influenced the crown shape (Rouvinen and Kuuluvainen, 1997). It is considered that the local competition is the dominant effect in determining crown shape (Skatter and Kuncera, 1998).

Radiata pine crowns are not necessarily symmetrical in terms of crown width. The most extreme asymmetry is likely to occur on trees growing in shelterbelts, on forest edges, or on slopes. Bedingfield (1980) showed that the crown width was wider on the downhill side of trees growing on both north and south facing slopes. This is likely to be due to at least one larger branch on the downhill side of the tree as branch diameter has been found to be positively correlated with branch length (Grace, 1992). From sampling two single row shelterbelts (one orientated North-South, and one orientated East-West), Tombleson and Inglis (1988) found that both neighbouring tree size and aspect influenced the mean branch diameter per quadrant in a 5.5 m log.

Within the branch model (Grace and Pont, 1998), functions are required to position branches within a cluster. Provided that the azimuth angle and diameter of one branch (the largest) is known, the azimuth angles of the other branches can be determined using phyllotaxy (Pont, 1999). Their relative diameters can be determined from the diameter of the largest branch using the function developed by Grace (1996).

The objective of this study is firstly to determine the distribution for the azimuth angle of the largest branch in a cluster; secondly to determine whether the azimuth angle between the largest branch in adjacent clusters is random; and thirdly whether there is any correlation between azimuth angle and branch diameter for the largest branch.

DATA AVAILABLE

Branch diameter and azimuth angle have been measured on several trees from four different sites as outlined below.

Taringatura, Southland

Diameter and azimuth angle were measured for each branch in each cluster below 20- 21 m (or until a stem diameter of approx 10 cm if that came first) for 5 trees from the "850" diallel trial at Taringatura (see Grace *et al* (1999) for further details on the sample trees).
The trial was adjacent to a forestry track running downhill in approximately a SW direction. The sample trees were on the northern side of the track where the land sloped down to a stream (approximately NW direction).

Kaingaroa, Compartment 905

Diameter and azimuth angle were measured for each branch in each cluster above the lowest live branch for 8 trees in the "850" diallel and 8 trees in the uninodal progeny trial at Compartment 905, Kaingaroa. Data from the topmost clusters with approximately 5 or less growth rings have not been considered as azimuth angles were measured using a different technique from the rest of the data (see Grace *et al* (1998) for further details on the sample trees).
The trial site was flat and adjacent to a forestry road.

Kaingaroa, Experiment RO905

Diameter and azimuth angle were measured for each branch in each cluster with more than 9 stem growth rings for 9 trees. These trees were from plots which had been thinned at various times (see Grace *et al* (1996) for further details on the sample trees).
The site was undulating.

Woodhill

Diameter was measured for each branch in each cluster for 8 trees from the "850" diallel at Woodhill. Azimuth angle was measured for all branches on 6 of these trees. Azimuth angle of the largest branch in a cluster was measured on the two other trees (see Grace *et al* (1999) for further details on the sample trees).
The site was flat.

For each of the above trees, the location of all neighbouring trees within a circular plot centred on the sample tree was recorded. The radius of the plot was chosen to give 10 trees at the nominal stocking. The distance to, the bearing of , and the DBH of the neighbouring trees were measured

Apart from Experiment RO905 which had been subjected to various thinning treatments, the location of neighbours at time of felling is likely to be representative of the competition the tree and branches had grown under.

AZIMUTH ANGLE OF THE LARGEST BRANCH IN A CLUSTER.

Methods

For the above trees, maximum branch diameter in each cluster was determined. The cluster was considered in the following analysis, provided that:

- diameter had been recorded for all branches in the cluster (occasionally a branch was too badly damaged to be measured),
- there was only one branch with the maximum diameter.

Two uninodal trees were excluded from further analyses as data were available for less than 10 clusters.

For each tree:

- maximum branch diameter was plotted against azimuth angle (Appendix 4),
- the mean azimuth angle (mean direction) and mean vector length (a measure of concentration) were calculated using circular statistics (Appendix 1),
- the Rayleigh test of uniformity was used to determine whether the azimuth angle of the largest branch in a cluster was uniformly distributed around the circumference, or whether there was a preferred direction for the azimuth angle of the largest branch in a cluster,
- mean azimuth angle was visually compared with the position of the neighbouring trees (except for RO905 where position of neighbours at time of felling is not representative due to previous thinnings).

Results

When these trees were measured, a preferred direction for the largest branch per cluster was not obvious. Plots of maximum branch diameter versus azimuth angle indicated that there is generally a wide scatter in the azimuth angles and there is only a small sector (generally towards the south) where the largest branch tends not to occur (Appendix 4).

The sample size, mean azimuth angle, mean vector length are shown in Table 1. The final column (Table 1) indicates the outcome of the Rayleigh test of uniformity. "Yes" means that there is a preferred azimuth direction. "No" means that the azimuth angles are uniformly distributed round the circumference. The results indicate that there is generally a preferred azimuth angle for the largest branch per cluster for the majority of the trees. However the mean vector length was generally small indicating that the azimuth angles are not tightly concentrated around the mean value. From examining the graphs (Appendix 4), the main reason that a non-uniform distribution occurs is that branches are avoiding southerly azimuths.

The mean azimuth angle was plotted as a point on the same graph as the position of the neighbours (Appendix 4). This enabled the preferred azimuth direction to be visually compared with the position of the neighbours.

Taringatura

The variability in azimuth angle was least for tree 6. This tree was leaning. The other trees were essentially straight. The direction of maximum lean was not recorded but, from examining the "PHOTOMARVL" picture, it appears that the preferred azimuth angle is on the upper side of the tree.

The variability in azimuth angle was most for tree 7. This tree was at the edge of the trial, adjacent to a forest track and did not have any neighbouring trees between east and south.

For trees 3 and 5, the neighbouring trees were fairly evenly spaced. The preferred azimuth direction was close to North, and is likely to be close to the direction of maximum slope.

Tree 8 was in a flatter area compared to the other trees. There were fewer neighbours to the north, and the preferred azimuth was to the north.

Kaingaroa, Compartment 905

No record was kept of the straightness of each tree. The "850" trees are considered to have been fairly straight. At least two of the uninodal trees (trees 9 and 12) were leaning.

"850" trees (trees: 1-8)

The "850" trees in Compartment 905 (trees 1-8) were very regularly spaced. Here only 50% of the trees had a preferred azimuth angle for the largest branch per cluster.

Trees1-3 and 6-8 were from plots adjacent to, and on the east side of a main forestry road running approximately North-South. Tree 4 was from a plot, adjacent to a slash heap on the east side of the road. Tree 5 was from a plot, one plot in from the road. It is thus likely that the trees had more available light on the west side of the tree, and it is of note that, all but tree 5 have a preferred azimuth angle on the west side of the tree suggesting that the proximity to the road may have affected light availability.

Uninodal trees (trees: 9 - 16)

These trees were also on the east side of a main forestry road, but were further from the edge. Originally there were 2 m between trees in the rows running approximately E-W and 4 m between rows running approximately N-S. However the stand has been thinned and mortality has occurred. For all trees, the preferred azimuth angle was to the North of West. Trees 9 and 12 were leaning in approximately an easterly direction.

Kaingaroa, Experiment RO905

Due to the fact azimuth angles had been measured from the base of the tree and the trial having been thinned, it is not logical to compare the preferred azimuth angle with the position of the neighbouring trees.
It is of note that the mean azimuth angle was quite variable at this site. The trial site was undulating and it is wondered whether the mean azimuth angle was affected by local slope. It is suggested that slope direction is measured in future.

Woodhill

The trees at Woodhill were visually different from the trees at the other sites, the crowns were narrower and more open which is typical of trees growing in this area. The site was practically flat and there were no major roads in the vicinity of the trial. The mean azimuth angle for the largest diameter branch in each cluster varied between 312° and 358°.

Table 1. Circular statistics for sample trees.

Site	Tree	Number of clusters	Mean vector length	Mean Azimuth Angle (degrees)	Significant ($p \leq 0.05$)
Taringatura	3	21	0.38	3	yes
	5	28	0.39	359	yes
	6	29	0.74	342	yes
	7	33	0.17	63	no
	8	41	0.55	323	yes
Kaingaroa,	1	30	0.32	324	yes
Compartment 905	2	27	0.22	232	no
	3	36	0.45	317	yes
	4	43	0.49	338	yes
	5	12	0.10	56	no
	6	24	0.20	268	no
	7	18	0.53	324	yes
	8	33	0.22	321	no
	9	56	0.16	338	no
	10	30	0.42	310	yes
	12	47	0.45	302	yes
	13	32	0.45	332	yes
	14	23	0.51	338	yes
	16	24	0.53	321	yes
Kaingaroa,	1	45	0.55	9	yes
RO 905	6	42	0.27	97	yes
	7	32	0.38	79	yes
	8	48	0.19	301	no
	9	42	0.56	178	yes
	10	52	0.40	225	yes
	11	43	0.18	304	no
	12	44	0.13	306	no
	13	40	0.37	262	yes
Woodhill	1	56	0.20	356	no
	2	76	0.35	337	yes
	3	74	0.27	315	yes
	4	68	0.49	341	yes
	5	55	0.36	358	yes
	6	54	0.24	327	yes
	7	58	0.26	312	yes
	8	43	0.49	333	yes

AZIMUTH ANGLE BETWEEN LARGEST BRANCH IN ADJACENT CLUSTERS

Methods

The difference in azimuth angle between the largest branch in adjacent clusters was calculated provided that:

- diameter had been recorded for all branches in the cluster (occasionally a branch was too badly damaged to be measured),
- there was only one branch with the maximum diameter.

The mean direction and a mean vector length were calculated using circular statistics (Appendix 1).

Results

The distribution could generally be considered uniform (Table 2). The distribution was non-uniform for 4 trees: tree 6, Taringatura (which was swept); and trees 1, 6 and 13 in Kaingaroa, Experiment RO905.

Table 2. Circular statistics for difference in azimuth angle between adjacent clusters

Site	Tree	Number of observations	Mean vector length	Mean Direction (degrees)
Taringatura	3	19	0.12	9
	5	26	0.14	3
	6	28	0.45	356
	7	31	0.03	268
	8	38	0.22	337
Kaingaroa,	1	28	0.09	337
Compartment 905	2	24	0.27	138
	3	32	0.19	295
	4	38	0.16	318
	5	11	0.31	75
	6	21	0.04	59
	7	14	0.33	350
	8	32	0.08	337
	9	51	0.14	91
	10	23	0.09	207
	12	40	0.22	360
	13	27	0.10	0
	14	21	0.34	20
	16	21	0.28	9
Kaingaroa,	1	34	0.42	352
RO905	6	36	0.37	330
	7	28	0.22	346
	8	33	0.14	104
	9	30	0.15	5
	10	42	0.15	21
	11	30	0.15	292
	12	34	0.16	80
	13	34	0.30	352
Woodhill	1	51	0.06	38
	2	71	0.11	340
	3	63	0.06	336
	4	59	0.20	359
	5	45	0.15	20
	6	45	0.06	111
	7	53	0.14	119
	8	33	0.08	15

CORRELATION BETWEEN AZIMUTH ANGLE AND BRANCH DIAMETER

Methods

The other question which needs to be addressed is whether there is any significant correlation between azimuth angle and branch diameter. Visually there is little correlation between the two variables (see Appendix 4). The method described by Batschelet (1981) (see Appendix 2 for further details) was used to determine the correlation between a circular variable (azimuth angle) and a linear variable (branch diameter) for each tree individually. The correlation was not calculated for the trees from Experiment 905 because it would be difficult to interpret the results without knowing the location of neighbours prior to thinning.

Results

The correlation between azimuth angle and branch diameter was significant for only 4 out of 27 trees: tree 2 and tree 16 compartment 905; tree 7, Taringatura; and tree 6, Woodhill. The graphs (Appendix 4) were examined to determine the reason for the significant correlation:

Tree 2, Compartment 905
The stand spacing is regular and there is no obvious reason for the significant correlation.

Tree 16, Compartment 905
The larger diameter branches occurred towards the west whereas there was a gap towards the south-east.

Tree 7, Taringatura
The larger diameter branches occurred between east and south where there was a large gap due to a vehicle track. This implies that the larger branches have formed in the gap and there is a logical reason for the significant correlation.

Tree 6, Woodhill
Slightly larger diameter branches occurred between east and west where there was a gap. This implies that the larger branches have formed in the gap and there is a logical reason for the significant correlation.

DISCUSSION

The above results indicate that:

- statistically, there is generally a preferred azimuth angle for the largest branch per cluster
- the azimuth angles were not tightly concentrated around the mean angle
- the angle between the largest branch in adjacent clusters is random
- the diameter of the largest branch is generally not correlated with azimuth angle

There is a lot of variability in the azimuth angle of the largest branch per cluster. The most obvious feature of the graphs (Appendix 4) is the paucity of observations towards the south. Statistical tests indicate that there tends to be a preferred direction for the azimuth angle of the largest branch per cluster. For the trees from Kaingaroa (Compartment 905), Taringatura, and Woodhill the preferred azimuth direction tends to be on the northern side of the tree. Visually, the location of neighbours appears to have little impact on the azimuth angle of the largest branch suggesting that in a stand situation macro-availability of light (due to the path of the sun, plantation edge and / or slope) rather than the location of neighbouring trees has influenced the azimuth angle of the largest branch.

It appears realistic to assume that the difference in azimuth angle between the largest branches in adjacent clusters is random as the correlation was generally non-significant.

The diameter of the largest branch was generally not correlated with azimuth angle. It is likely that a significant correlation will occur where there is a large gap in one direction.

In future studies, to aid interpretation of the results, it is recommended that:

- the direction of the slope is recorded for each tree
- the direction of maximum lean is recorded for any tree
- plots of neighbouring trees are checked on site

MODELLING AZIMUTH ANGLE OF LARGEST BRANCH IN A CLUSTER

In the 1997 version of the branch model (Pont, 1997), the azimuth angle of the largest branch per cluster was chosen at random and the diameter of the largest branch in a cluster was independent of its azimuth angle. Realistic trees were generated using these assumptions. The large variability in azimuth angle of the largest branch (Appendix 4) is the reason why the random assumption produced realistic trees. The above results (Table 1) suggest it may be more appropriate to determine the azimuth angle of the largest branch in a cluster by selecting a random number from a circular distribution. In most cases (except where trees are at a stand edge or beside a very large gap) it appears reasonable to assume that branch diameter is independent of azimuth angle.

To implement a preferred direction for the azimuth angle of the largest branch, we will need to determine the preferred direction and measure of concentration (mean vector length) for a specific tree. So far we have only gained a limited understanding of the mechanisms involved. It appears that availability of light is important. This depends on the path of the sun, slope, and stand edges. To gain a better understanding of the mechanisms and to be able to develop a realistic model, further data collection from a range of trees with different aspects and proximity of stand edges is recommended.

Three steps are required to implement a preferred direction and measure of concentration.

1. define the preferred azimuth direction
2. define the mean vector length
3. define the appropriate circular distribution to use

1&2. Preferred azimuth direction and mean vector length

As stated above, further data collection are required to understand the factors influencing the preferred azimuth direction for an individual tree. It has been difficult to decide on the most appropriate approach in the interim. The above data has indicated that the preferred azimuth direction is generally to the north. However it is clearly inappropriate to combine data from different sites due to differences in slope etc. Of the sites sampled to date, the data from Woodhill is considered to show the influence of position of sun without the confounding effects of slope and stand margins. The data from all the Woodhill trees were combined and an overall mean direction and mean vector length calculated.

The mean azimuth angle was 335° with a mean vector length of 0.32.

3. Appropriate circular distribution

A method for generating random numbers from an appropriate circular distribution is required. From examining the graphs (Appendix 4), a unimodal symmetric distribution appeared appropriate. Four possibilities outlined by Batschelet (1981) are the von Mises, wrapped normal, wrapped Cauchy and cosine. The mean vector length must be less than 0.5 for the cosine distribution, hence is inappropriate for all trees. Visually, the wrapped normal and von Mises appeared to be the most likely. For each tree from Woodhill, Taringatura, and "850" trees at Kaingaroa (Compartment 905), a series of random numbers were generated

from a von Mises distribution and a wrapped normal distribution using the observed mean direction and mean vector length. The generated distribution was compared with the actual data using a χ^2 test with six 60° classes.

The results are summarised in Table 3. In most cases, the von Mises distribution is appropriate for predicting the distribution of azimuth angle of the largest branch. There was little difference between the two distribution in the cases where the wrapped normal distribution was more appropriate. A multimodal distribution would possibly be appropriate in the cases where there was a significant difference between actual and predicted distributions.

Table 3. Suitability of circular distributions to model azimuth angle

Site	Tree	More appropriate distribution VM = von Mises WN = wrapped normal	Significantly different from actual distribution
Woodhill	1	VM	no
	2	VM	no
	3	VM	no
	4	VM	no
	5	VM	yes
	6	VM	no
	7	VM	no
	8	WN	yes
Taringatura	3	VM	Yes (p=0.05), No (p=0.01)
	5	VM	no
	6	VM	no
	7	VM	no
	8	VM	no
Compartment 905	1	VM	no
	2	VM	no
	3	VM	yes
	4	VM	no
	5	WN	no
	6	VM	yes
	7	VM	no
	8	VM	no

Observations from a von Mises distribution can be predicted using the method outlined by Ripley (1987) and Appendix 3.

IMPLEMENTATION

It is suggested that a von Mises distribution is implemented as well as a random distribution and the implications assessed using AUTOSAW. For flat sites away from stand margins, a mean azimuth angle of 335° and a mean vector length of 0.32 should be used (kappa= 0.68). The appropriate values in other situations is not known.

FUTURE RESEARCH

Further data need to be collected to understand and then predict preferred azimuth direction and mean vector length from site factors.

The function to predict the azimuth angle of the largest branch needs to be included in the branch model, and model results compared for individual trees. As branching influences wood quality, it would be appropriate to using the sawing simulator, AUTOSAW (Todoroki, 1997), to determine the importance of differences between actual and predicted results.

The implications of having a preferred azimuth angle for the largest branch, as opposed to a random azimuth angle when processing a tree, needs to be investigated. It is suggested that trees be simulated with both uniform and non-uniform distributions for the azimuth angle of the largest branch in a cluster with all other factors held constant. These trees should then be passed to the AUTOSAW simulator to determine the effect of non-uniform distributions.

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APPENDIX 1. Calculation of circular statistics.

The mean of several angles cannot be found by simple averaging. For example, it is illogical for the mean of 10° and 330° to be 70°. For angular data, it is assumed that each observation is a unit vector with respect to the zero direction. These unit vectors are added together. The angle that the resultant vector makes with the zero direction is the mean direction. In the above example the mean direction is 350° . The length of the resultant vector divided by the sample size, the mean vector length is a measure of concentration. A large value implies that the data points are close together. A small value implies that the data points are scattered.

The mean direction and mean vector length are calculated as follows:

If we have n observations of direction: $\theta_1 .....\theta_n$ then:

$R_x = C = \Sigma \cos \theta_i$

$R_y = S = \Sigma \sin \theta_i$

$R^2 = C^2 + S^2$

$r = R/n$ is the mean vector length

$\phi = \tan^{-1} (S/C)$ is the mean direction

Note: the sign of S and C need to be taken into account in calculating ϕ.

($s^2 = 2(1-r)$ is defined as an angular variance)

The Rayleigh test for uniformity utilises the value of r and the sample size to determine whether the distribution is uniform. A look-up table is used to determine the significance.

APPENDIX 2. Calculation of circular- linear correlation

The circular-linear correlation was calculated using the method outlined in Batschelet (1981).

If the circular variable is represented by ϕ and the linear variable by y then the following variables need to be calculated:

r_{yC} = corr (y, cos ϕ)

r_{yS} = corr (y, sin ϕ)

r_{CS} = corr (cosϕ, sinϕ)

The correlation between y and ϕ is defined by:

$$r^2 = (r_{yC}^2 + r_{yS}^2 - 2r_{yC}r_{yS}r_{CS}) / (1 - r_{CS}^2)$$

When y and ϕ are independent then for large n (where n is the sample size):

n r^2 is approximately a chi-square variable.

This method requires the regression line between y and ϕ to be approximately sinusoidal and the joint distribution of y and x to be approximately normal where x= cos (ϕ - ϕ_o) and ϕ_o is the acrophase angle (see Batschelet, 1981).

Appendix 3. SAS code used to generate a von Mises distribution

This code, derived from the description in Ripley (1987) generates a von Mises distribution with a mean angle of 356° and a mean vector length of 0.20 (Woodhill, tree 1). Kappa is derived from the mean vector length using a look-up table (eg. Batschelet, 1981).

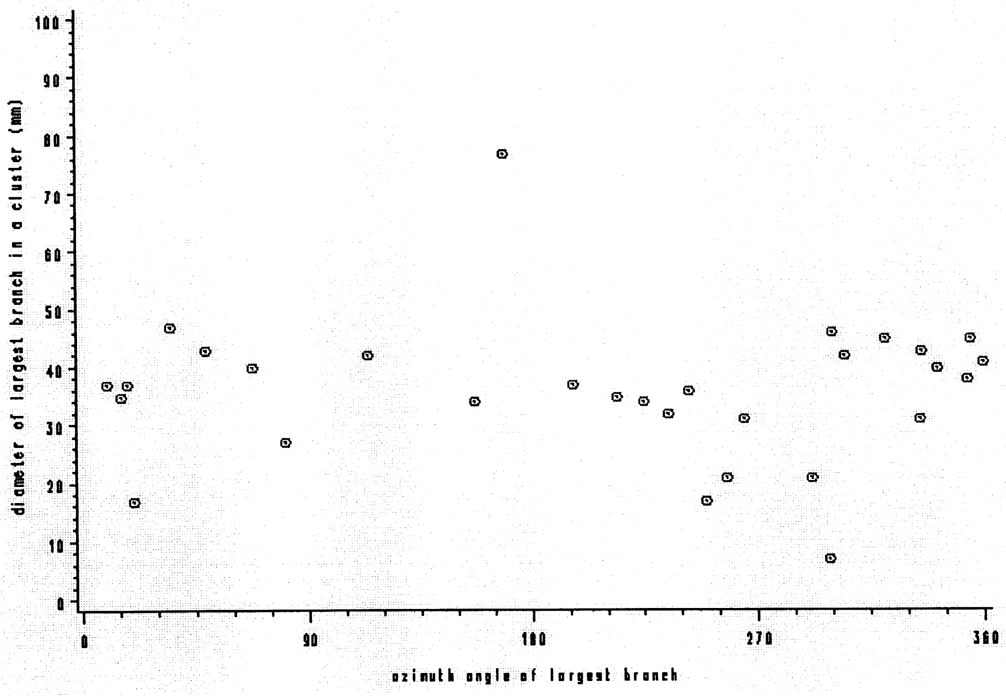
```
data temp1;

kappa = 0.41; /* has to be derived from tables*/

do i = 1 to 100000;
y = ranuni(0) * (6.28);   /* 6.28 is 2π */
u = ranuni(0);
m = exp (kappa);
t = exp (kappa* (cos(y) -1.0));
output;
end;
run;

data temp1;
set temp1;
if u gt t then x=.;
if u le t then x=y;
run;

data temp1;
set temp1;
if x = . then delete;
x1 = x * 57.29577951;  /* 57.29577951 is 180 / π */
a = 356 + x1;
a2 = mod (a, 360);
if a2 lt 0 then a2 = a2 + 360;
azimuth = a2;
run;
```

APPENDIX 4.

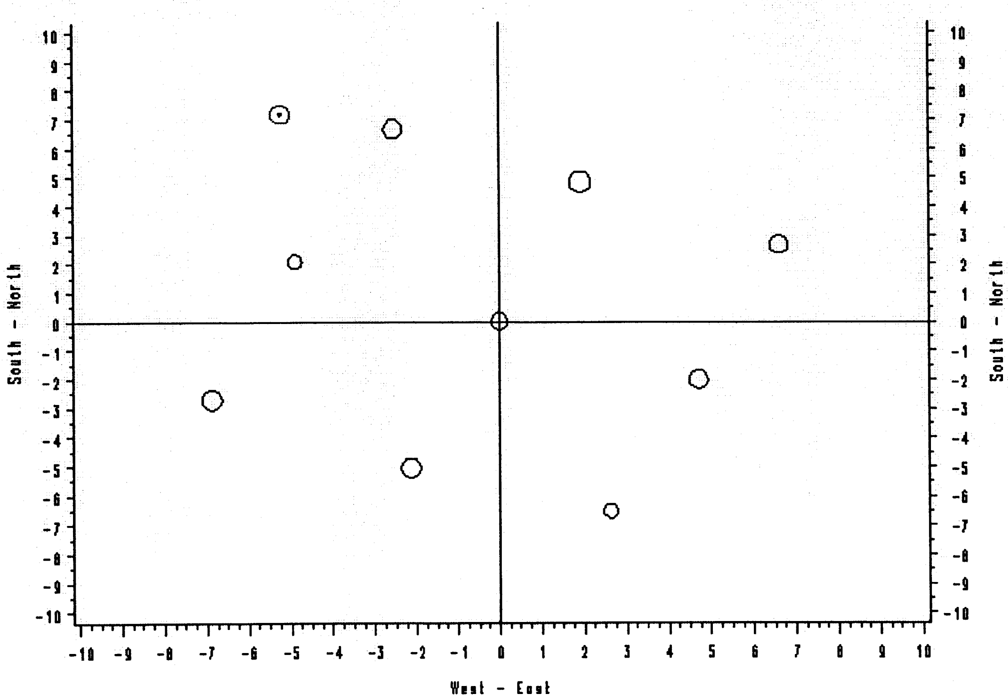
Top graph:
Plots showing the relationship between diameter of the largest branch in a cluster and its azimuth angle.

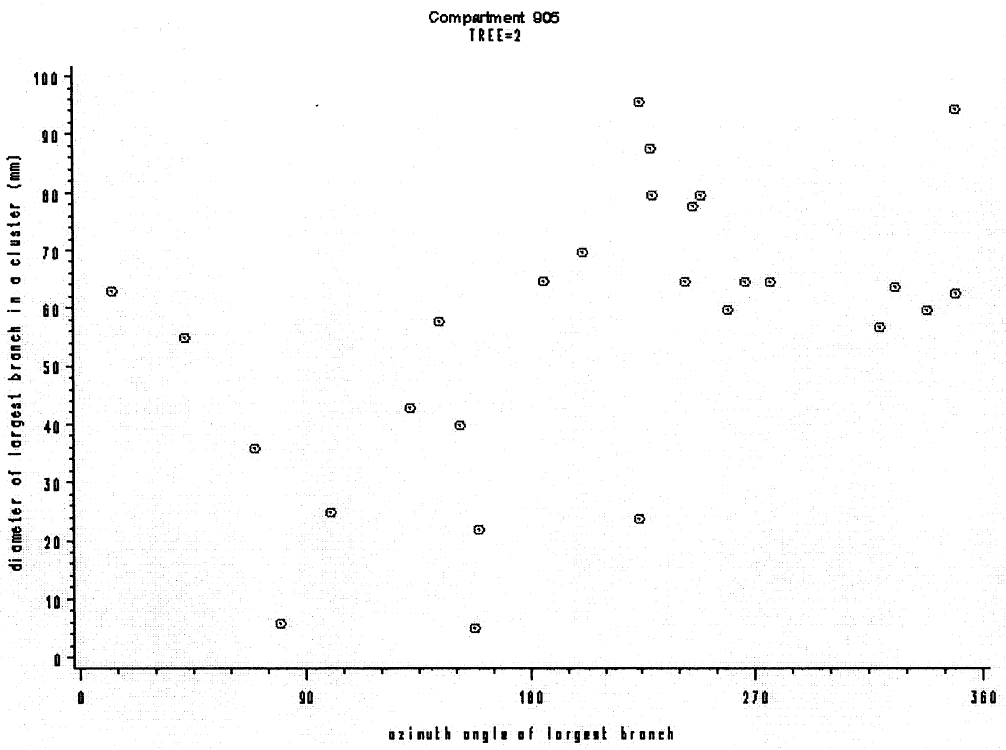
Bottom graph:
Plots showing the location of the sample tree, its nearest neighbours and the preferred azimuth direction. (The tree positions are represented by open circles scaled according to tree DBH. The sample tree is in the centre. The location of the preferred azimuth direction is marked by a circle with a dot in the centre. The units for both axes are metres)

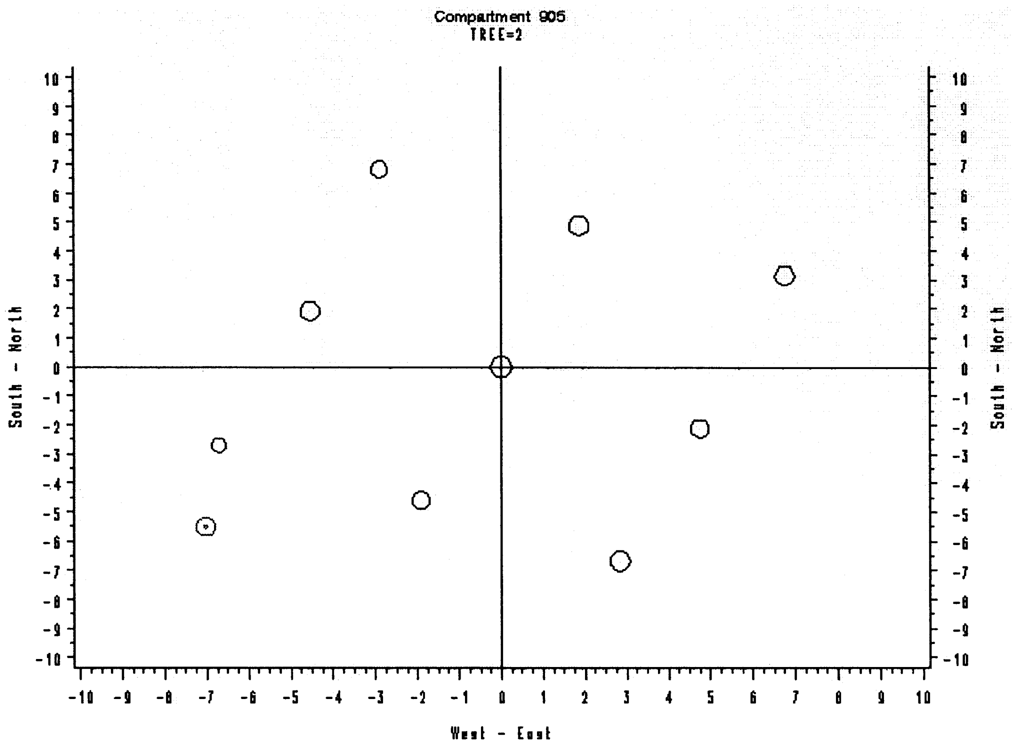
Compartment 905
TREE=1

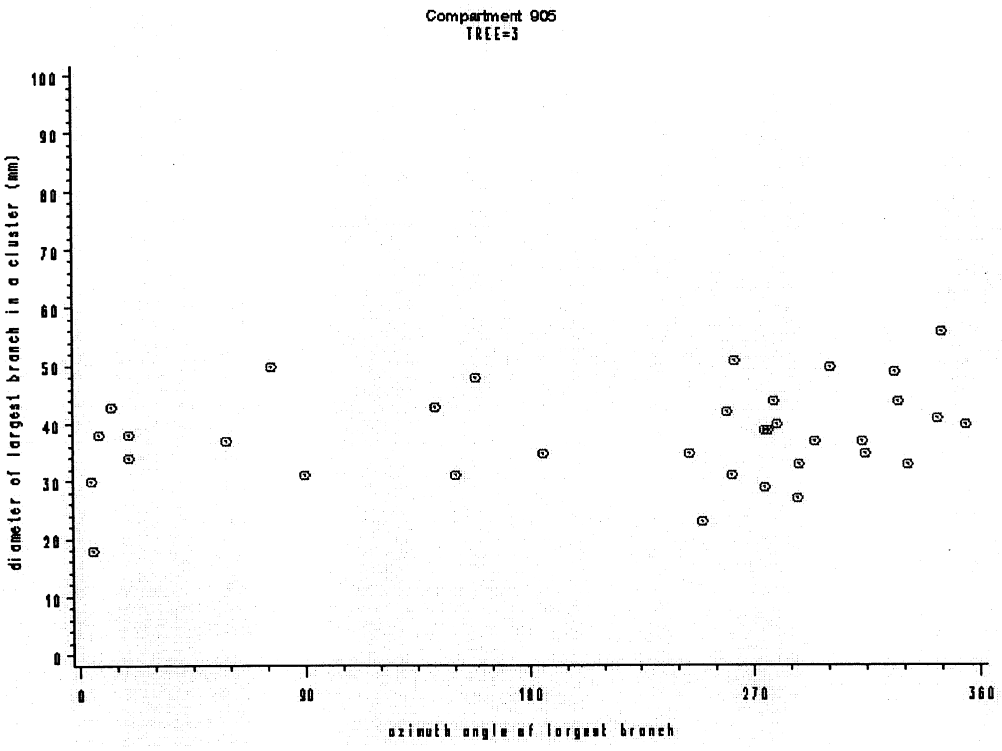


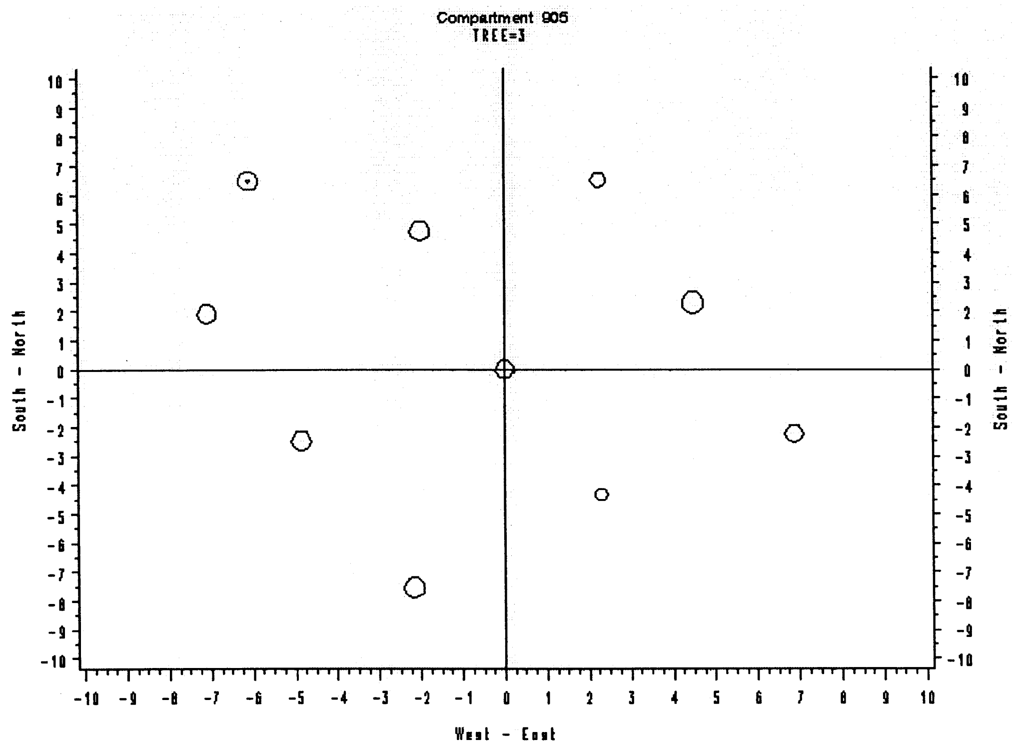
Compartment 905
TREE=1

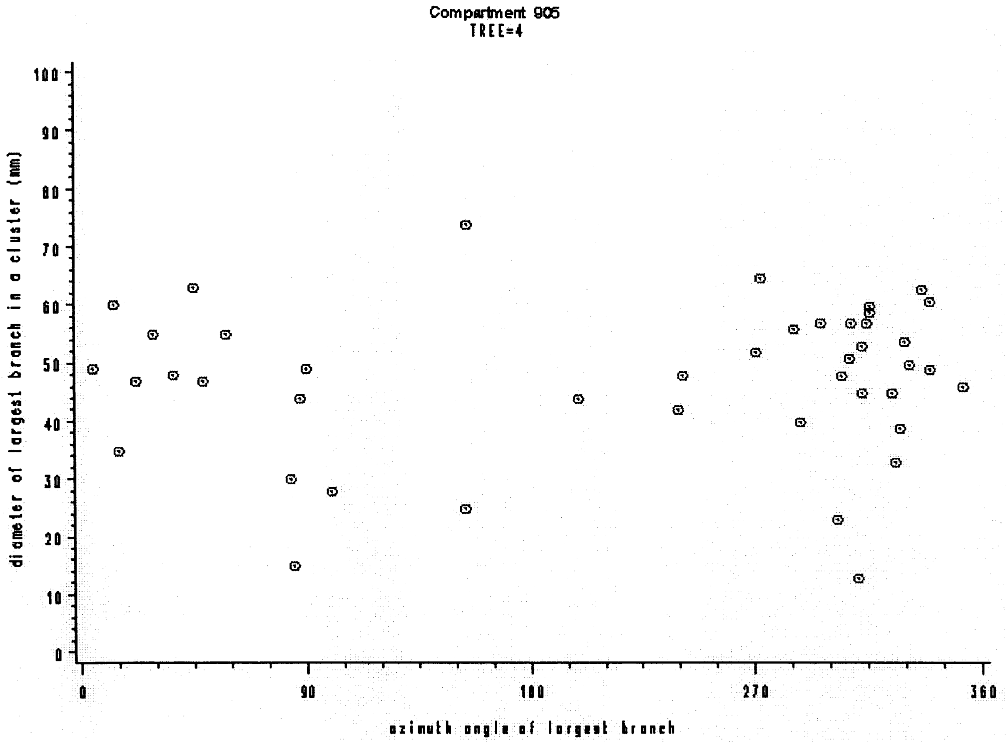


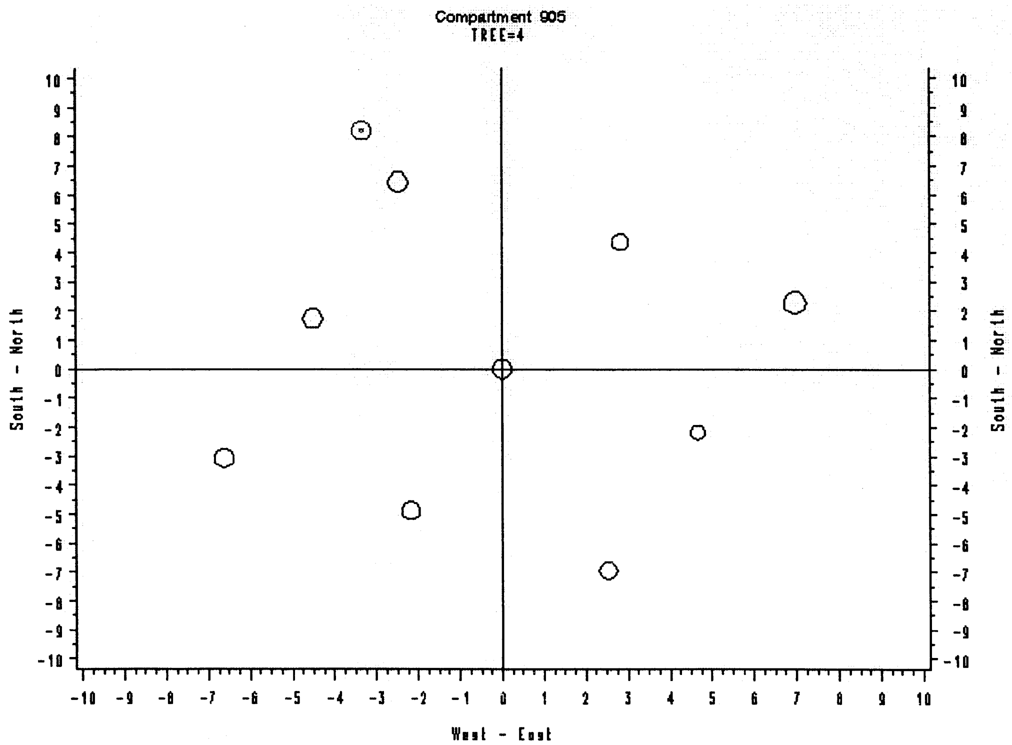

Compartment 905
TREE=2
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100

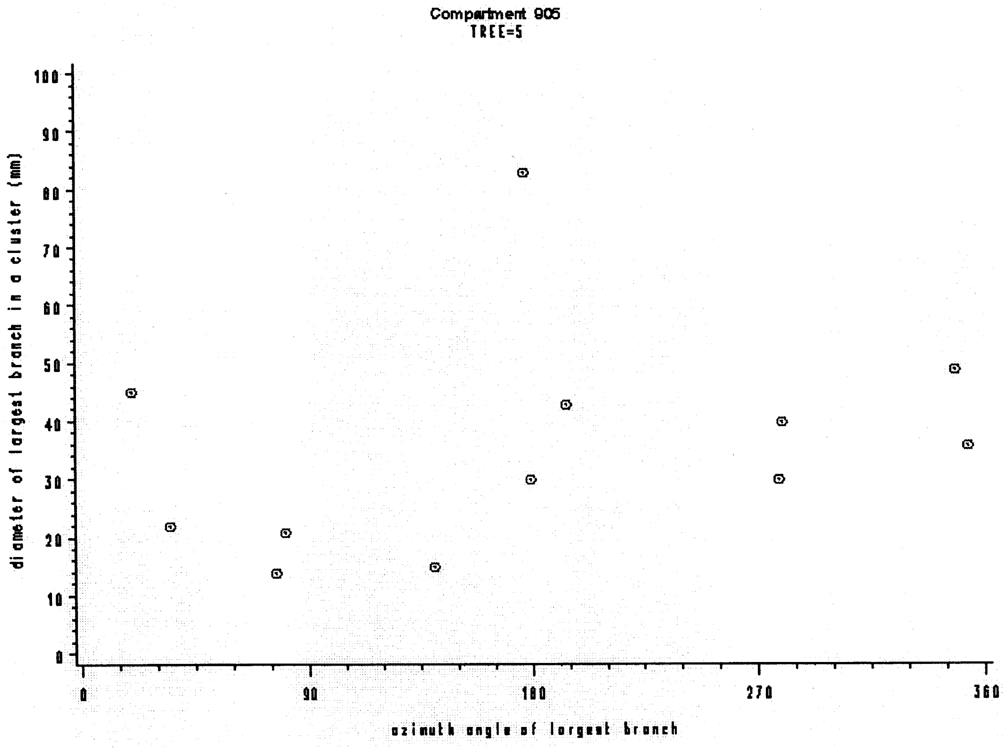

Compartment 905
TREE=2
South - North
West - East

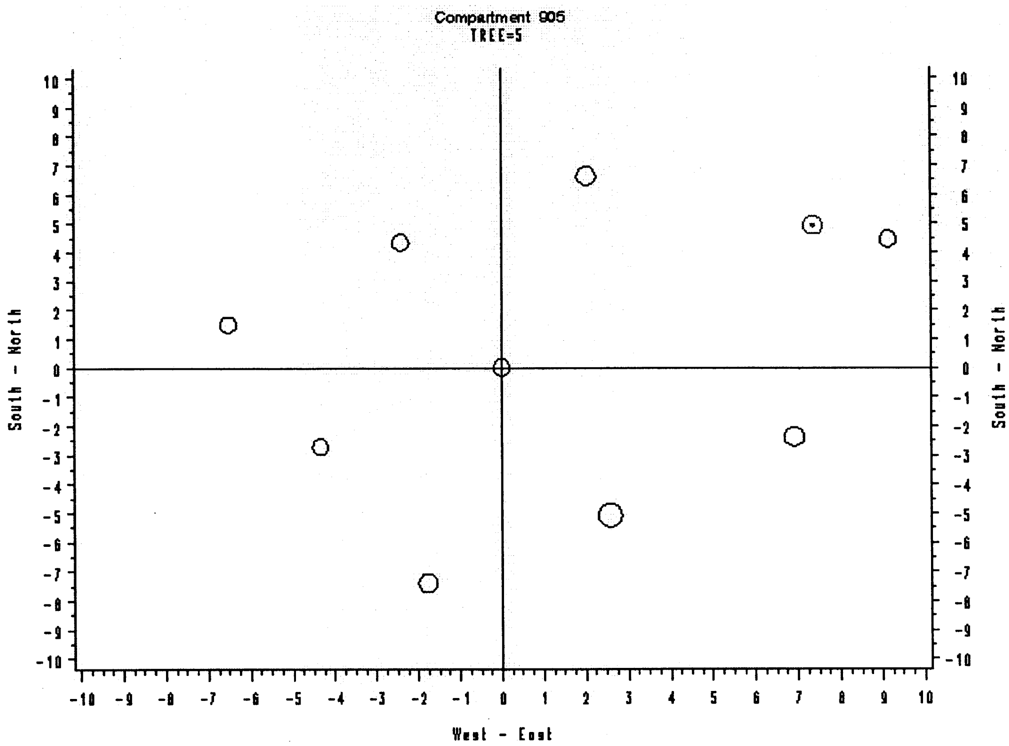

Compartment 905
TREE=3
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
10
20
30
40
50
60
70
80
90
100


Compartment 905
TREE=3
South - North
West - East


Compartment 905
TREE=4
diameter of largest branch in a cluster (mm)
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360
azimuth angle of largest branch


Compartment 905
TREE=4
South - North
West - East
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10


Compartment 905
TREE=5
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360


Compartment 905
TREE=5
South - North
West - East
-10
-9
-8
-7
-6
-5
-4
-3
-2
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0
1
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3
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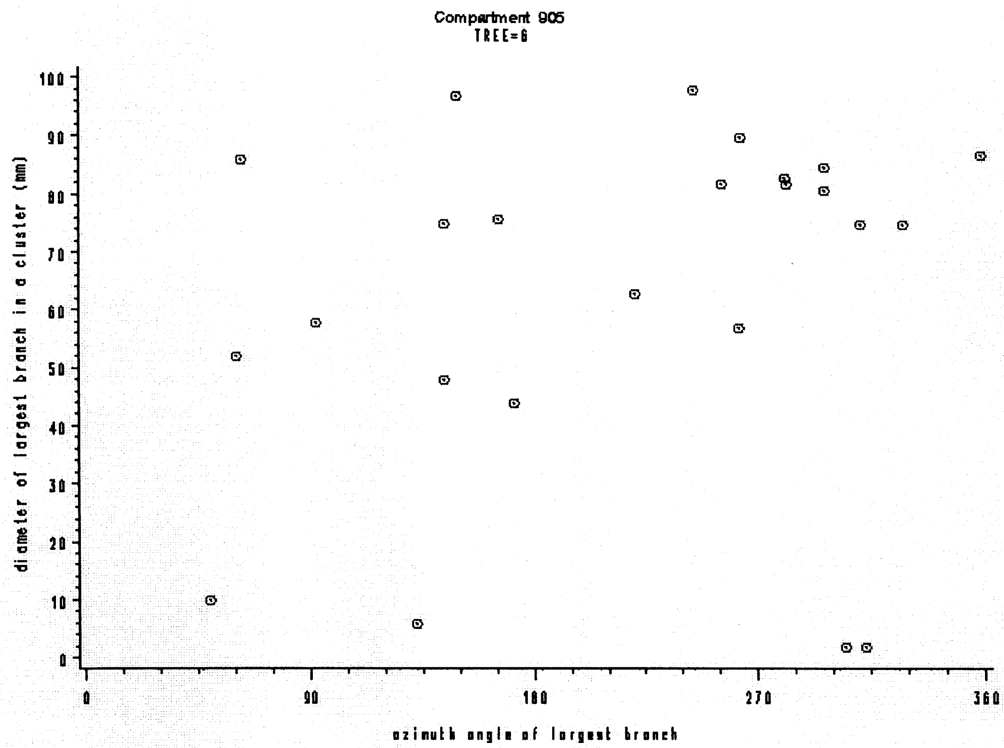
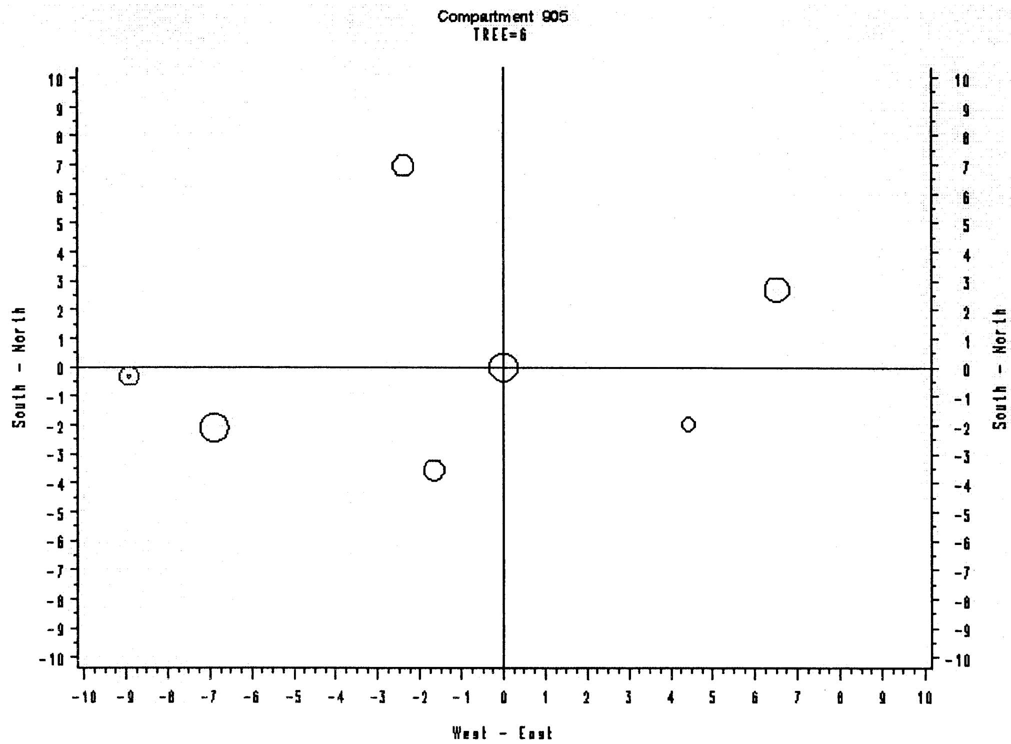
6
7
8
9
10



Compartment 905
TREE=6
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360



Compartment 905
TREE=6
South - North
West - East
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
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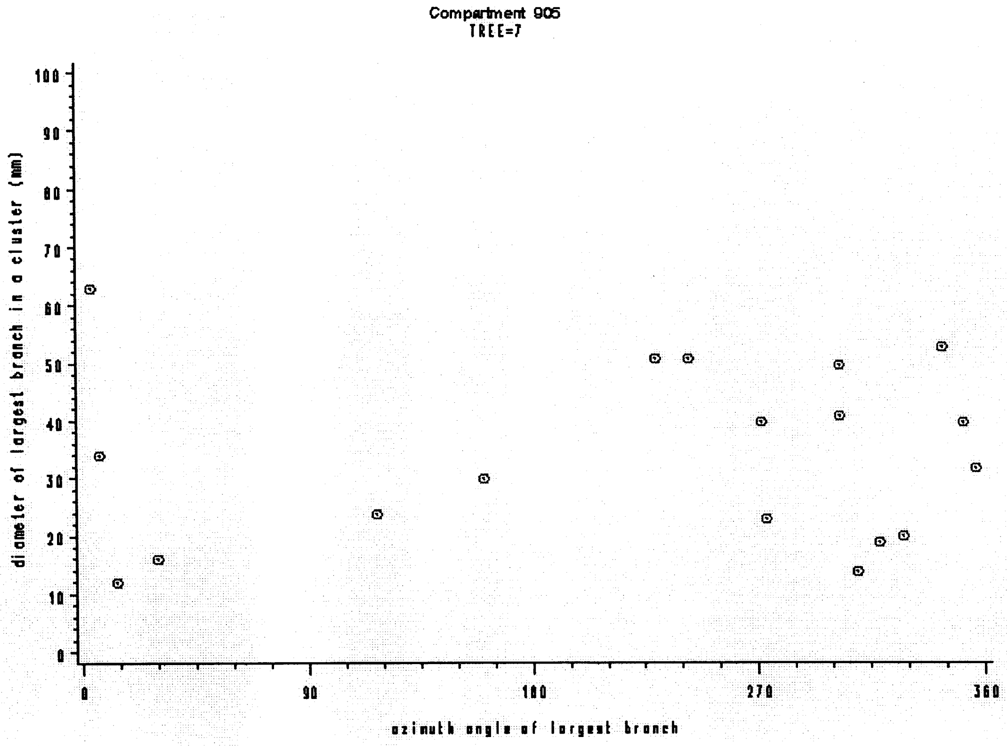
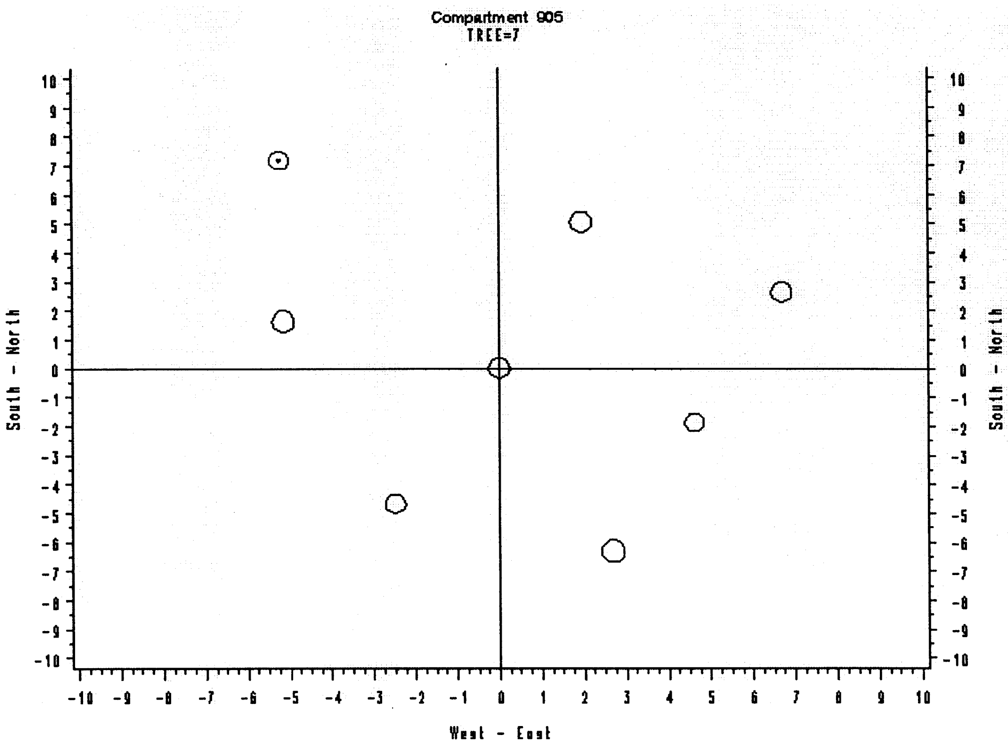
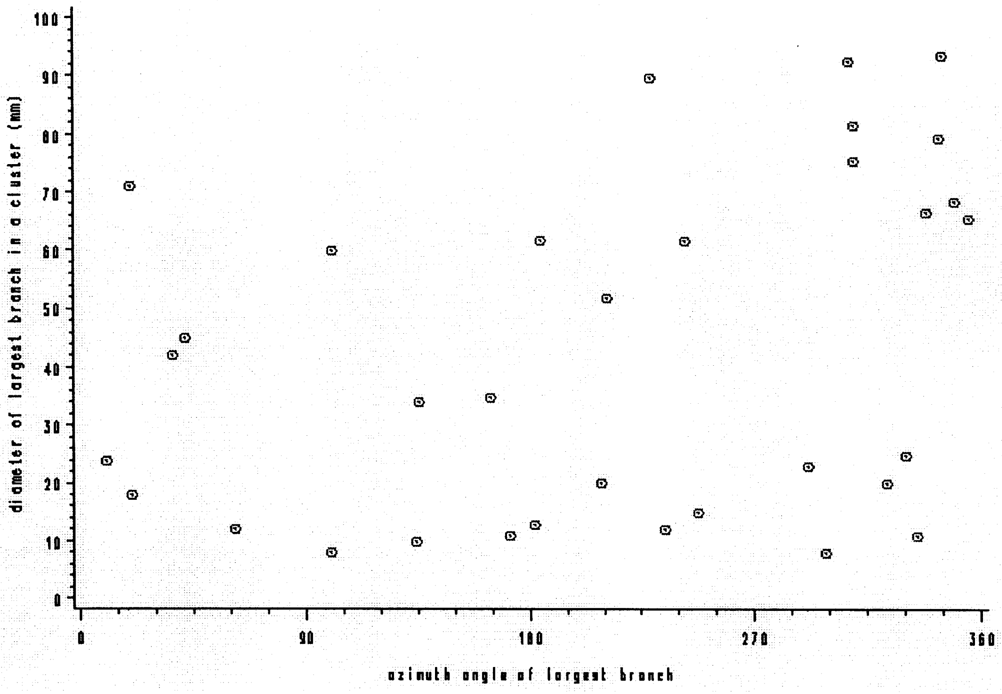
3
4
5
6
7
8
9
10

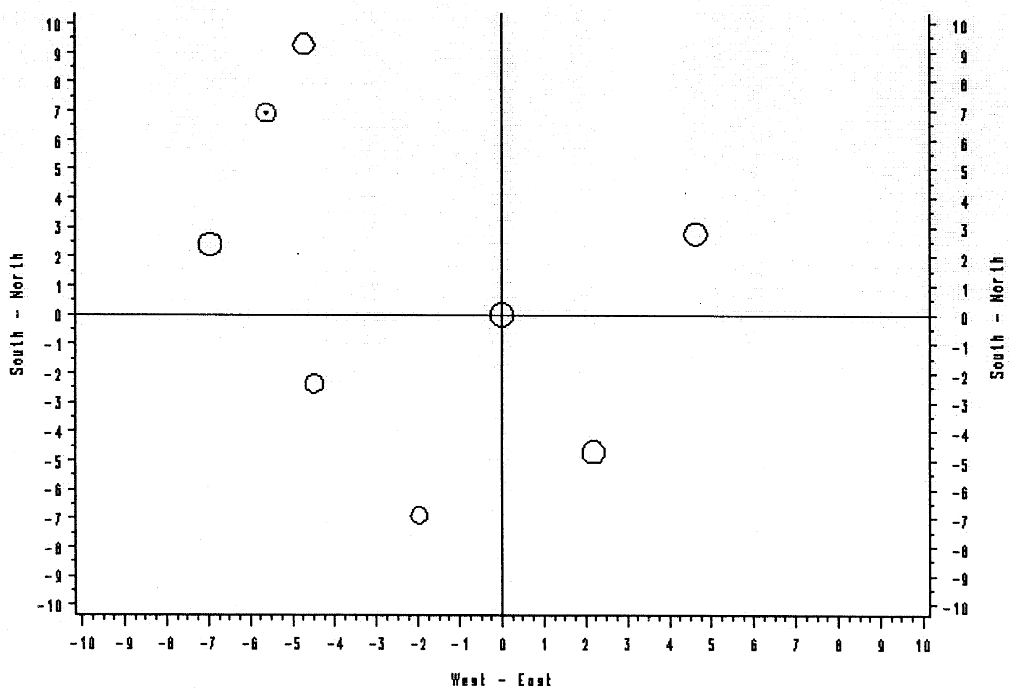

Compartment 905
TREE=7
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
10
20
30
40
50
60
70
80
90
100
90
180
270
360

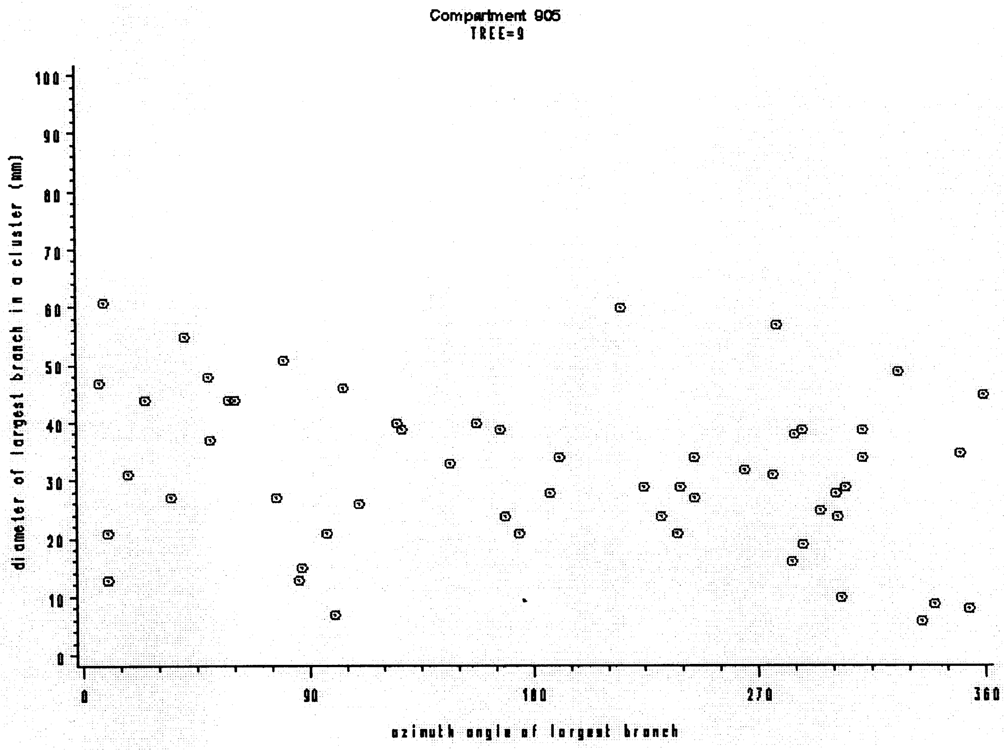

Compartment 905
TREE=7
South - North
West - East

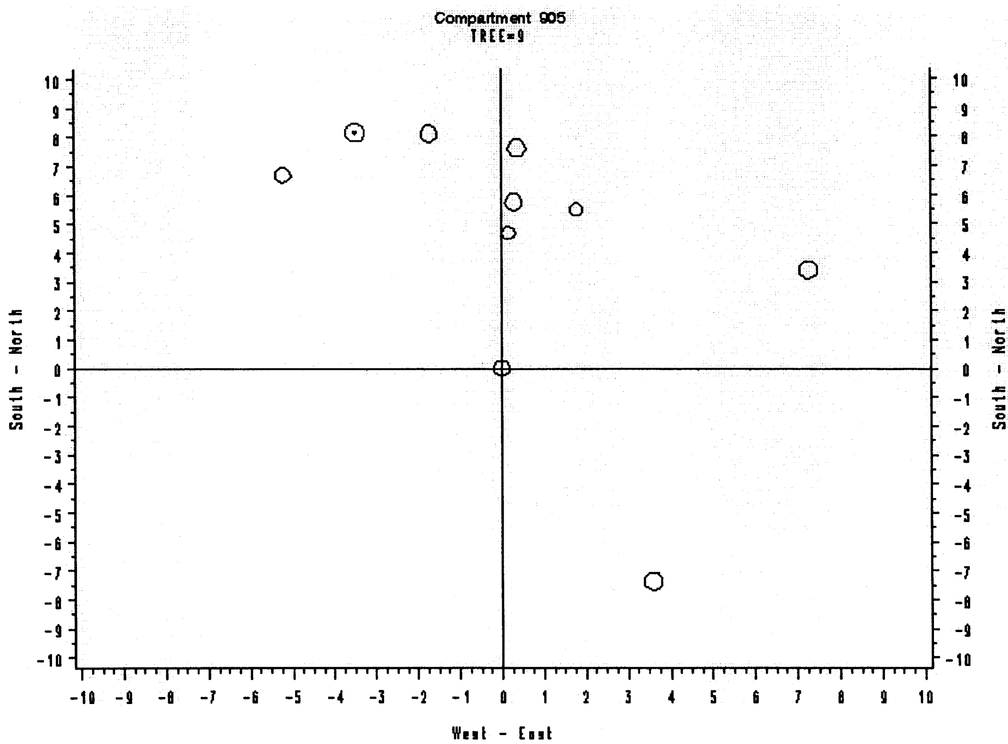
Compartment 905
TREE=8



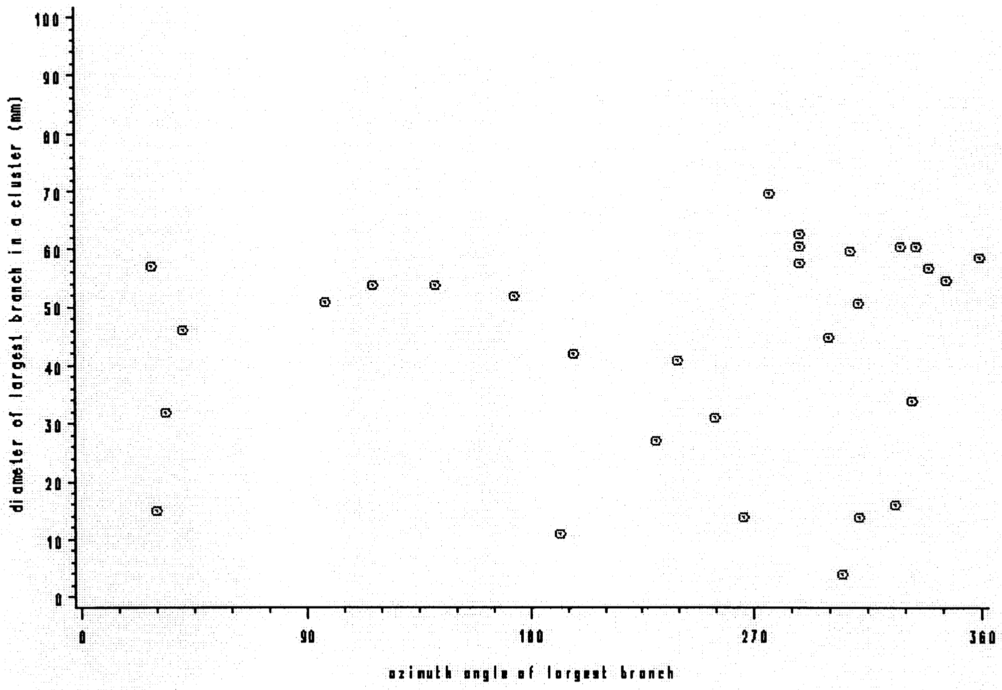
Compartment 905
TREE=8



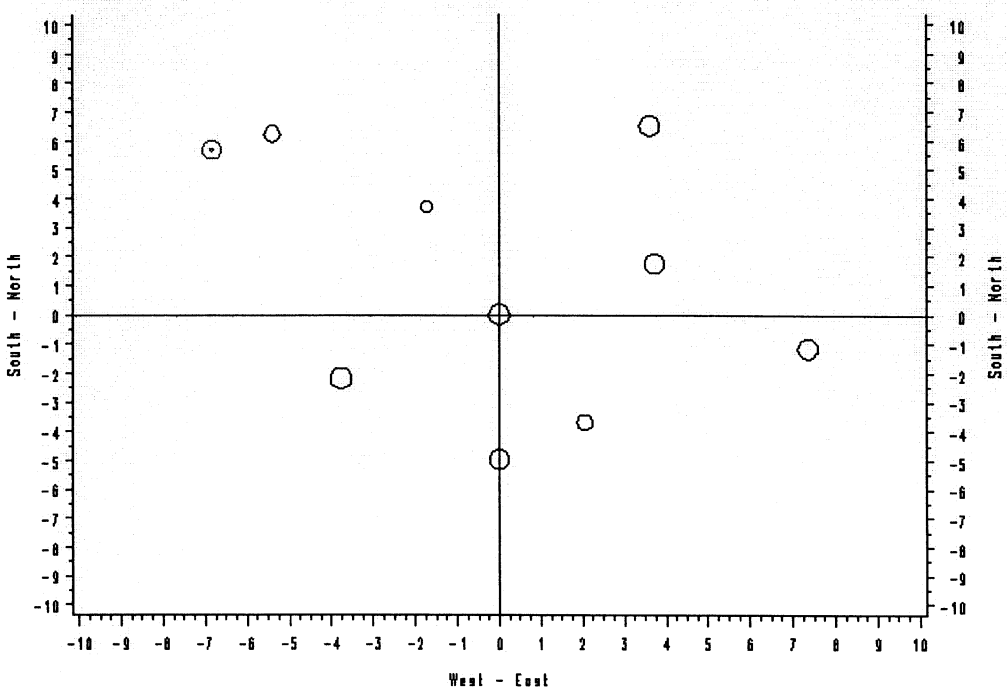

Compartment 905
TREE=9
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100

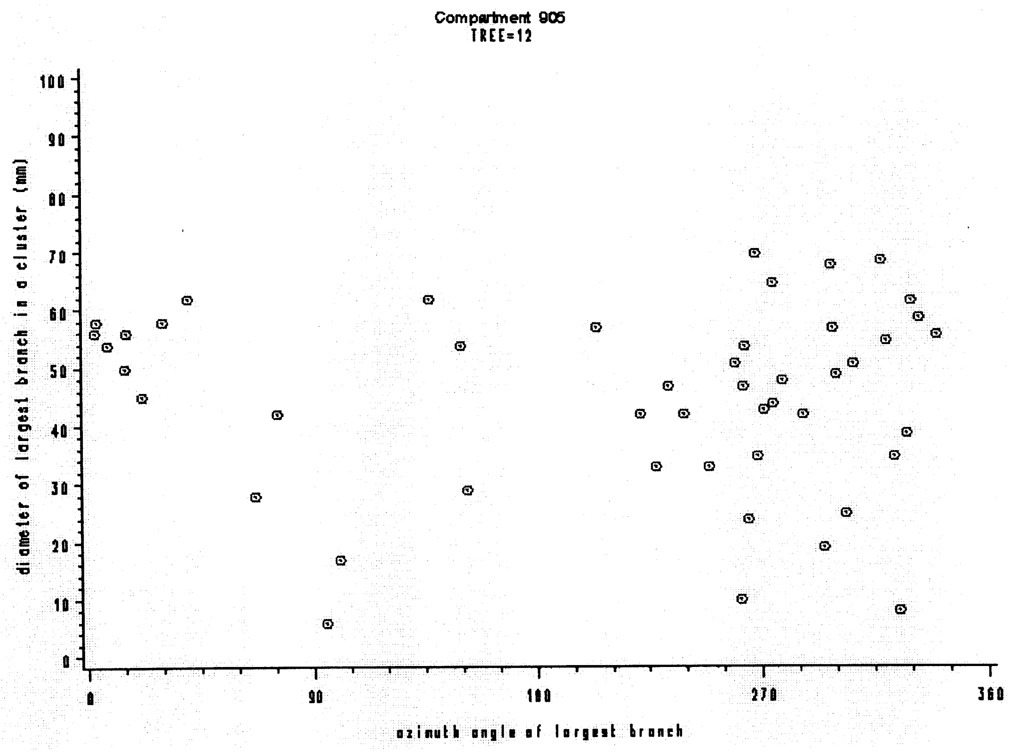

Compartment 905
TREE=9
South - North
West - East

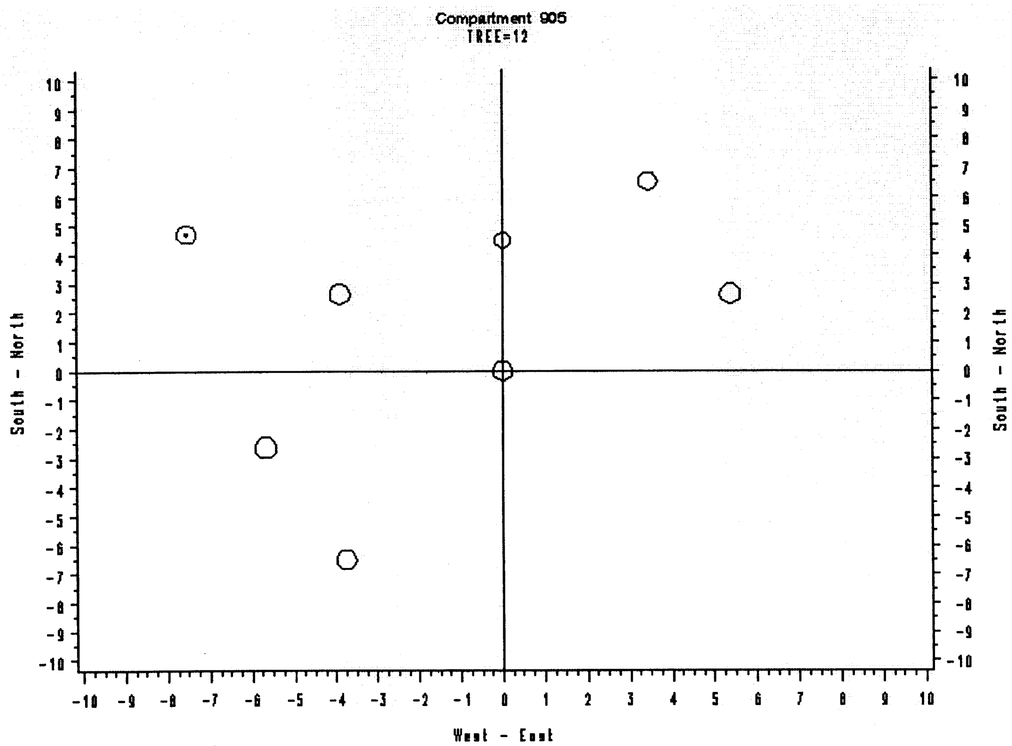
Compartment 905
TREE=10

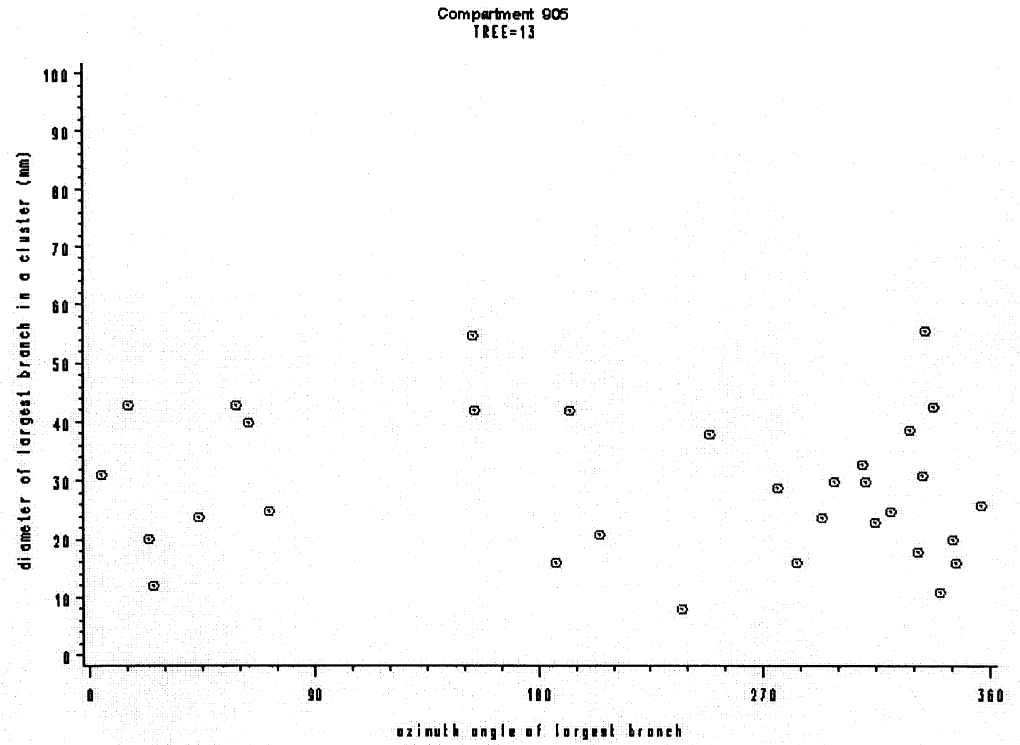


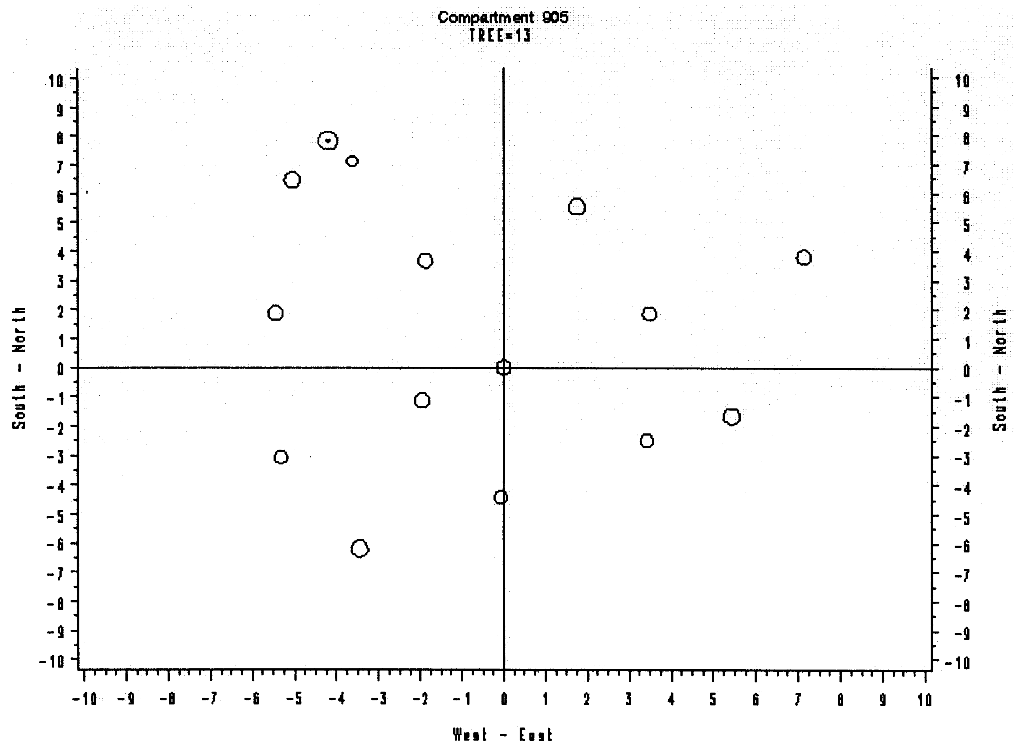
Compartment 905
TREE=10

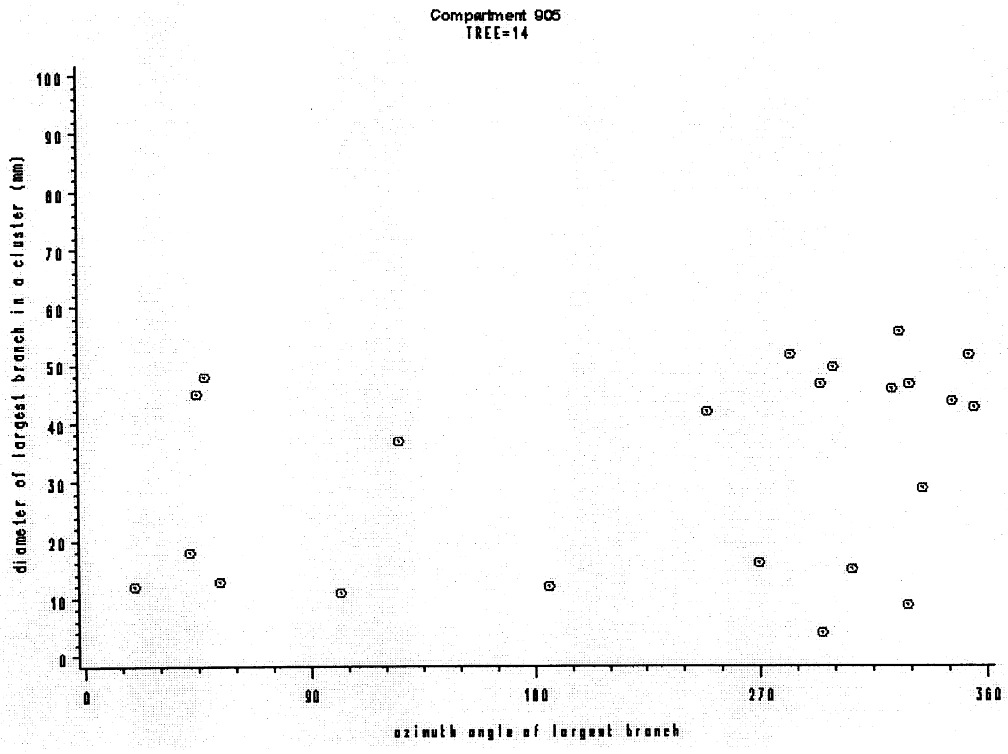


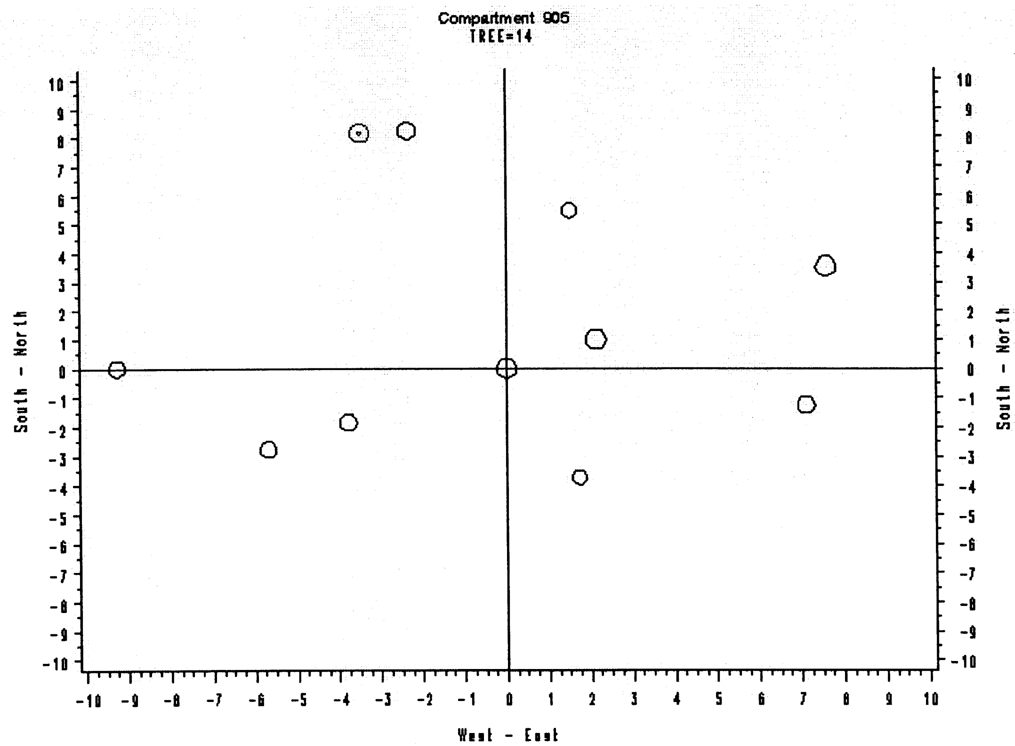

Compartment 905
TREE=12
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100


Compartment 905
TREE=12
South - North
West - East
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10


Compartment 905
TREE=13
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100


Compartment 905
TREE=13
South - North
West - East


Compartment 905
TREE=14
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360


Compartment 905
TREE=14
South - North
West - East
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
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3
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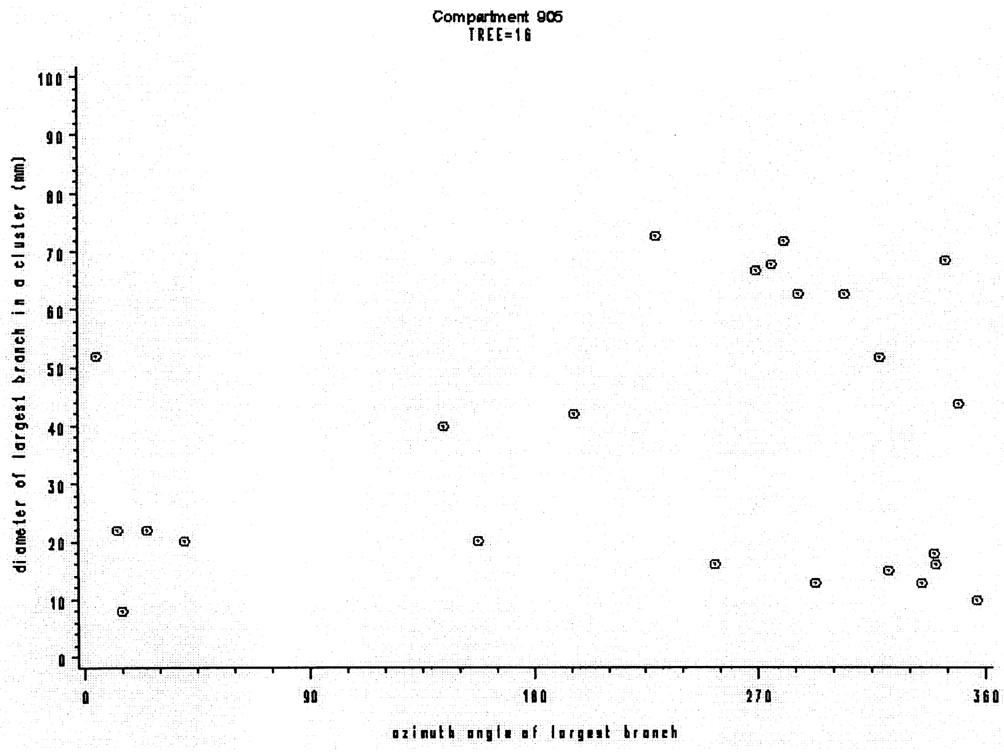
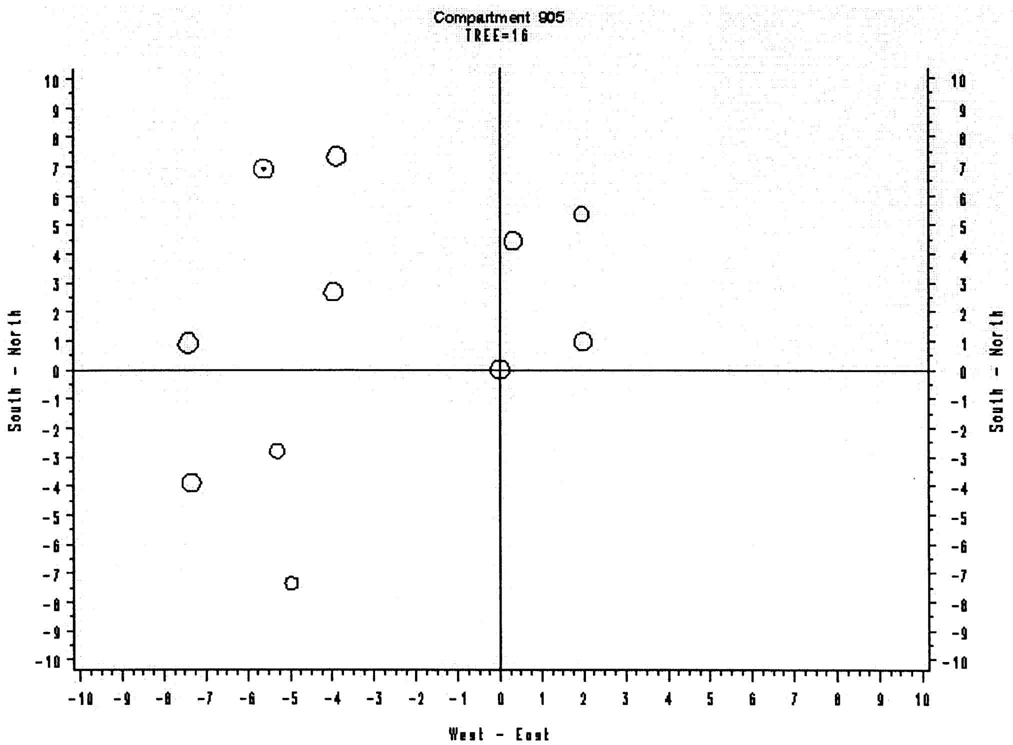
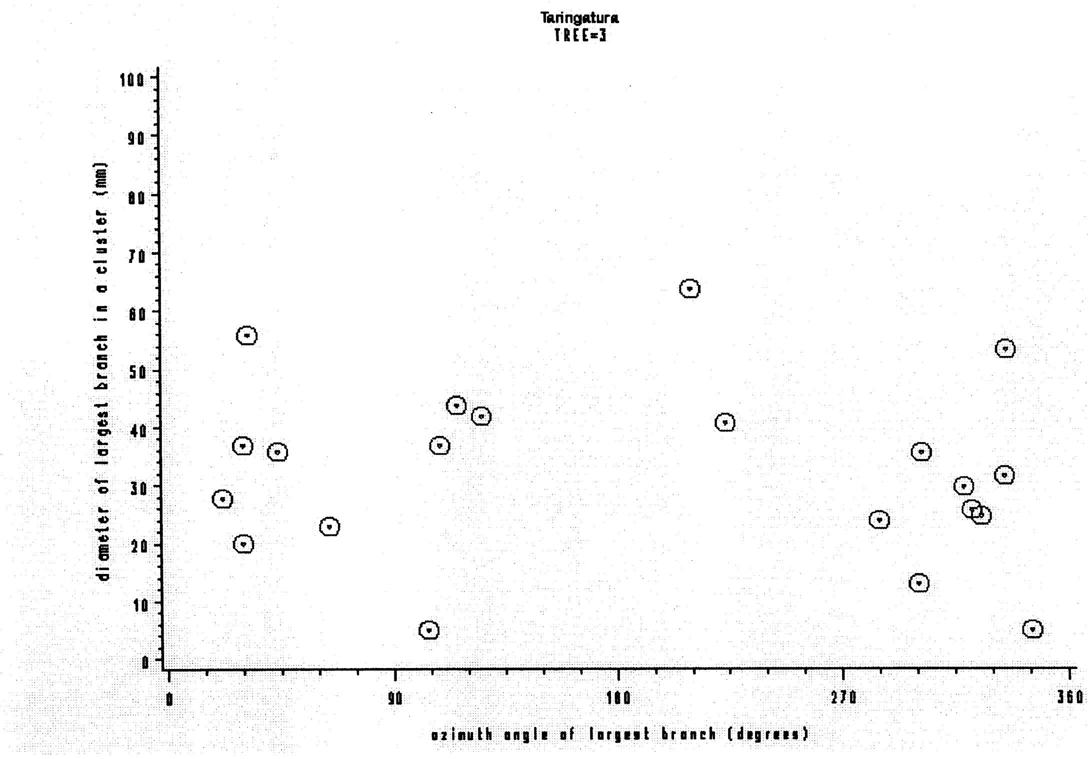
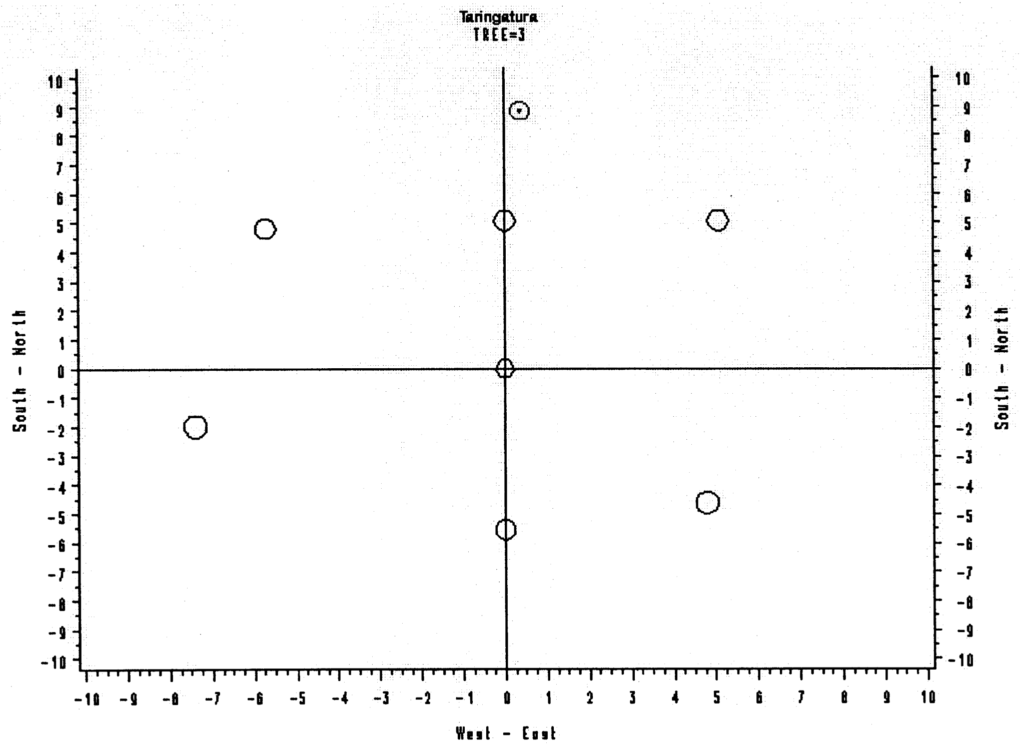
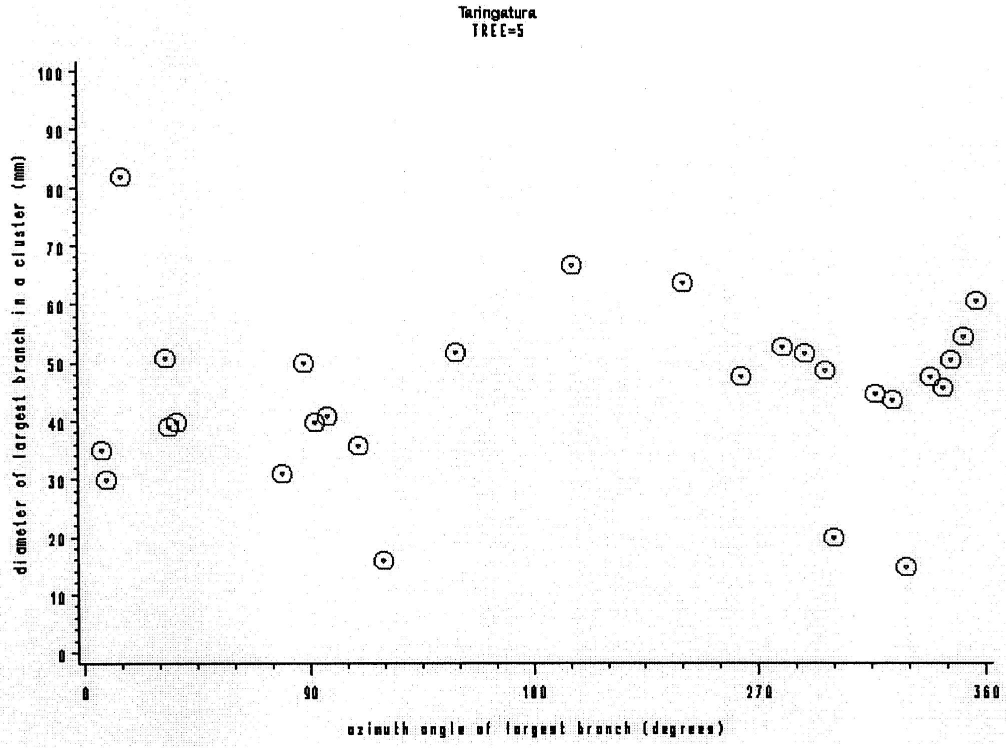
5
6
7
8
9
10

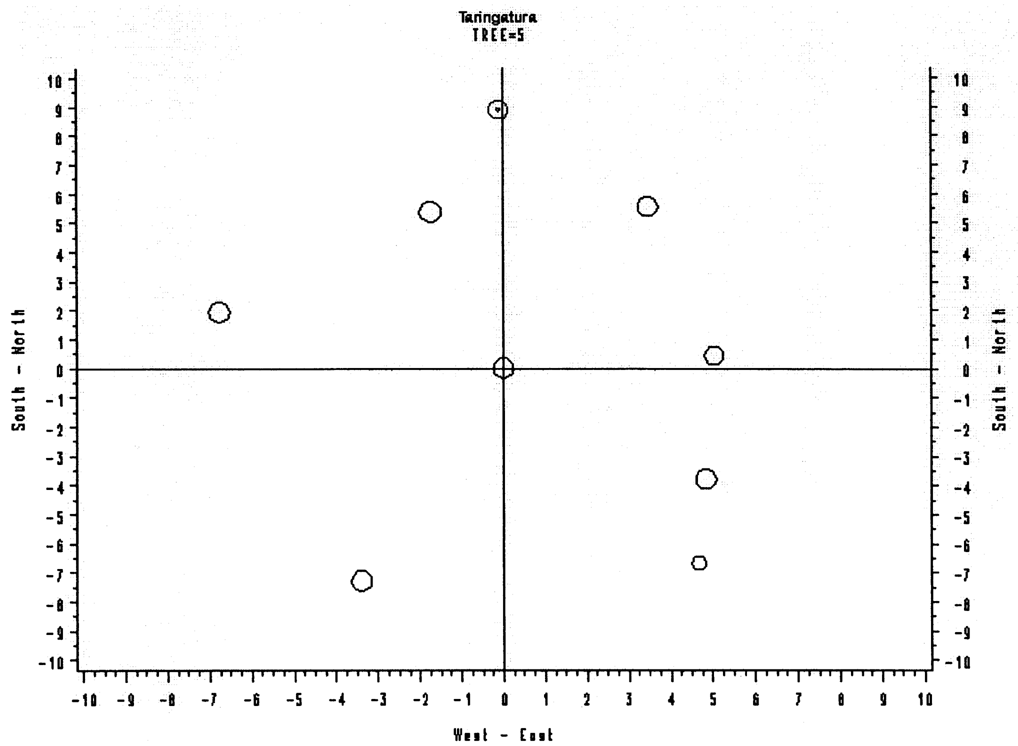

Compartment 905
TREE=16
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100


Compartment 905
TREE=16
South - North
West - East


Taringatura
TREE=3
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)


Taringatura
TREE=3
South - North
West - East


Taringatura
TREE=5
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360


Taringatura
TREE=5
South - North
West - East
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
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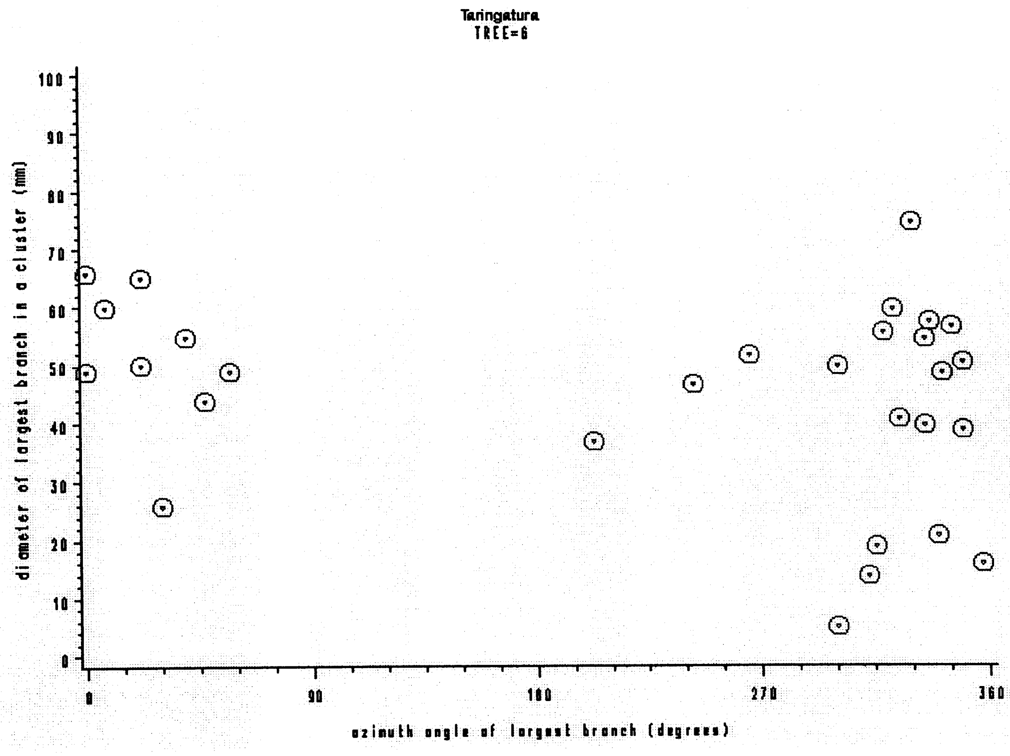
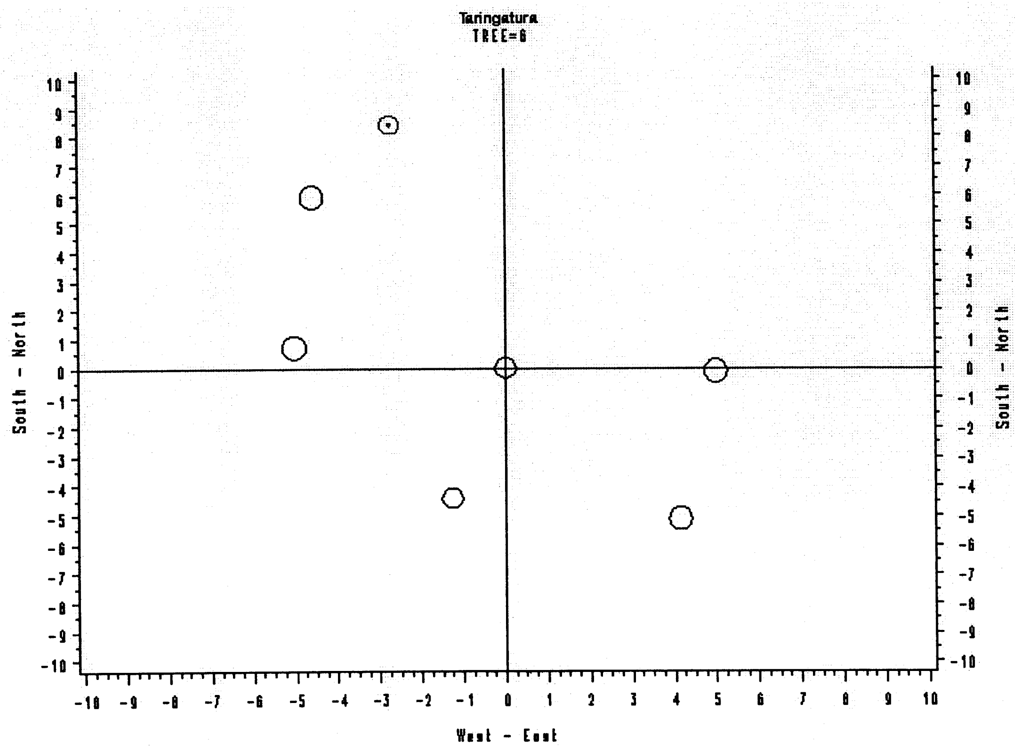
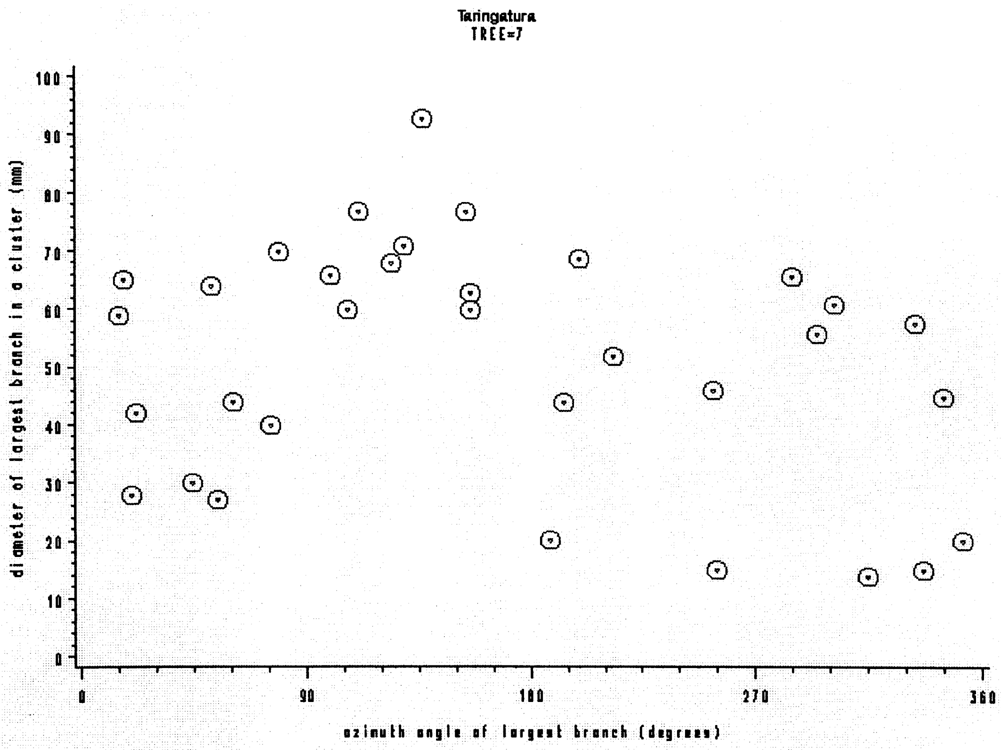
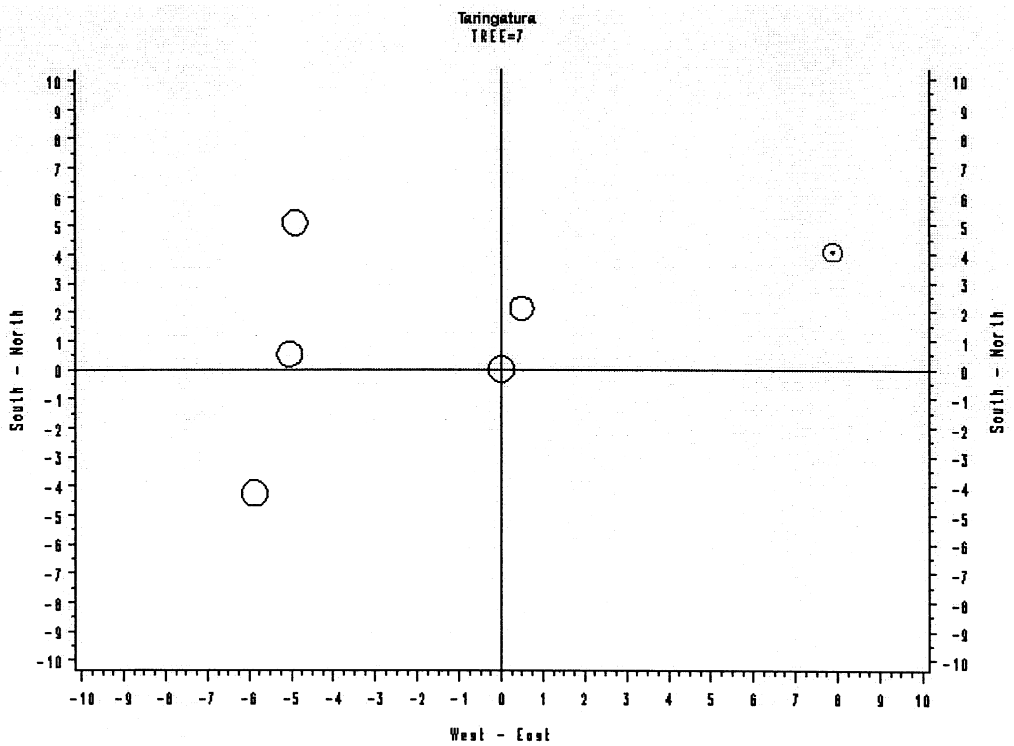
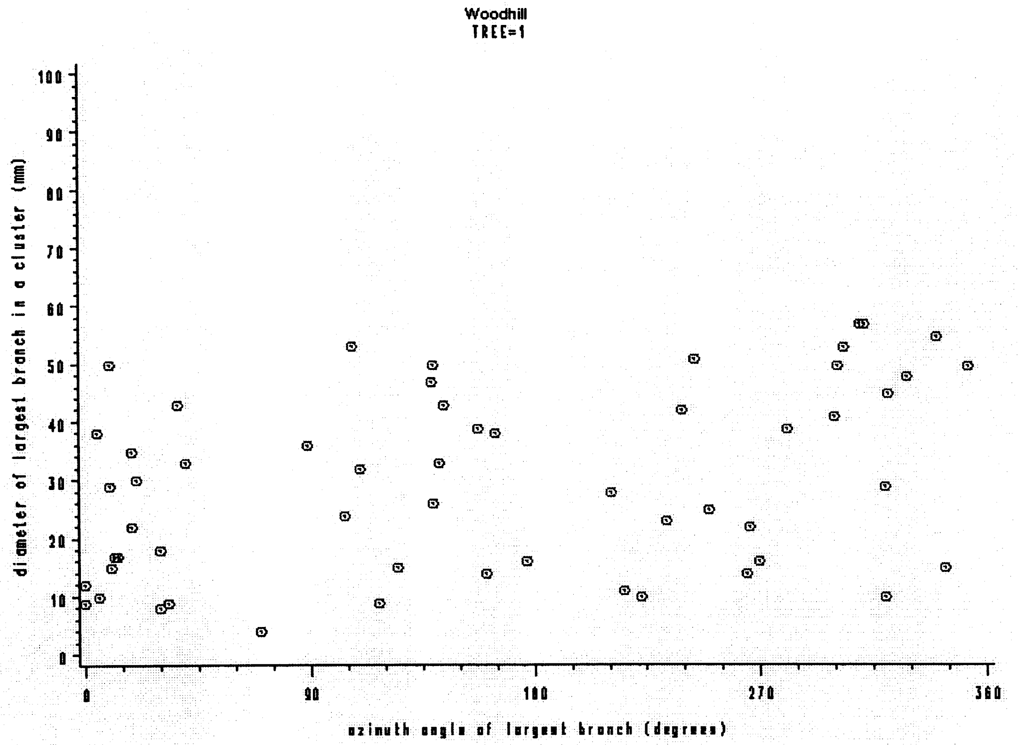
6
7
8
9
10

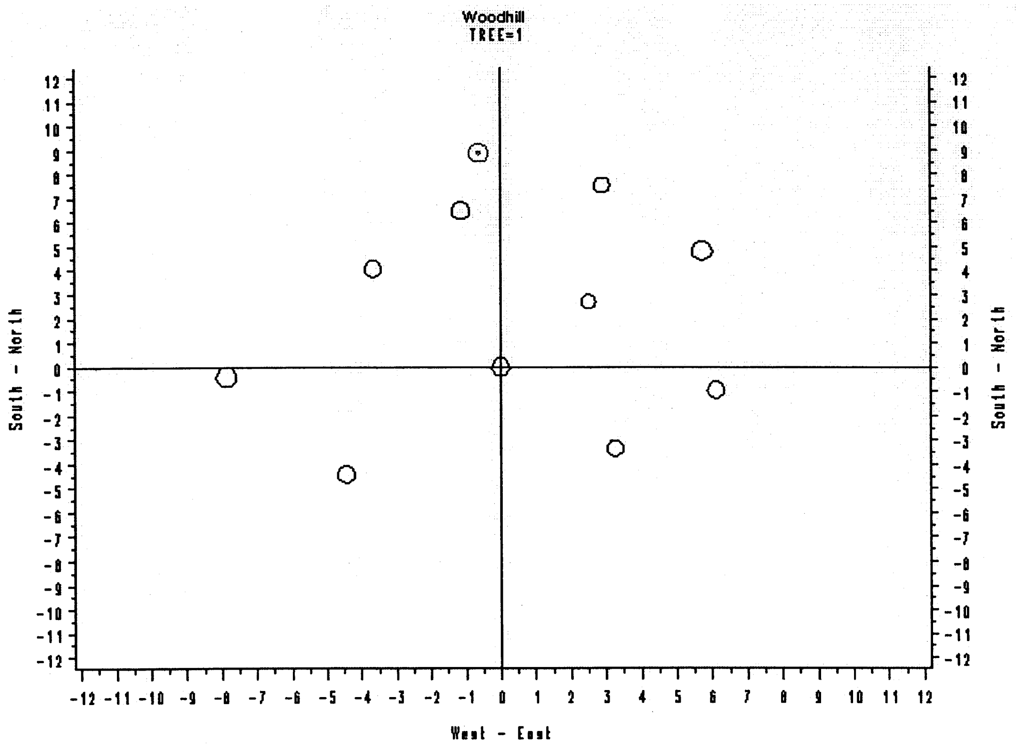

Taringatura
TREE=6
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100

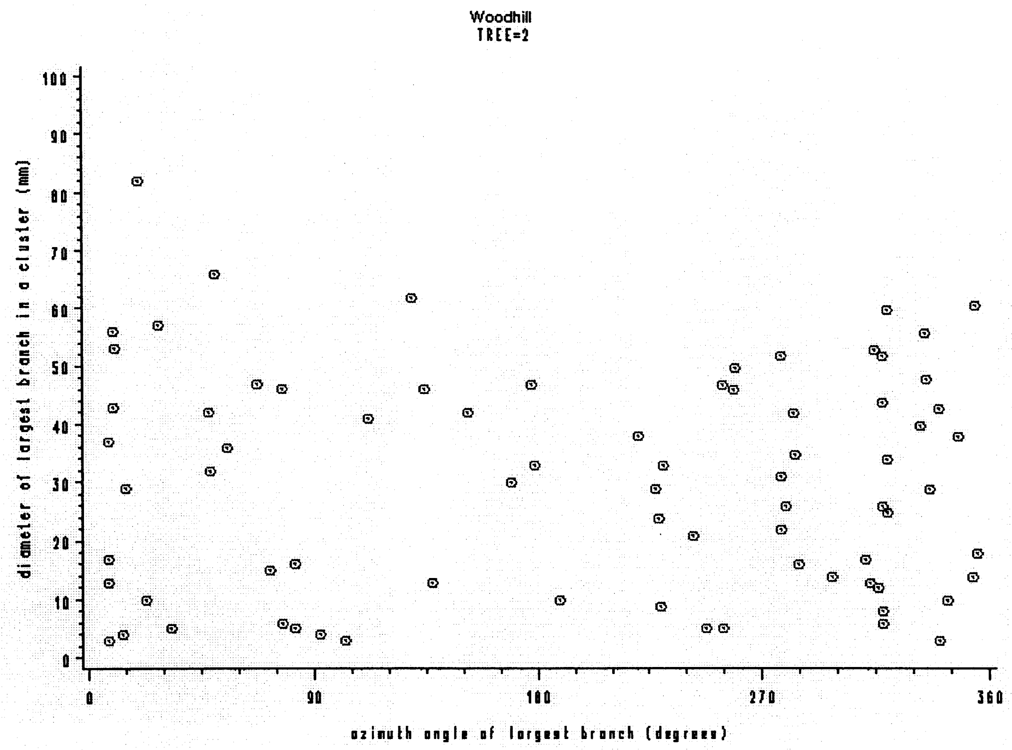

Taringatura
TREE=6
South - North
West - East

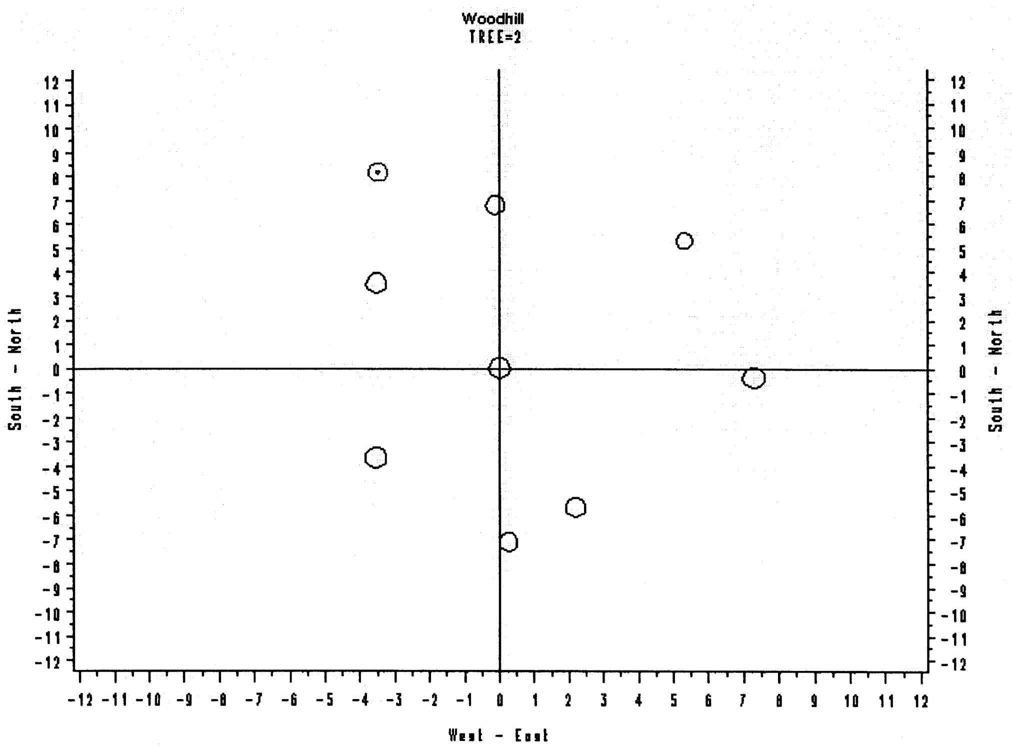

Taringatura
TREE=7
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100


Taringatura
TREE=7
South - North
West - East

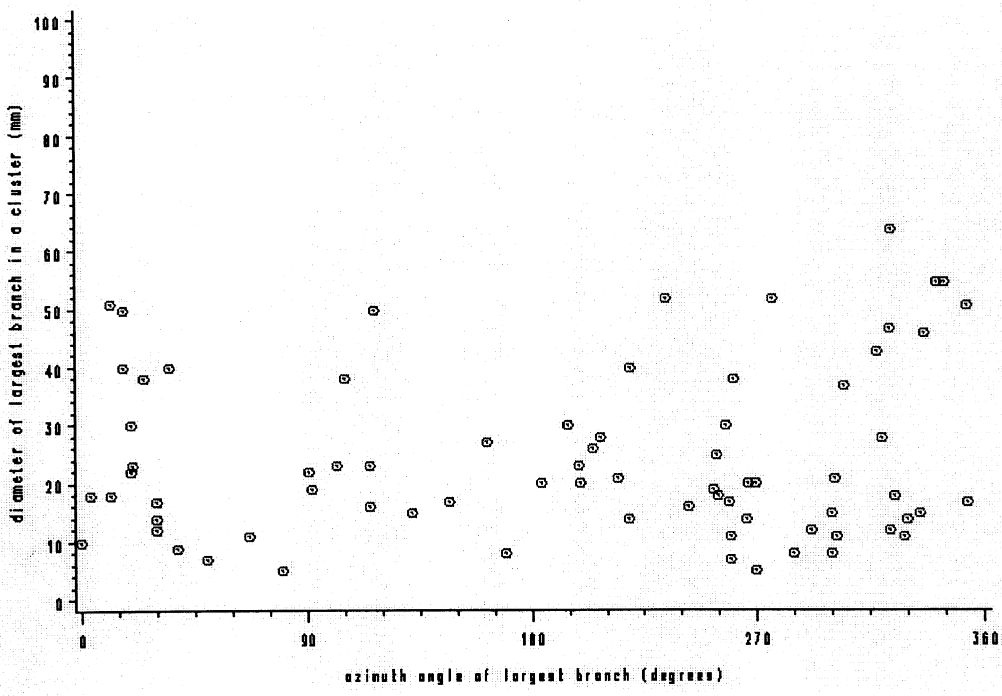

Woodhill
TREE=1
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100


Woodhill
TREE=1
South - North
West - East

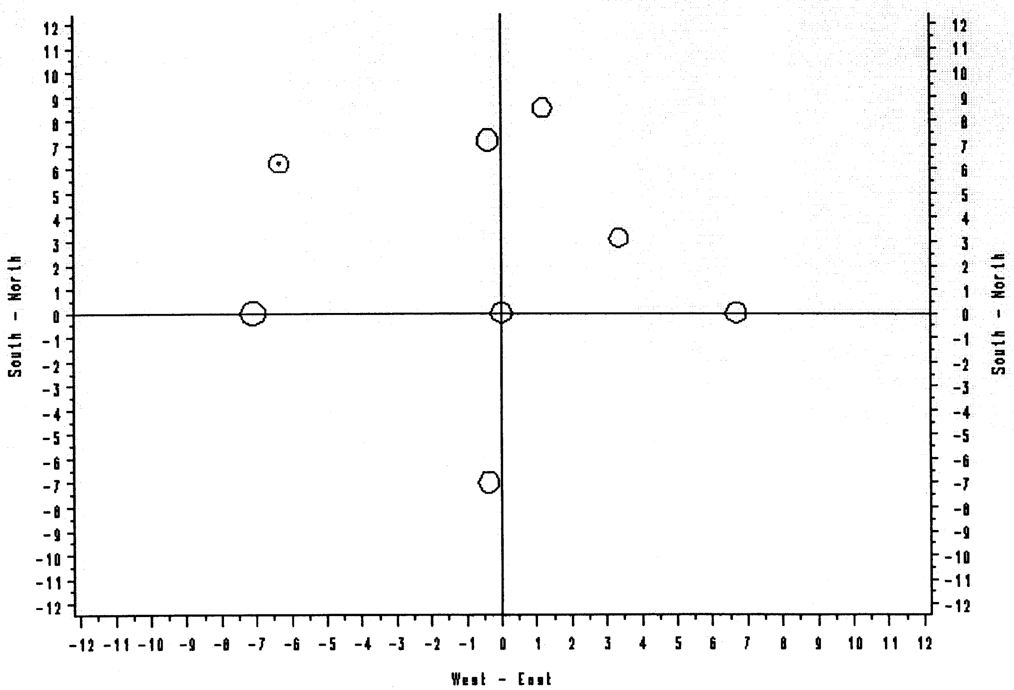

Woodhill
TREE=2
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)
0
90
180
270
360
0
10
20
30
40
50
60
70
80
90
100

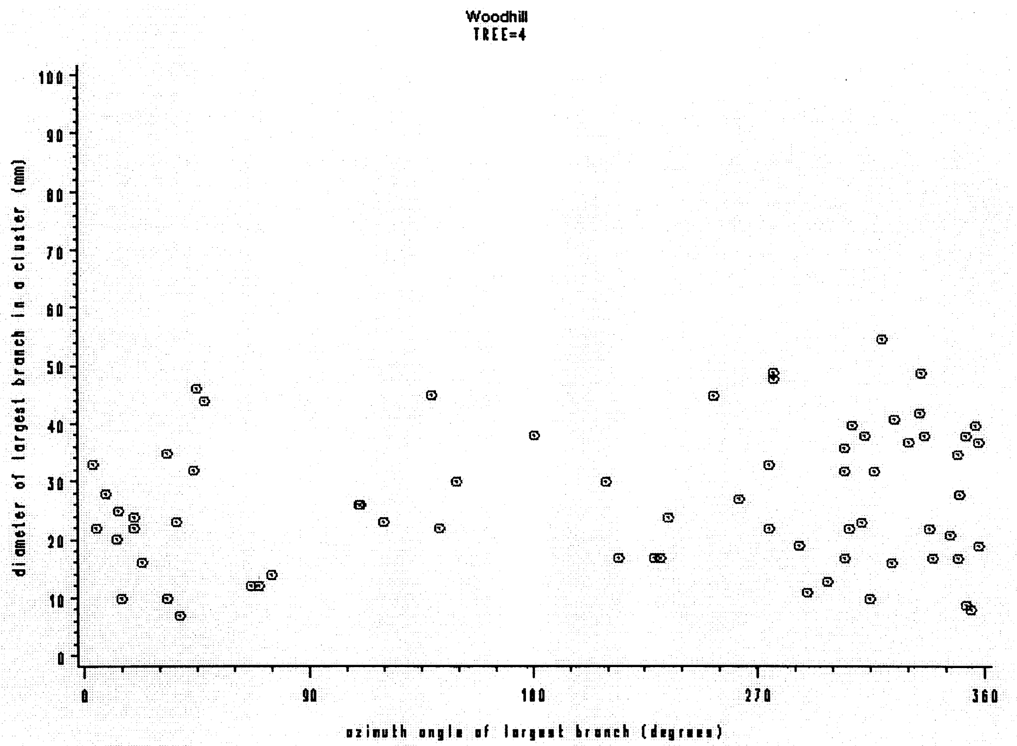

Woodhill
TREE=2
South - North
West - East

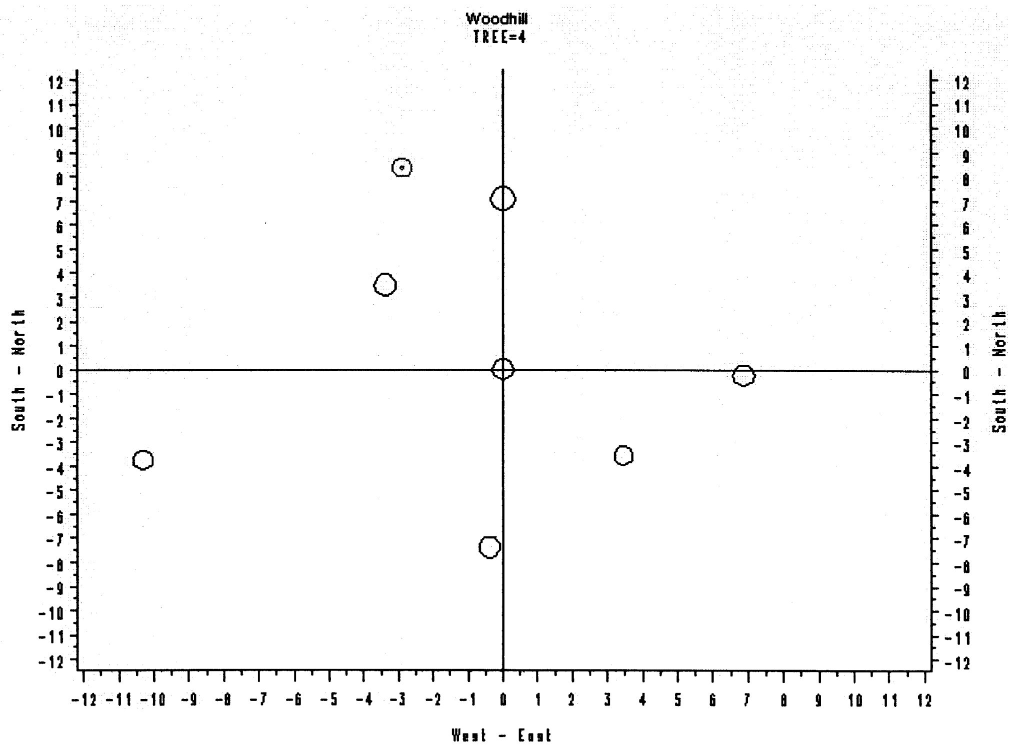
Woodhill
TREE=3

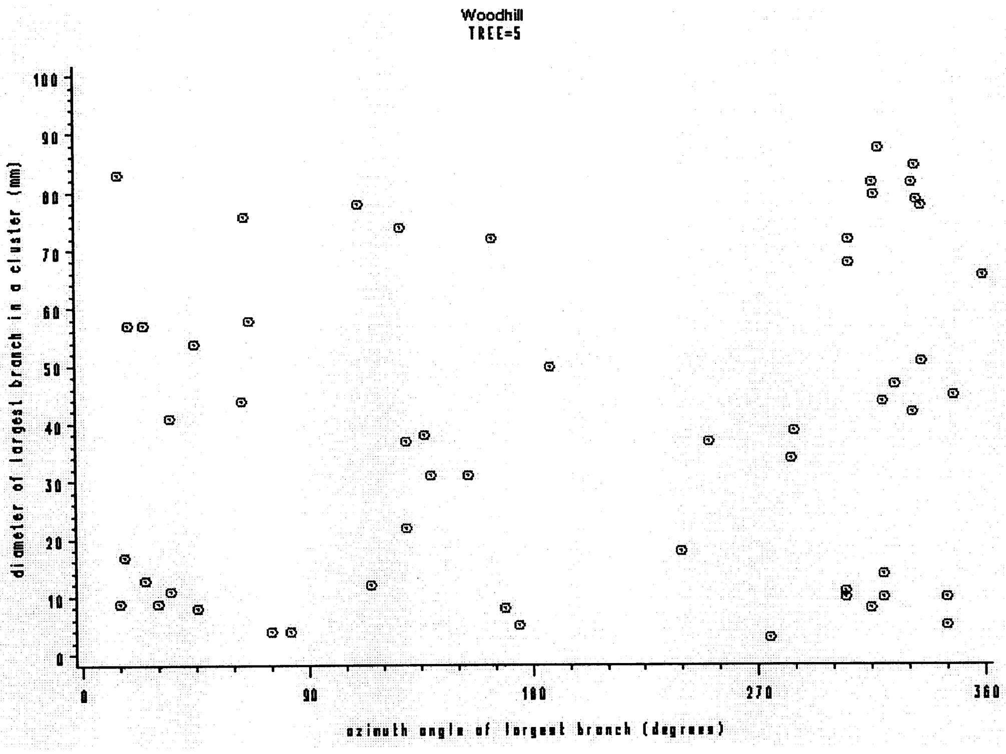


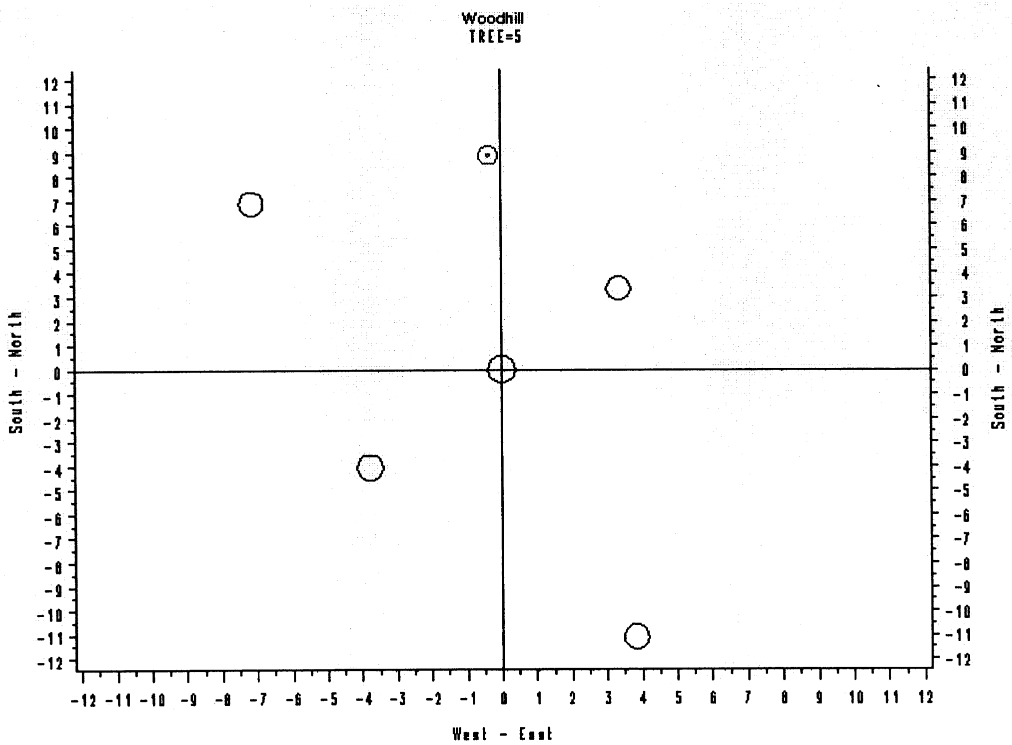
Woodhill
TREE=3

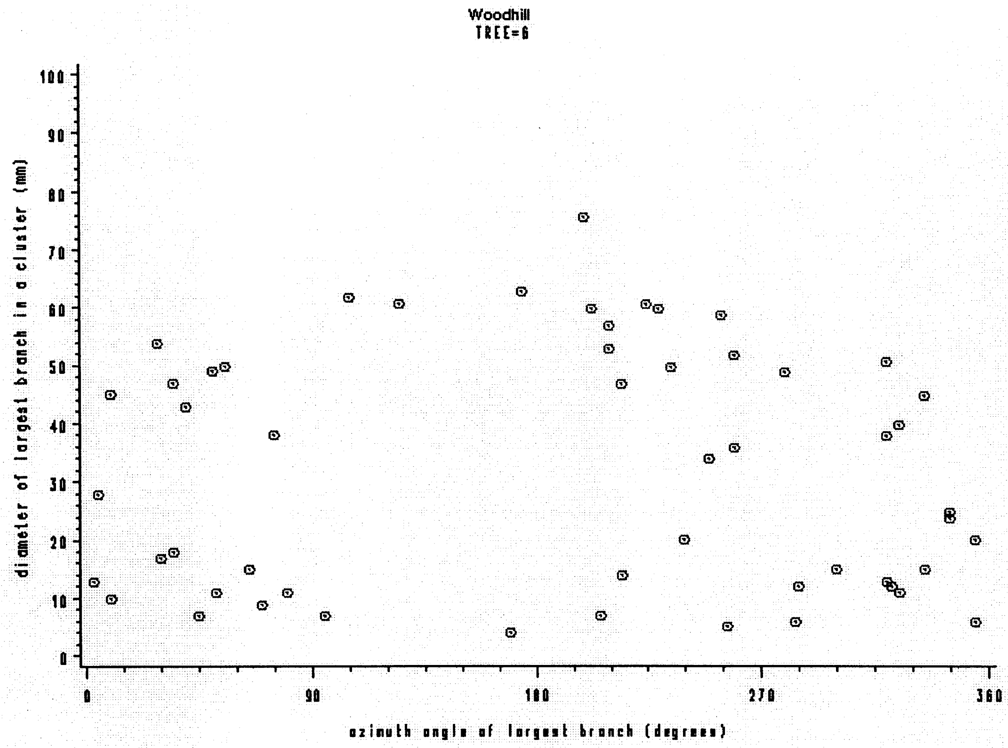


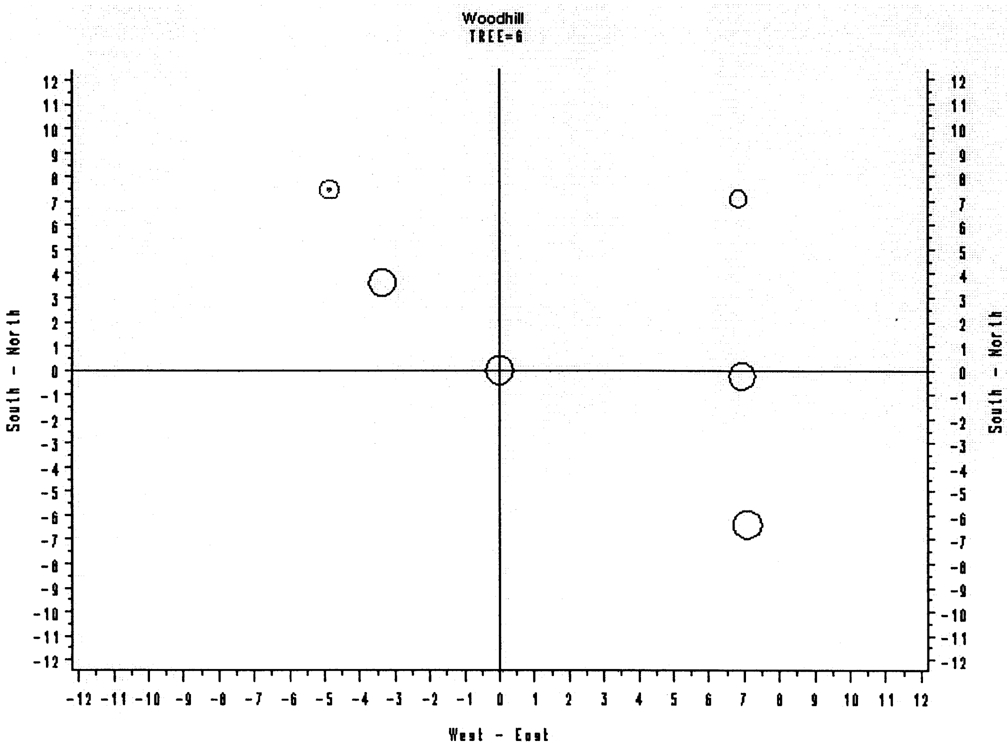

Woodhill
TREE=4
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)

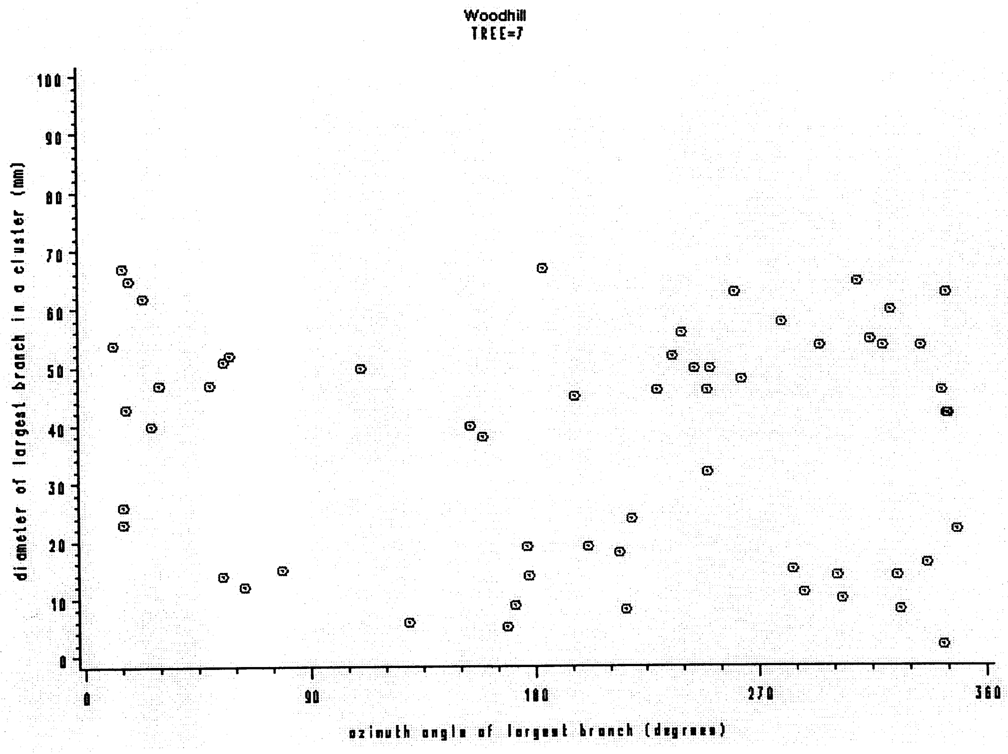

Woodhill
TREE=4
South - North
West - East

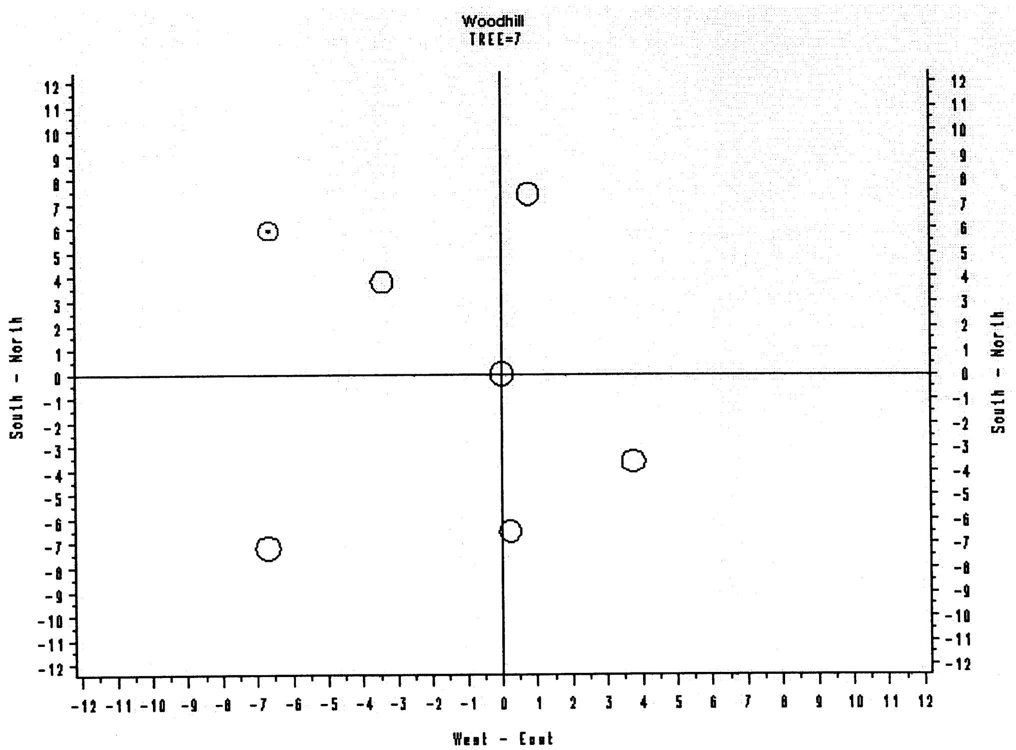

Woodhill
TREE=5
diameter of largest branch in a cluster (mm)
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360
azimuth angle of largest branch (degrees)

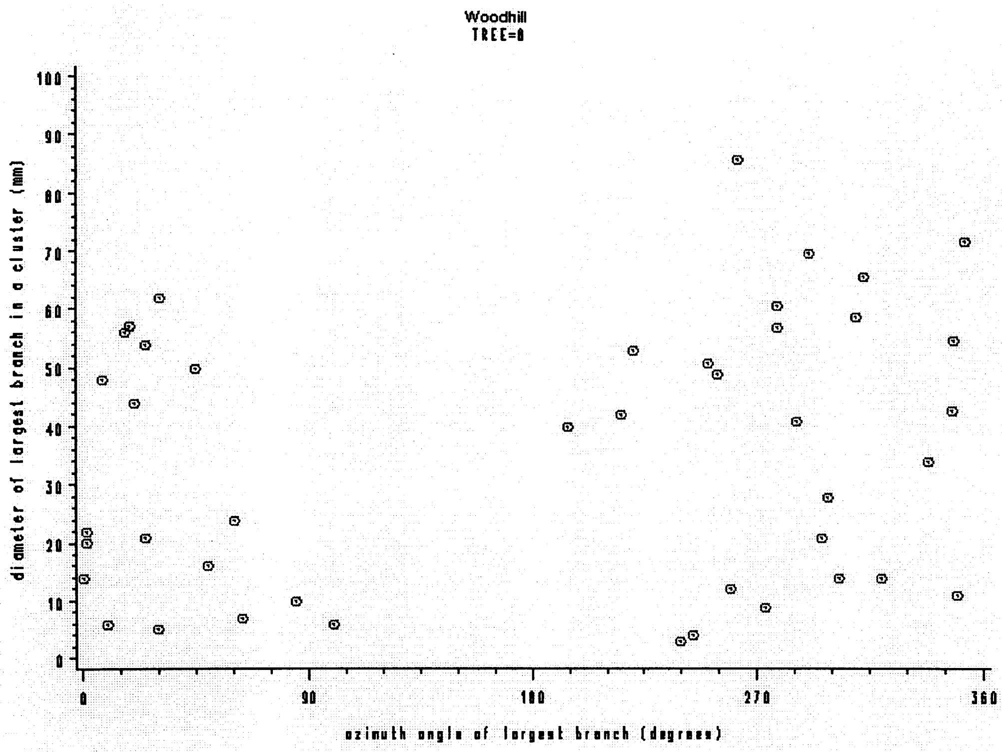

Woodhill
TREE=5
South - North
West - East
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12

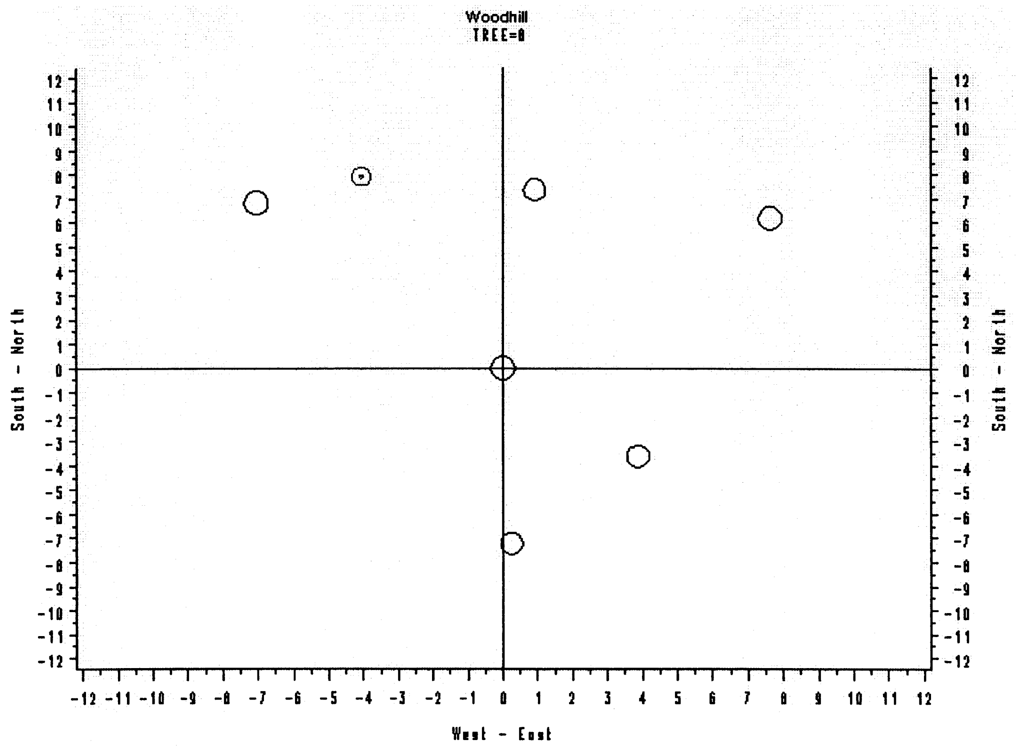

Woodhill
TREE=6
diameter of largest branch in a cluster (mm)
0
10
20
30
40
50
60
70
80
90
100
0
90
180
270
360
azimuth angle of largest branch (degrees)


Woodhill
TREE=6
South - North
West - East
-12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12


Woodhill
TREE=7
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)


Woodhill
TREE=7
South - North
West - East


Woodhill
TREE=8
diameter of largest branch in a cluster (mm)
azimuth angle of largest branch (degrees)


Woodhill
TREE=8
South - North
West - East