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## Dynamic of crowns as a function of slope and competition

Fleur Longuetaud

► **To cite this version:**

Fleur Longuetaud. Dynamic of crowns as a function of slope and competition. Seminar at the Chair of Forest Yield Science, TUM, Jan 2007, Freising, Germany. 42 p. ⟨hal-01194985⟩

**HAL Id: hal-01194985**

**<https://hal.science/hal-01194985v1>**

Submitted on 6 Jun 2020

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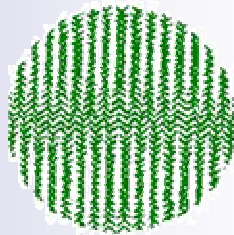
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# Dynamic of crowns as a function of slope and competition

Fleur Longuetaud



INRA

The logo for INRA (Institut National de la Recherche Agronomique) consists of the letters 'INRA' in a bold, green, sans-serif font.

TUM

The logo for TUM (Technische Universität München) consists of the letters 'TUM' in a bold, blue, sans-serif font.



# Plan of the presentation

- I. Database
  - 1. Materials
  - 2. Work on the database
  - 3. Summary of available variables
- II. Preliminary analyses at the plot level
- III. Spatial structure of plots
  - 1. Hypotheses
  - 2. Notions about the analysis of spatial structures
  - 3. Application to our plots
- IV. Analyses at the tree level
  - 1. Objective
  - 2. Computation of competition indexes
  - 3. Direction of the crown displacement (to be continued ...)



# I. Database

## ■ 1. Materials

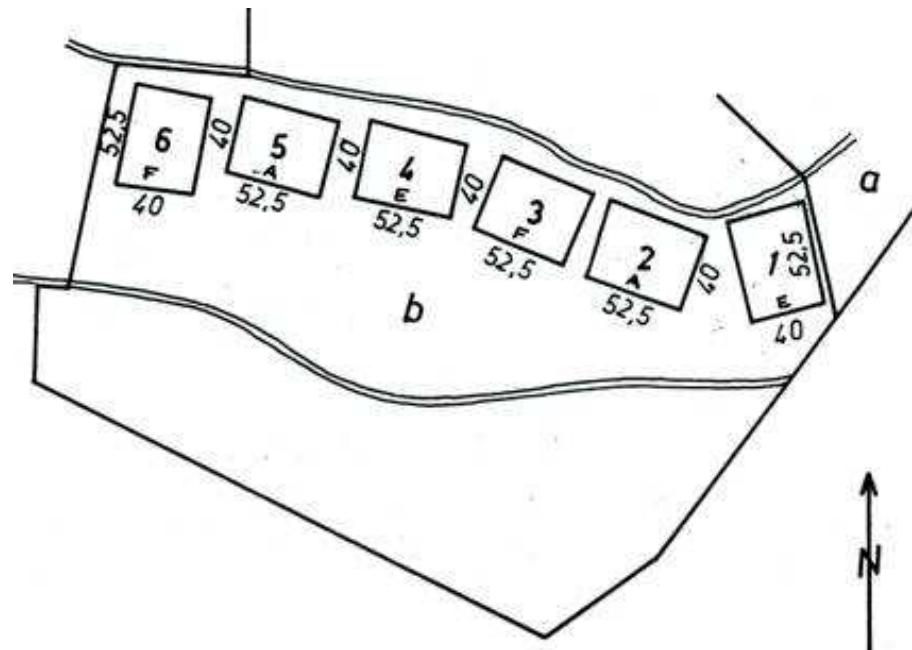
Experiment “Waldleiningen 88”, Rheinland-Pfalz

### □ **Stand characteristics**

- Oak stand with beech trees in the under storey
- Stand age = 118 years in 2004
- Alt. = 420 m
- Strong slope in the north direction

## □ Plot characteristics

- 6 plots 40 x 52.5 m, numbered from 1 to 6
- 3 thinning intensities
  - Plots 2 & 5: **unthinned** (A-Grad)
  - Plots 1 & 4: **moderate thinning** (E-Grad)
  - Plots 3 & 6: **intensive thinning** (F-Grad)

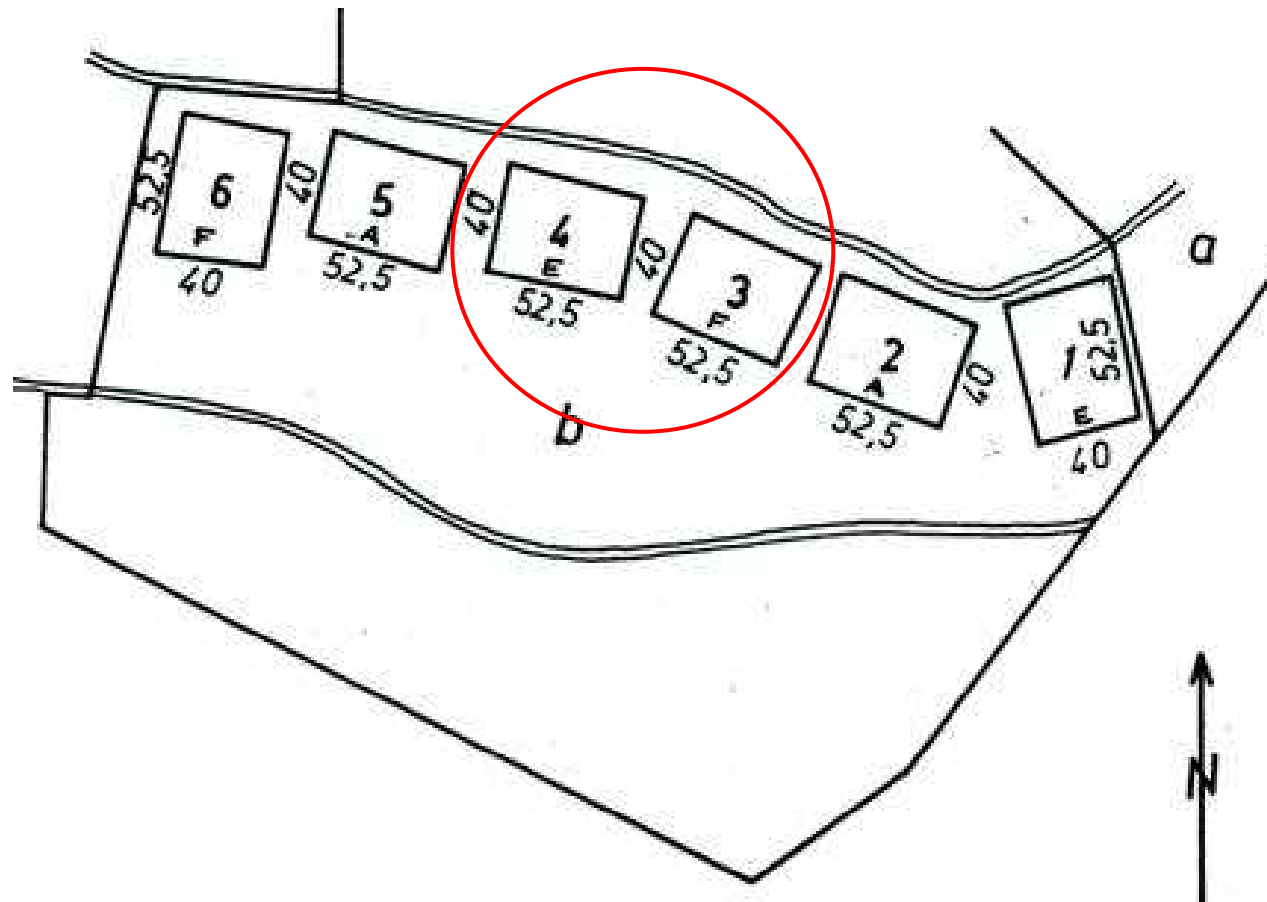




## □ Field measurements

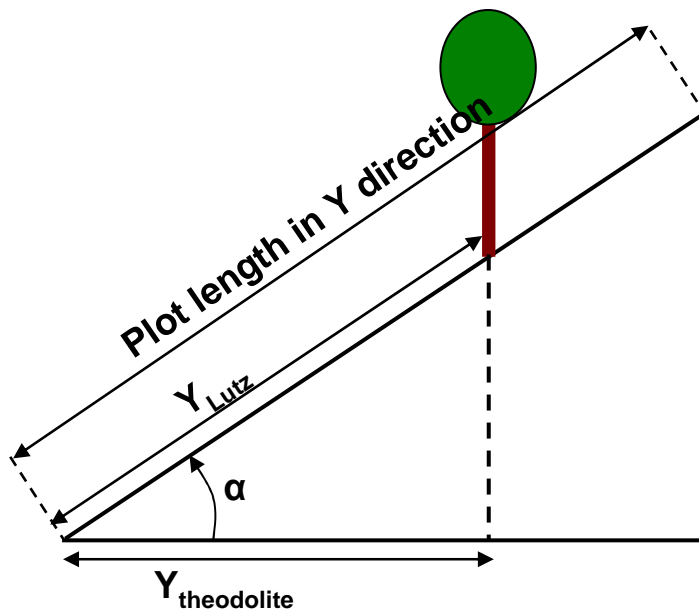
- 4 years of crown measurements: 1952, 1977, 1994 and 2004
- Variables:
  - **DBH** (for all trees)
  - **Height** and **height of crown base** (for all trees in 1994 and 2004; only on sub-samples in 1952 and 1977)
  - Dates of thinnings: 1952, 1958, 1965, 1973, 1977, 1982, 1989, 1994, 1999 and 2004
  - **X**, **Y** and **Z** coordinates since 1990 using a theodolite; **X** and **Y** coordinates manually measured in 1977 by Lutz.
  - **Crown projections** (8 radii)

For practical reasons only **plots 3** (intensive thinning) and **4** (moderate thinning) for **years 1977, 1994 and 2004** were considered in what follows



## ■ 2. Work on the database and computation of additional variables

### □ 2.1. Correction of X and Y coordinates for the slope



1. **Adjustment** of the following equations, for trees measured both with theodolite and by Lutz:

$$\mathbf{X}_{\text{theodolite}} = \mathbf{a}_X \mathbf{X}_{\text{Lutz}}$$

$$\mathbf{Y}_{\text{theodolite}} = \mathbf{a}_Y \mathbf{Y}_{\text{Lutz}}$$

2. For trees only measured by Lutz in 1977 (i.e. thinned or dead before 1990), **correction** of the X and Y coordinates:

$$\mathbf{X}_{\text{corrected}} = \mathbf{a}_X \mathbf{X}_{\text{Lutz}}$$

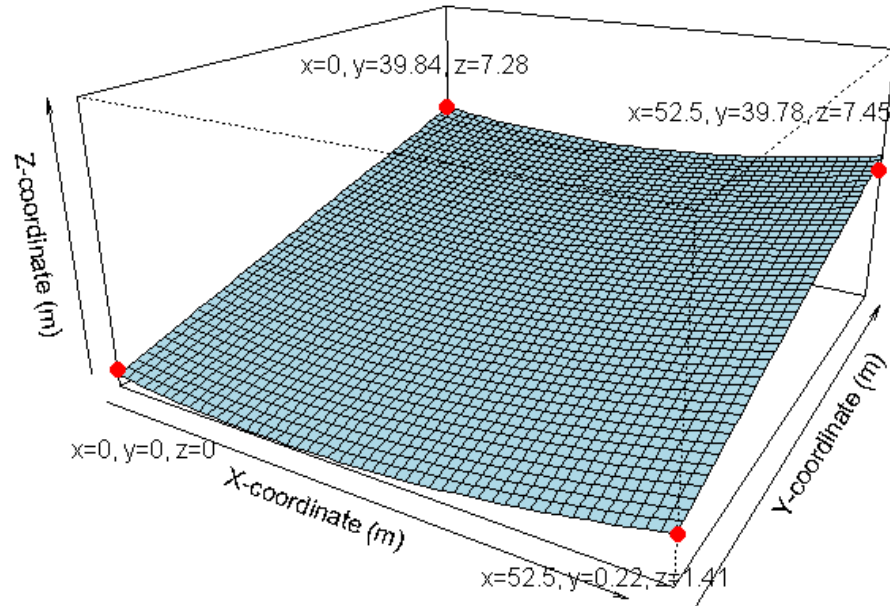
$$\mathbf{Y}_{\text{corrected}} = \mathbf{a}_Y \mathbf{Y}_{\text{Lutz}}$$

## □ 2.2. Estimation of the 3D surface of the plots

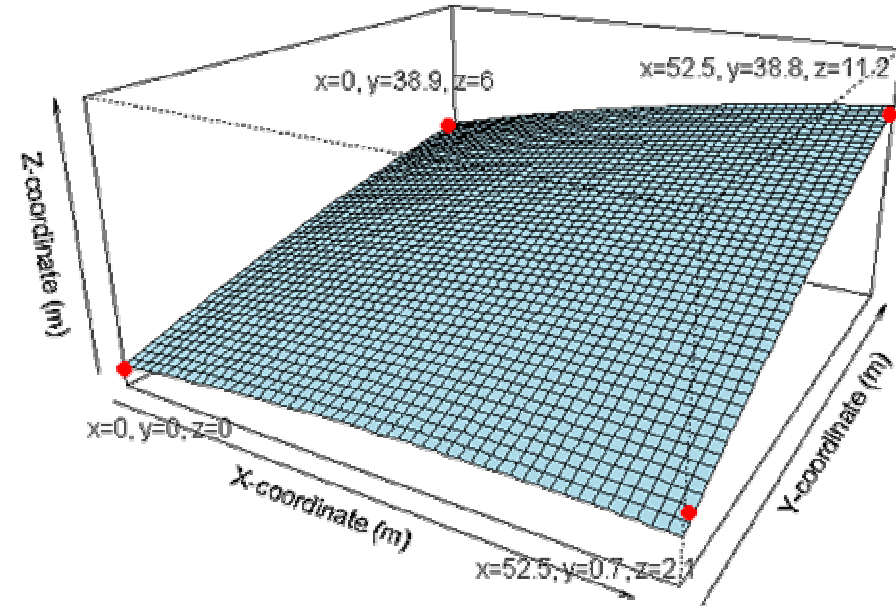
Adjustment of the following equation, for trees which were measured by theodolite:

$$Z = aX + bY + cX^2 + dY^2 + eXY + f$$

Estimation of a 3D view for plot n°3



Estimation of a 3D view for plot n°4





This equation was used:

1. To **predict the Z value** for trees which were only measured by Lutz

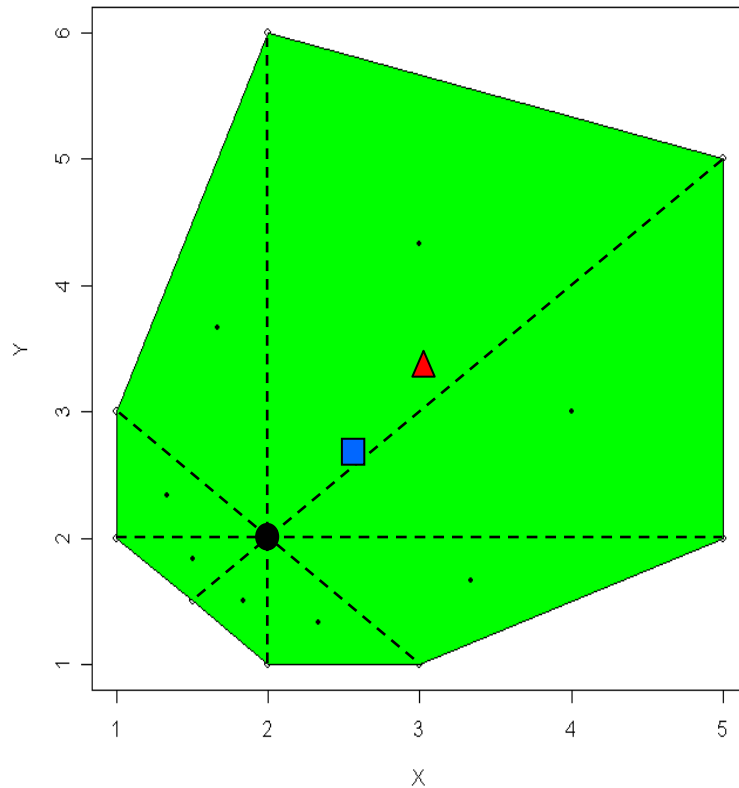
2. To compute for each tree a **local slope** (direction and intensity)

$$\begin{cases} \frac{\partial Z}{\partial X} = a + 2cX + eY \\ \frac{\partial Z}{\partial Y} = b + 2dY + eX \end{cases}$$

▪ **Slope intensity:**  $I = \sqrt{\left(\frac{\partial Z}{\partial X}\right)^2 + \left(\frac{\partial Z}{\partial Y}\right)^2}$

▪ **Slope direction:** 
$$\begin{cases} \theta = \arctan\left(\frac{\frac{\partial Z}{\partial Y}}{\frac{\partial Z}{\partial X}}\right) & \text{si } \frac{\partial Z}{\partial X} < 0 \\ \theta = \arctan\left(\frac{\frac{\partial Z}{\partial Y}}{\frac{\partial Z}{\partial X}}\right) + \pi & \text{si } \frac{\partial Z}{\partial X} > 0 \end{cases}$$

## □ 2.3. Computation of areas and gravity centers of crown projections



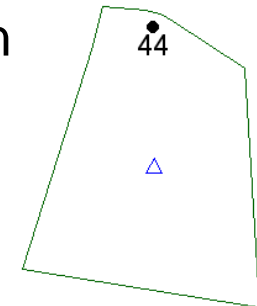
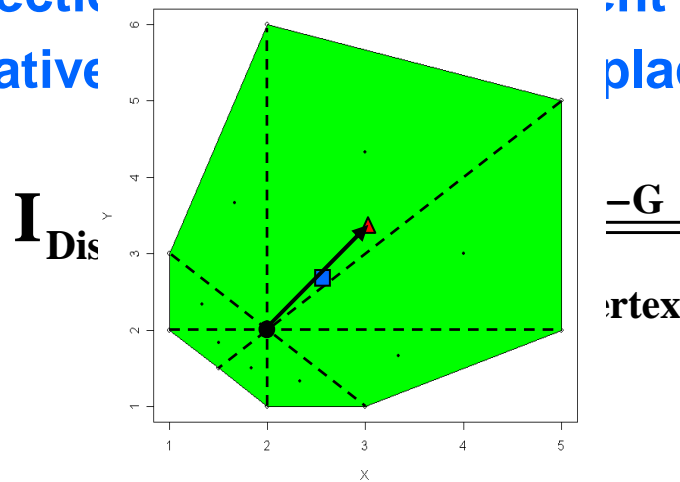
- Stem
- Gravity centre using the 8 points
- ▲ Gravity centre using the 8 triangles

## Crown size: area of crown projection

### Crown geometry:

1. Displacement of gravity centre G from stem location

- direction
- relative

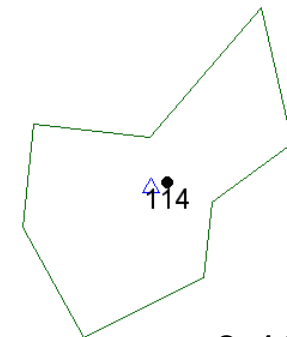


$$I_{\text{Displacement}} = 0.92$$

$$CV = 0.1$$

2. Regularity of the crown projection

$$CV = \frac{SD(\text{Dist}_{G-\text{Vertex}})}{\text{Dist}_{G-\text{Vertex}}}$$



$$I_{\text{Displacement}} = 0.13$$

$$CV = 0.43$$

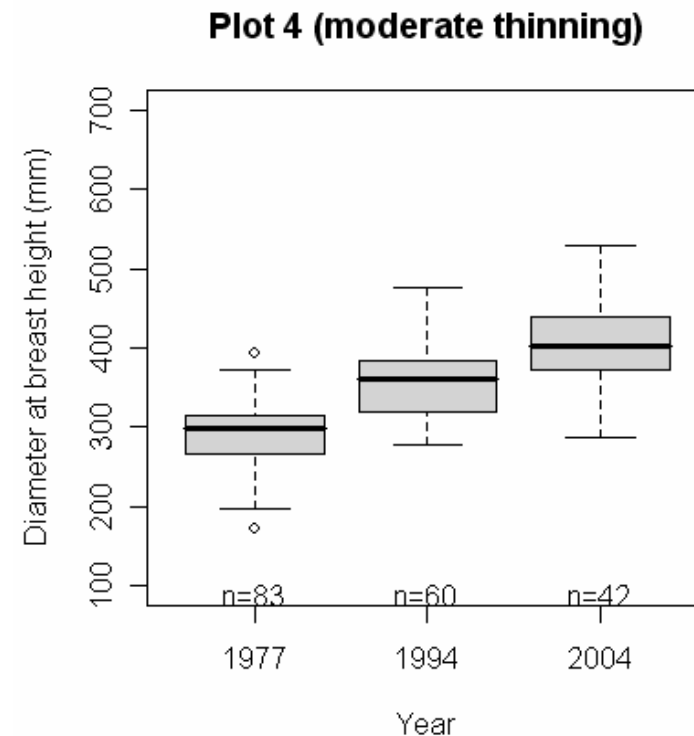
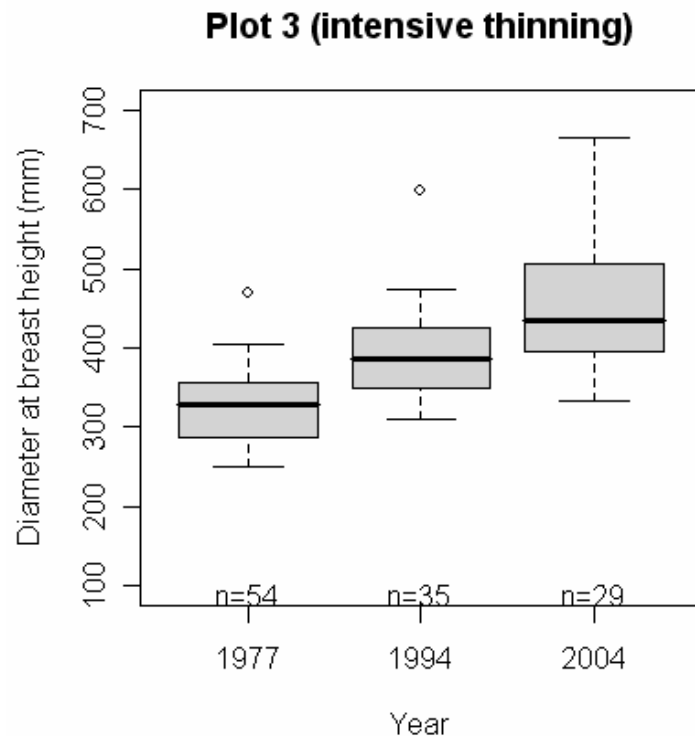


### ■ 3. Summary of available variables

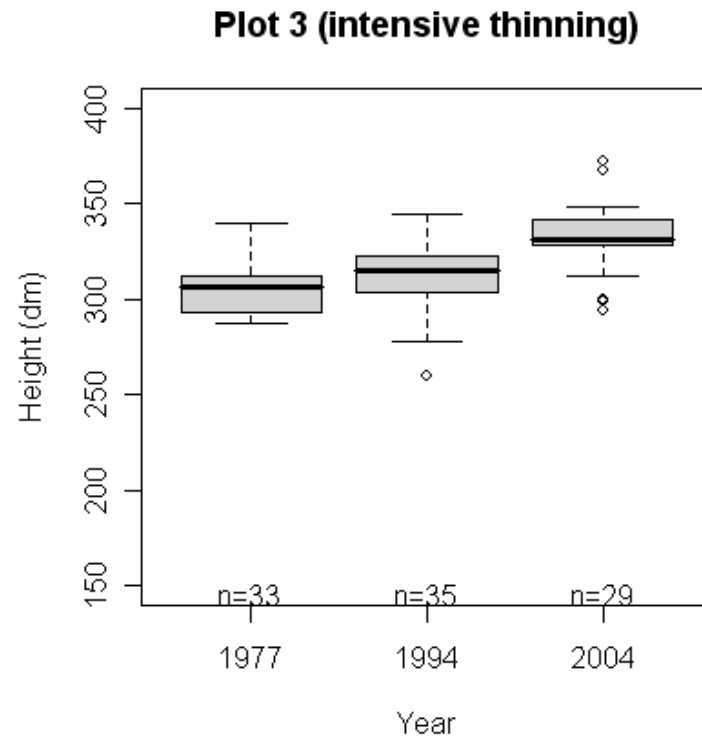
- DBH
- Total height and height of crown base (not for all trees)
- X, Y and Z coordinates of the stem
- Direction and intensity of the local slope
- Area of the crown projection
- Gravity centre of the crown projection
- Direction and intensity of the crown displacement
- Measurement of regularity of the shape of the projection

## II. Preliminary analyses at the plot level

### □ Diameter

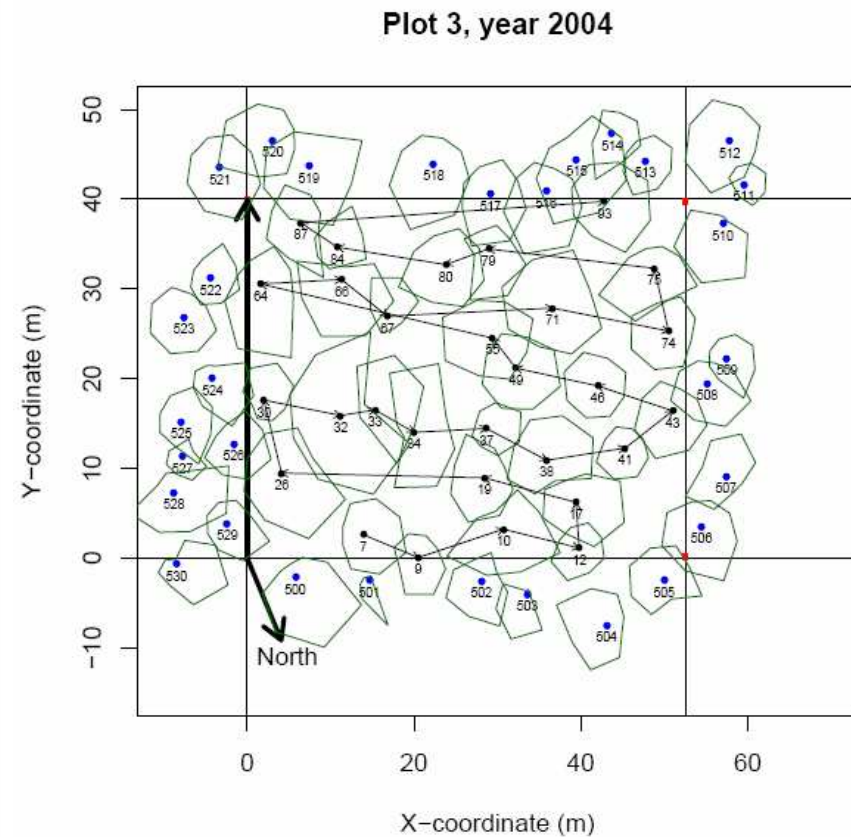
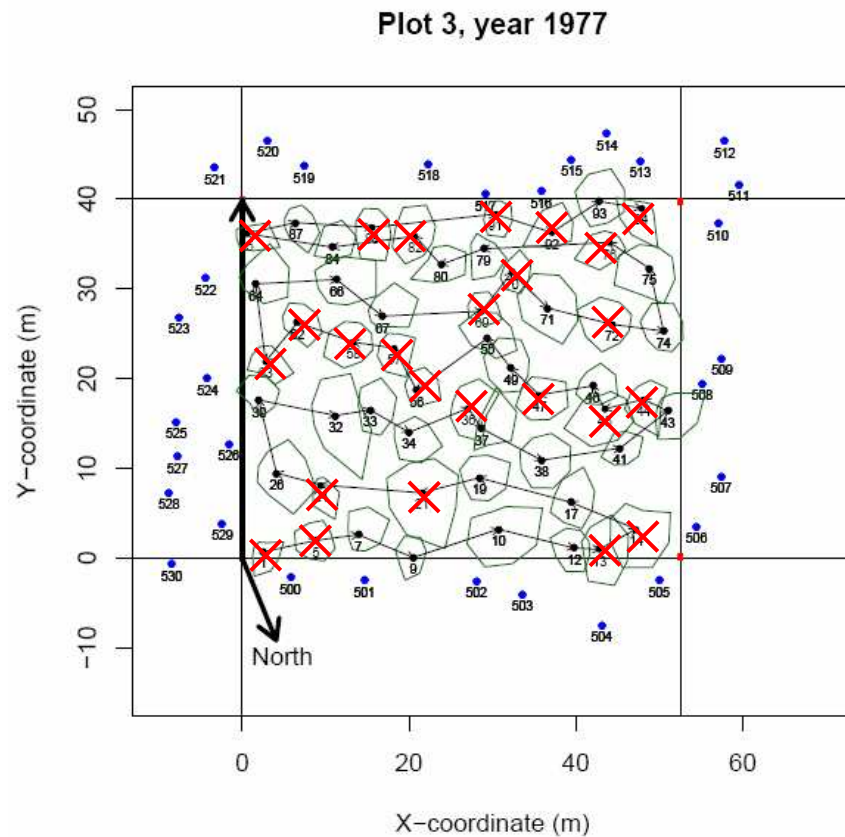


# □ Height

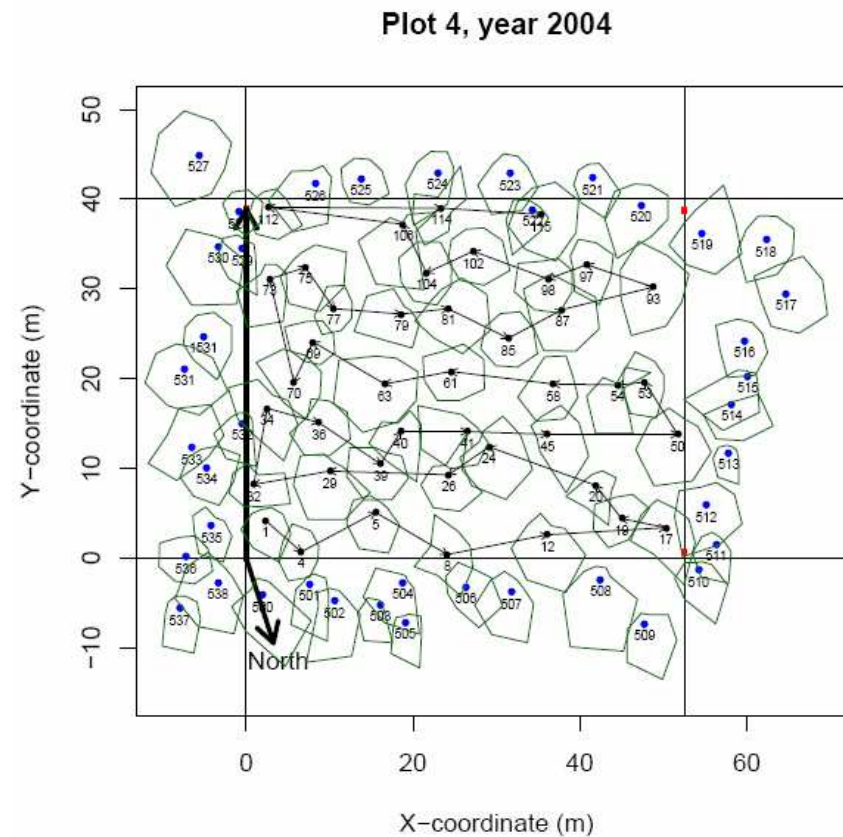
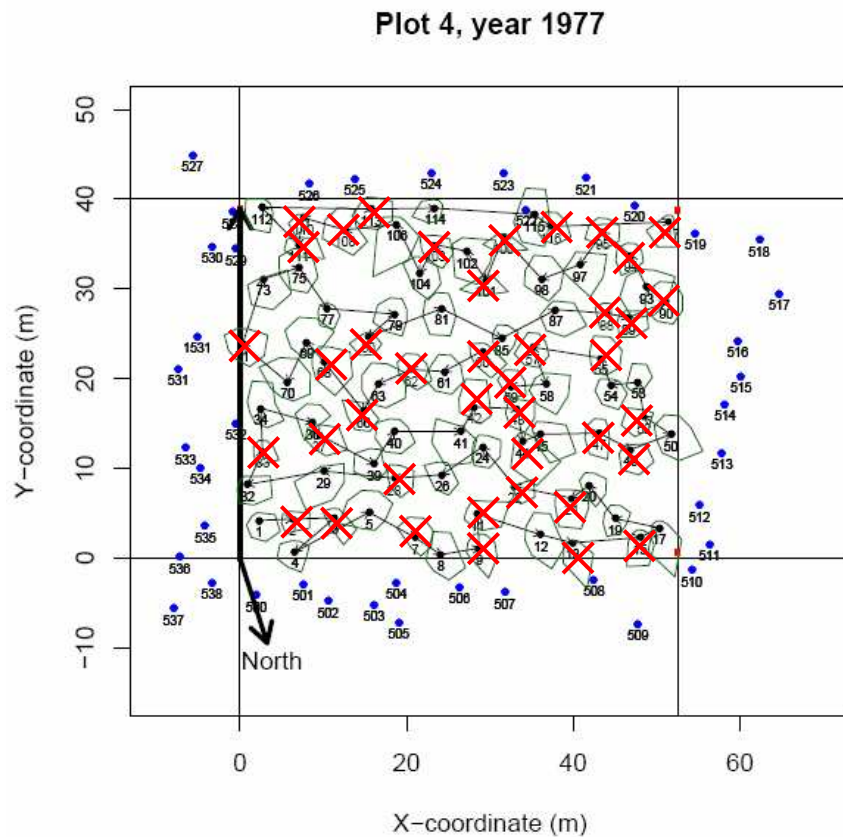


## □ Crown projections

✗ Trees thinned between 1977 and 2004 (n=41)

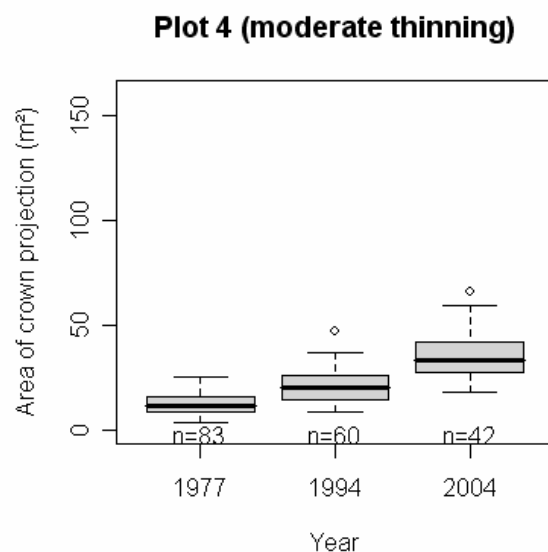
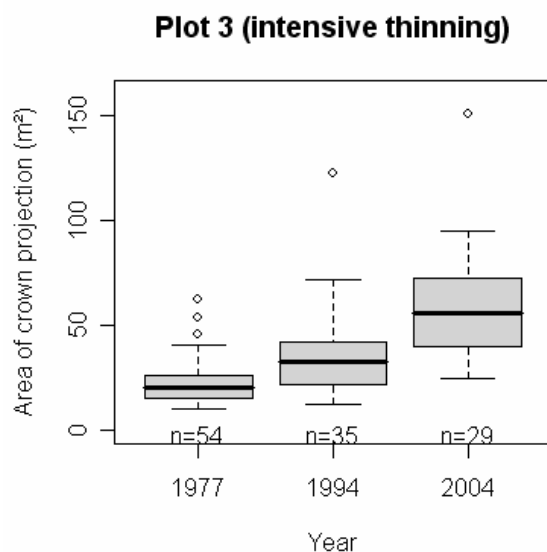


× Trees thinned between 1977 and 2004 (n=25)



## □ Area of crown projections

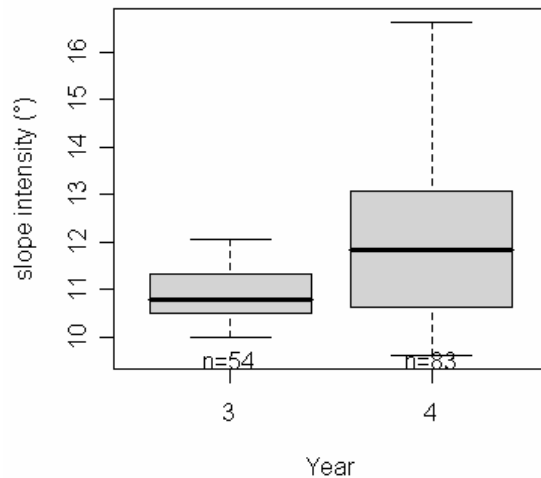
“**plot**” effect (mostly a thinning effect) and “**time**” effect were significant with interaction



Mean increment of  
**0.79 m<sup>2</sup>/year** in plot 4  
versus **1.03 m<sup>2</sup>/year** in  
plot 3

## □ Slope

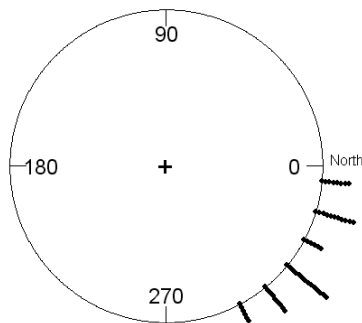
### ■ Intensity



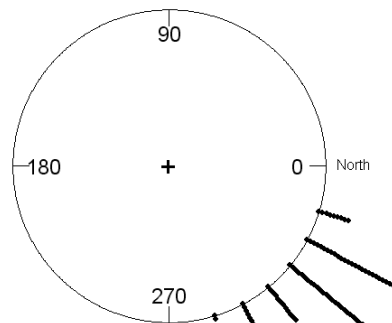
The slope intensity was slightly greater in plot 4 with **12.1°** than in plot 3 with **10.9°**

### ■ Direction

Distribution of local slope orientations, plot 3



Distribution of local slope orientations, plot 4



The local slopes were significantly (Rayleigh test) oriented to the north-east direction

Plot 3: **-32°** (mean value)

Plot 4: **-38°**



## □ Crown displacement

### ■ Intensity

No “time” effect can be shown but, significant difference between plot 3 and 4:

$I_{\text{Displacement}}$  in plot 3 = **0.29**

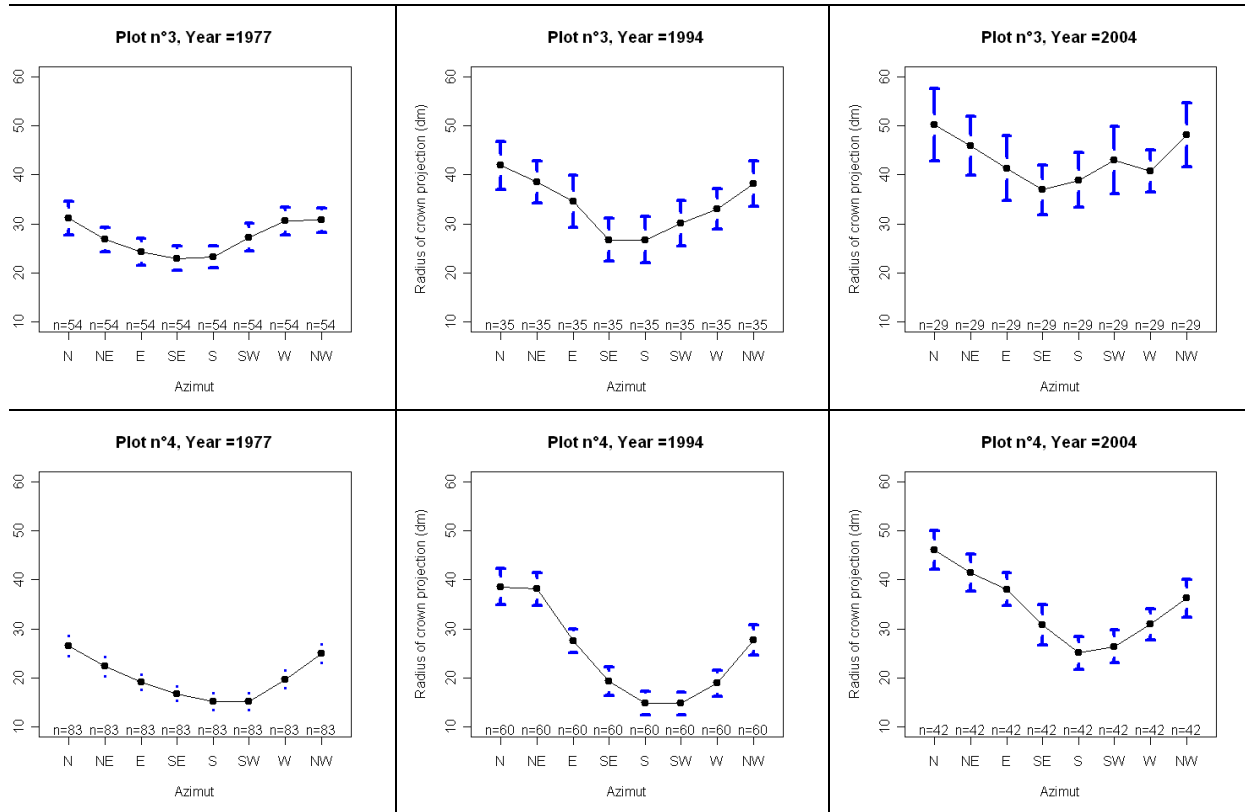
$I_{\text{Displacement}}$  in plot 4 = **0.39**

It seems that the crown displacement is higher for higher density (moderate thinning)

An effect of the slope (slightly greater in plot 4) is also possible ...

## ■ Direction of crown displacement

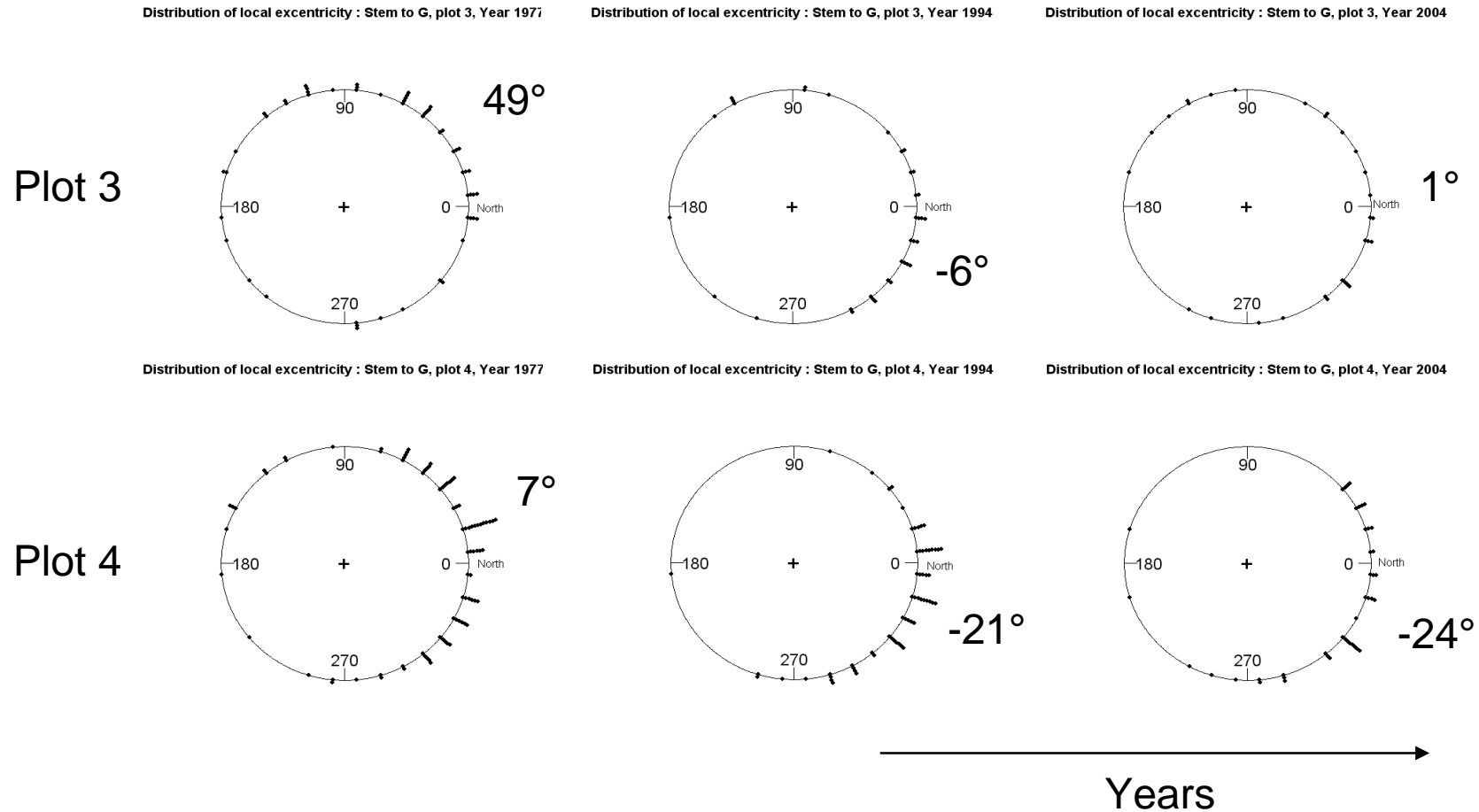
Plot 3



Plot 4

Means of crown radii are greater in north and north-east directions which correspond to the slope direction ...  
optimisation of light interception ?

# Displacement between stem and gravity centre





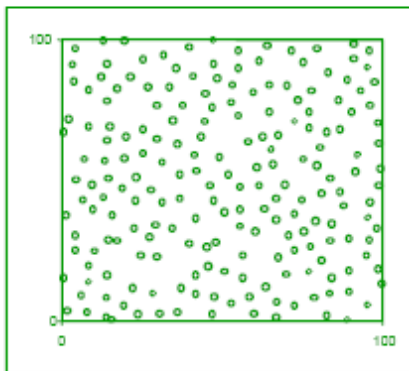
# III. Spatial structure of plots

- 1. Hypotheses:

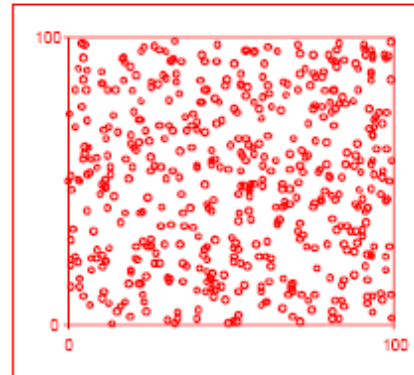
- The gravity centres of crown projections are more regularly distributed than stems (optimisation of space occupation ...)
- The distribution of gravity centres becomes more and more regular with time

- 2. Notions about the analysis of spatial structures (taken from F. Goreaud)

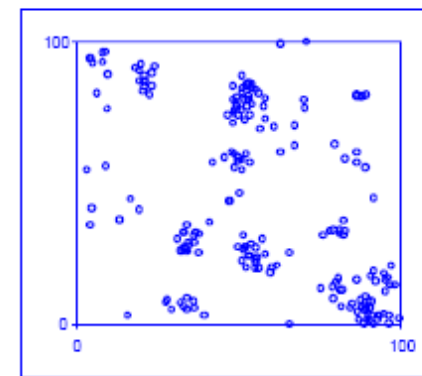
**Regular**



**Random**

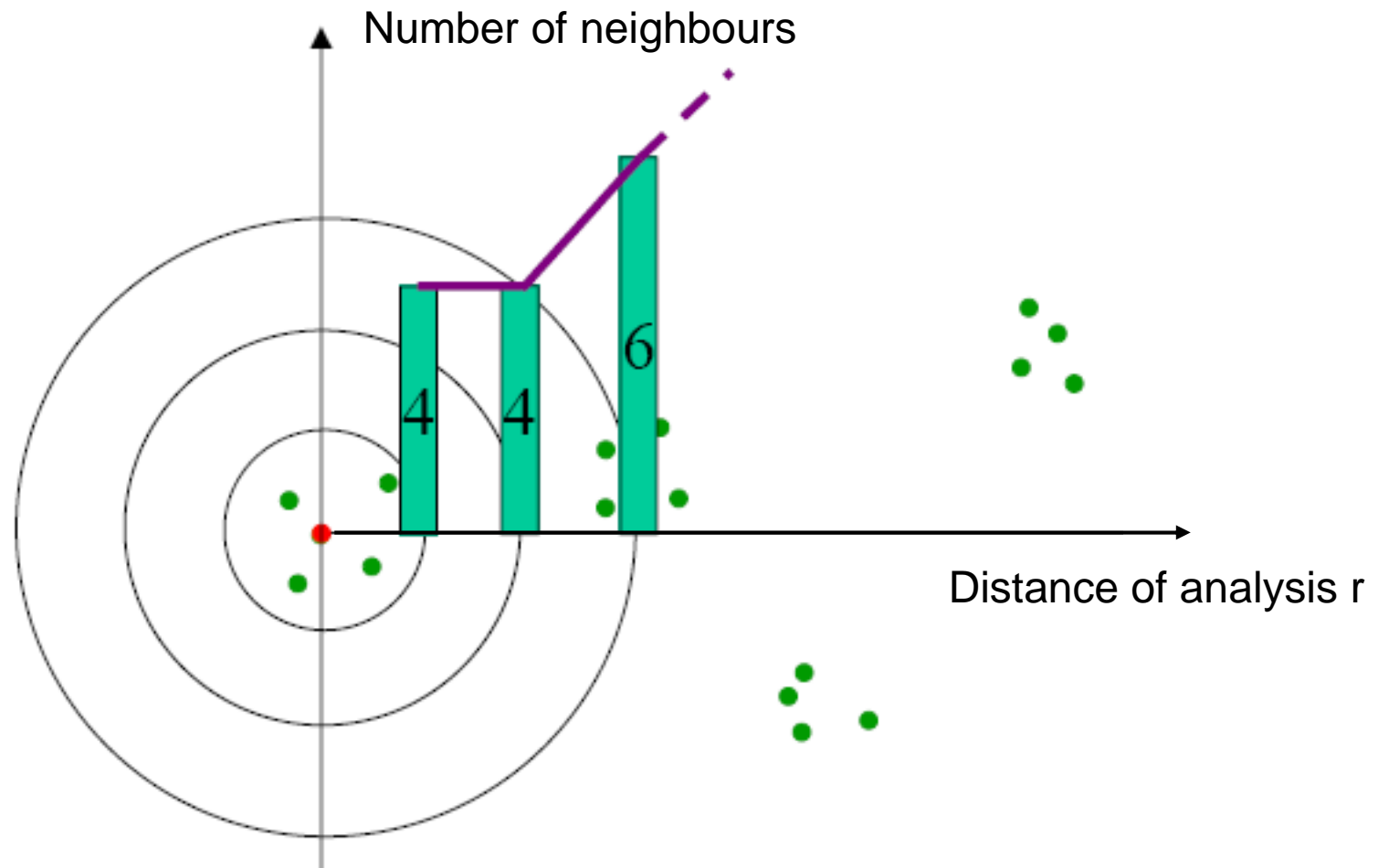


**Aggregated**

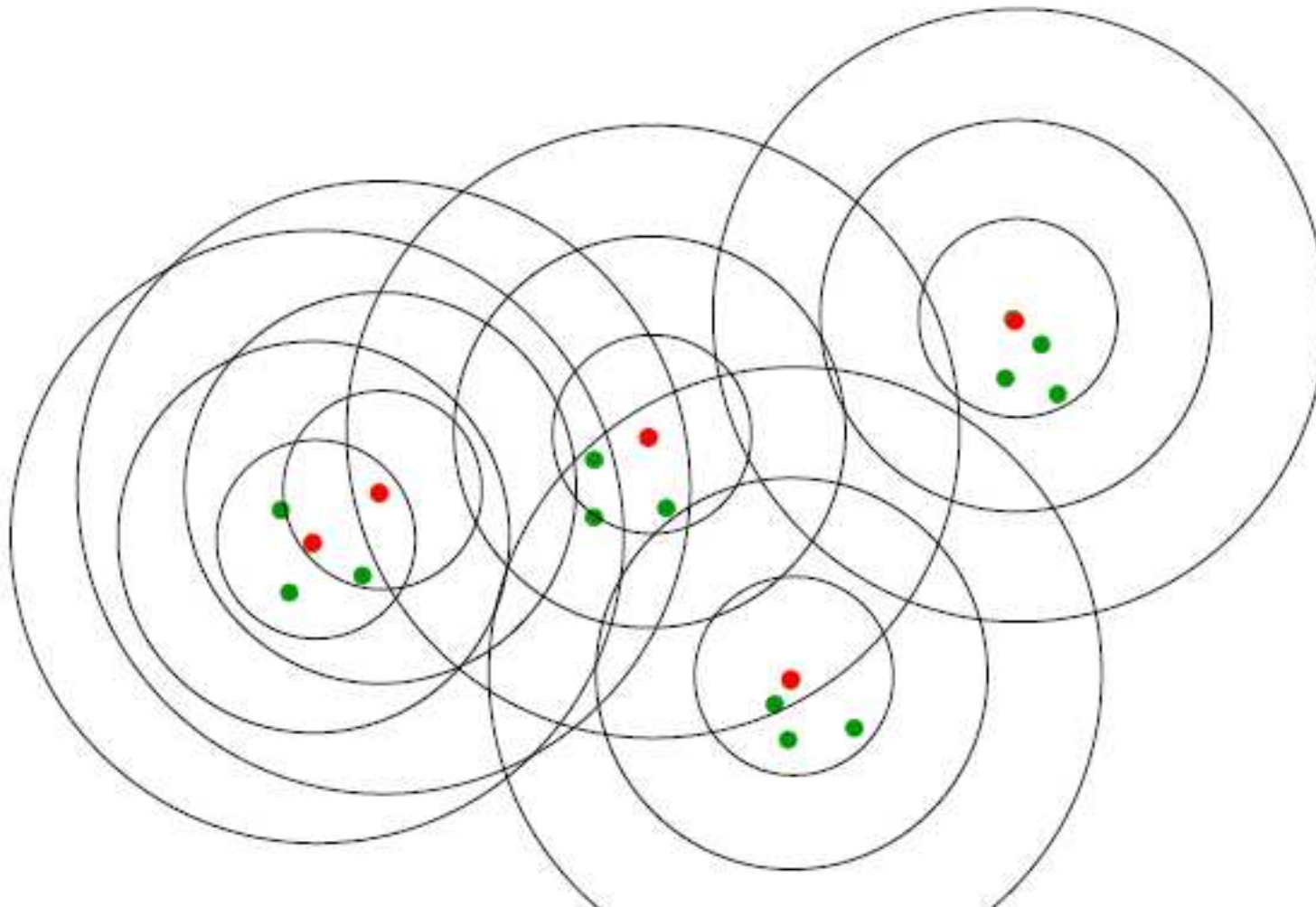


# The Ripley's K-function

We want to analyse several scale at the same time



We want a mean results on the points

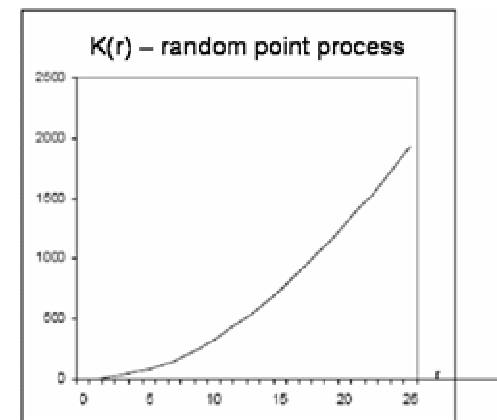


The K-function is a function of r and

$$K(r) = E(\text{number of neighbours at a distance } \leq r) / \lambda$$

For a completely random (Poisson) point process

$$(H_0): K(r) = \pi r^2$$



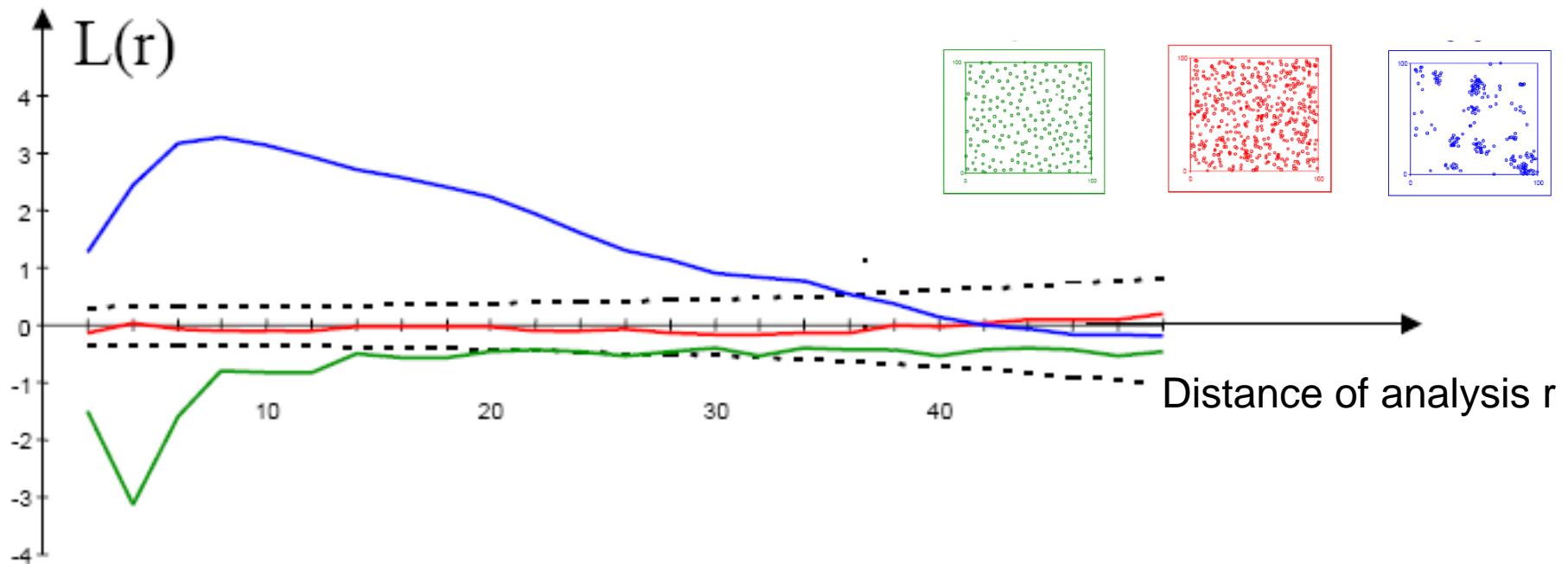
Then, for an **aggregated** distribution:  $K(r) > \pi r^2$ ,  
and for a **regular** distribution:  $K(r) < \pi r^2$ .

We are going to use the transformation proposed by Besag (1977):

$$\mathbf{L}(\mathbf{r}) = \sqrt{\frac{\mathbf{K}(\mathbf{r})}{\pi}} - \mathbf{r}$$

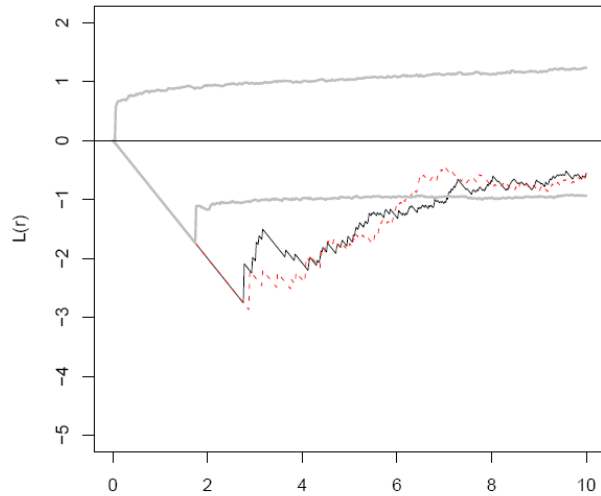
This function

- is easier to interpret as  $H_0$  corresponds to  $L(r)=0$
- has a more stable variance with  $r$



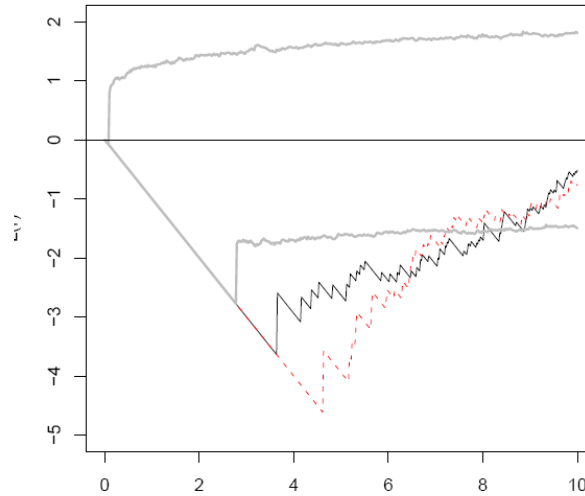
# 3. Application to our plots

L(r) function for plot 3, year 1977



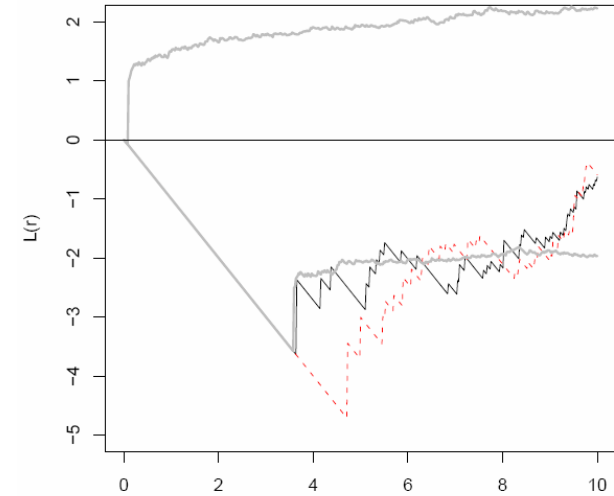
Nsim=10000, alpha=0.01

L(r) function for plot 3, year 1994



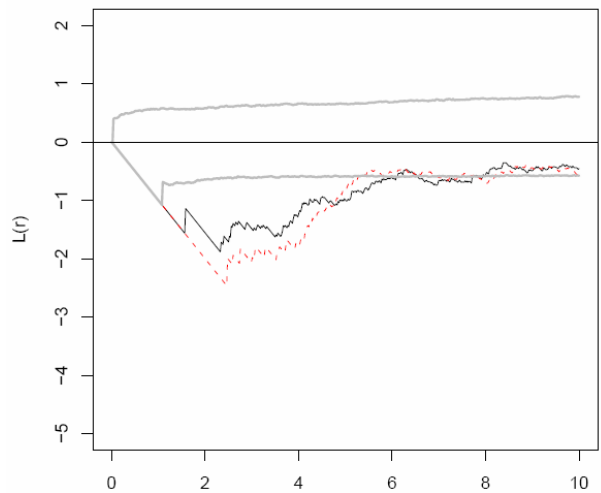
Nsim=10000, alpha=0.01

L(r) function for plot 3, year 2004



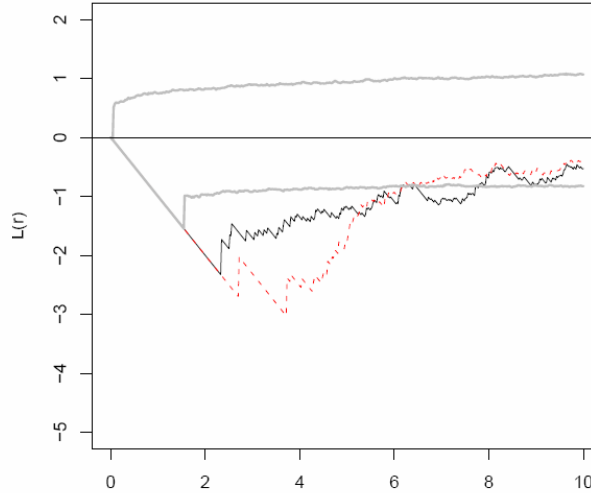
Nsim=10000, alpha=0.01

L(r) function for plot 4, year 1977



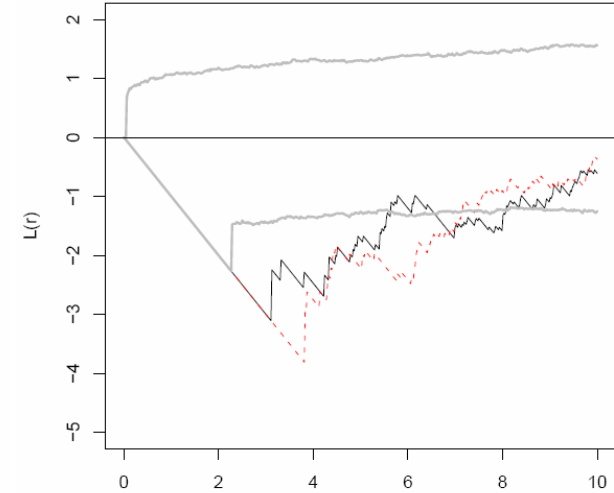
Nsim=10000, alpha=0.01

L(r) function for plot 4, year 1994



Nsim=10000, alpha=0.01

L(r) function for plot 4, year 2004



Nsim=10000, alpha=0.01



I also computed the Clark and Evans' index and the same tendencies were observed:

- **Regular distributions** of stems and gravity centres of crown projections
- The **gravity centres are more regularly distributed** than the stems
- Both stems and gravity centres seem to become **more and more regular with the time**
- Distributions seem more regular for **intensive thinning** (plot 3, in which displacements were lower)

## **Discussion of the results**

Our 2 plots were thinned about every 5 years

How to distinguish between the thinning effect and the natural reaction of trees ?

We are trying to get data from plot 5, which was unthinned



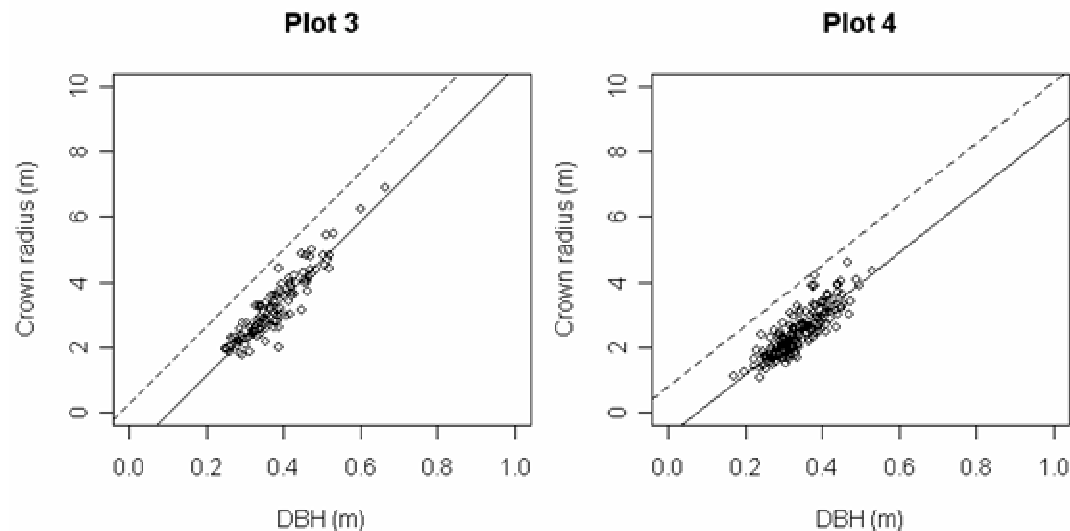
## IV. Analyses at the tree level

- **1. Objective:** to explain the crown characteristics of individual trees within a plot as a function of competition and slope, e.g.:
  - **crown size or  $\Delta(\text{crown size})=f(\text{DBH, intensity of the competition, slope intensity, ...})$**
  - **Direction of crown displacement=f(direction of competition, direction of slope, ...)**
  - **Intensity of crown displacement=f(DBH, intensity of the competition, slope intensity, ...)**

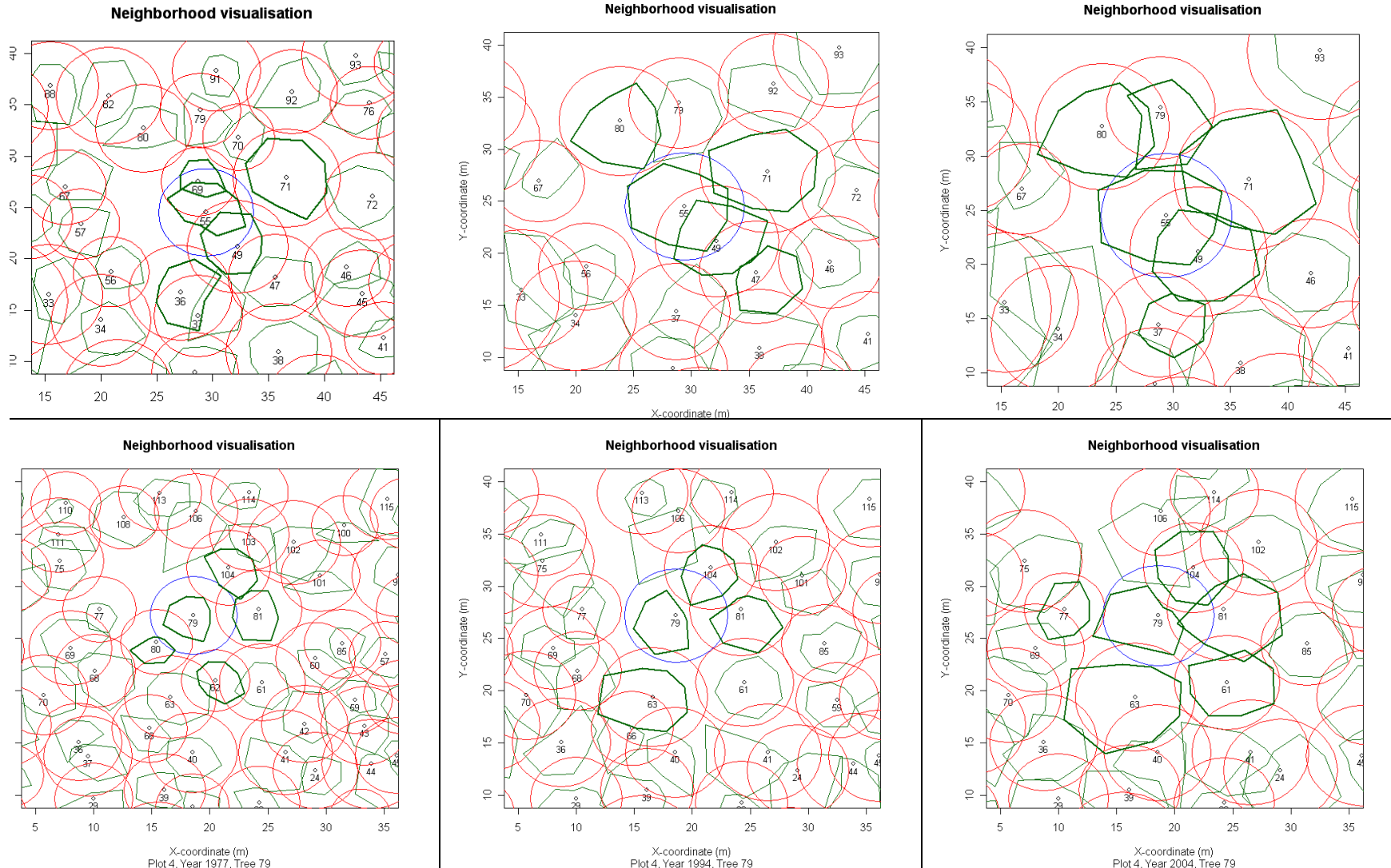
## ■ 2. Computation of competition indexes

### □ 2.1. Definition of the neighbourhood of a target tree

**Potential of horizontal extension** based on the tree size



# Examples of neighbourhoods obtained



## □ 2.2. Computation of direction and intensity of the competition from the literature

The indexes are based on diameter and distance to neighbouring trees

**Brisson (2001): weighted sum of vectors from competitors to the target tree**

Competitive vector	Neighbours considered
DBH/distance	All neighbours
DBH/distance <sup>2</sup>	All neighbours
DBH	All neighbours

**Rouvinen & Kuuluvainen (1997): weighted mean of competitor coordinates**

$$\text{CC1: } \bar{x} = (\sum x_j) / n; \bar{y} = (\sum y_j) / n$$

$$\text{CC2: } \bar{x} = (\sum d_j x_j) / (\sum d_j); \bar{y} = (\sum d_j y_j) / (\sum d_j)$$

$$\text{CC3: } \bar{x} = (\sum d_j^2 x_j) / (\sum d_j^2);$$

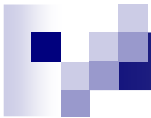
$$\bar{y} = (\sum d_j^2 y_j) / (\sum d_j^2)$$

$$\text{CC4: } \bar{x} = (\sum d_j x_j / L_j) / (\sum d_j / L_j);$$

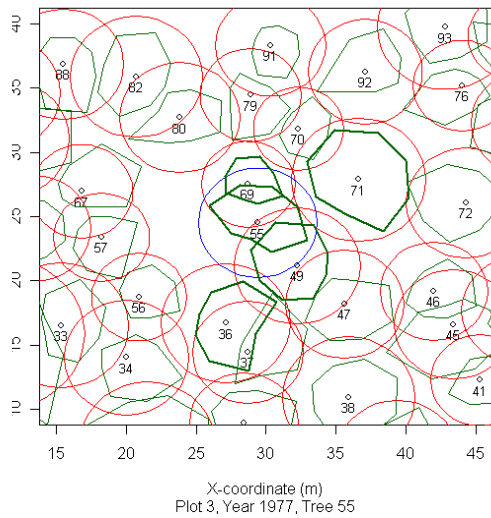
$$\bar{y} = (\sum d_j y_j / L_j) / (\sum d_j / L_j)$$

$$\text{CC5: } \bar{x} = (\sum d_j^2 x_j / L_j) / (\sum d_j^2 / L_j);$$

$$\bar{y} = (\sum d_j^2 y_j / L_j) / (\sum d_j^2 / L_j)$$

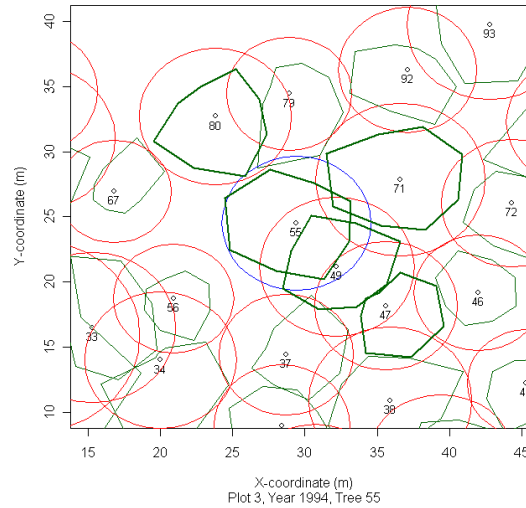


Neighborhood visualisation



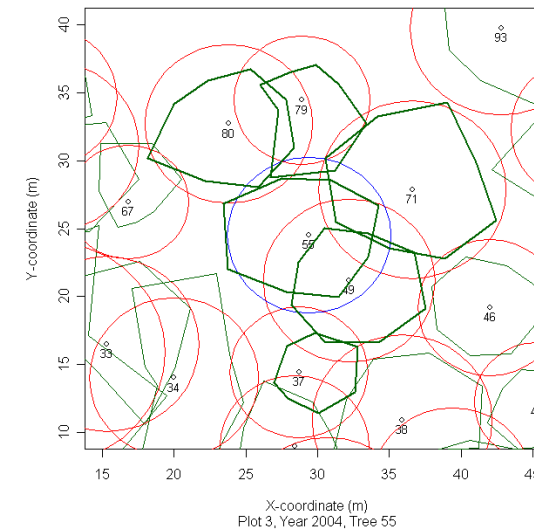
Plot 3, Year 1977, Tree 55

Neighborhood visualisation



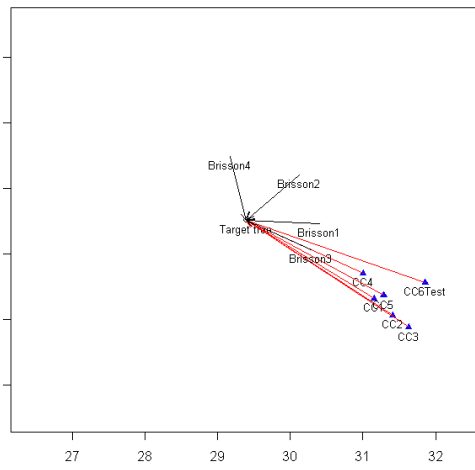
Plot 3, Year 1994, Tree 55

Neighborhood visualisation



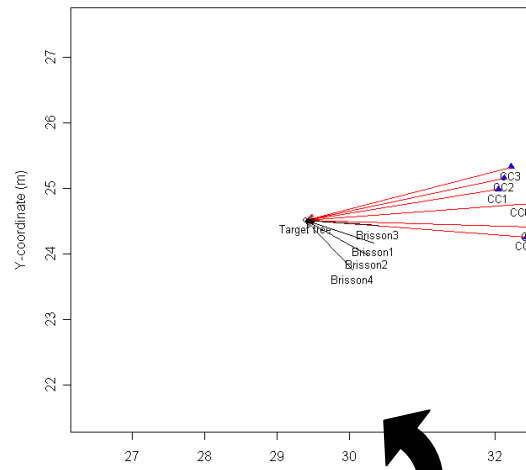
Plot 3, Year 2004, Tree 55

Direction of the competition



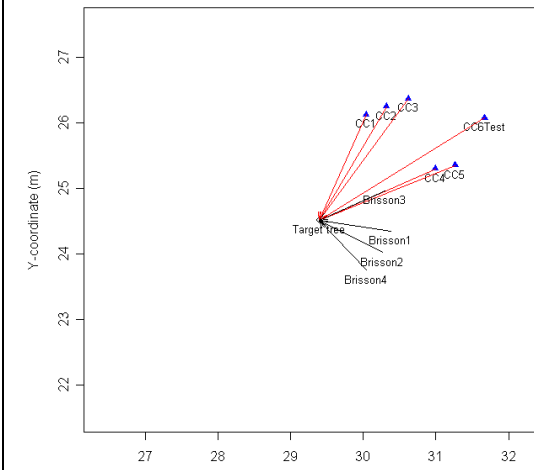
Plot 3, Year 1977, Tree 55, maximum neighborhood

Direction of the competition

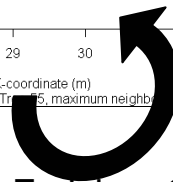


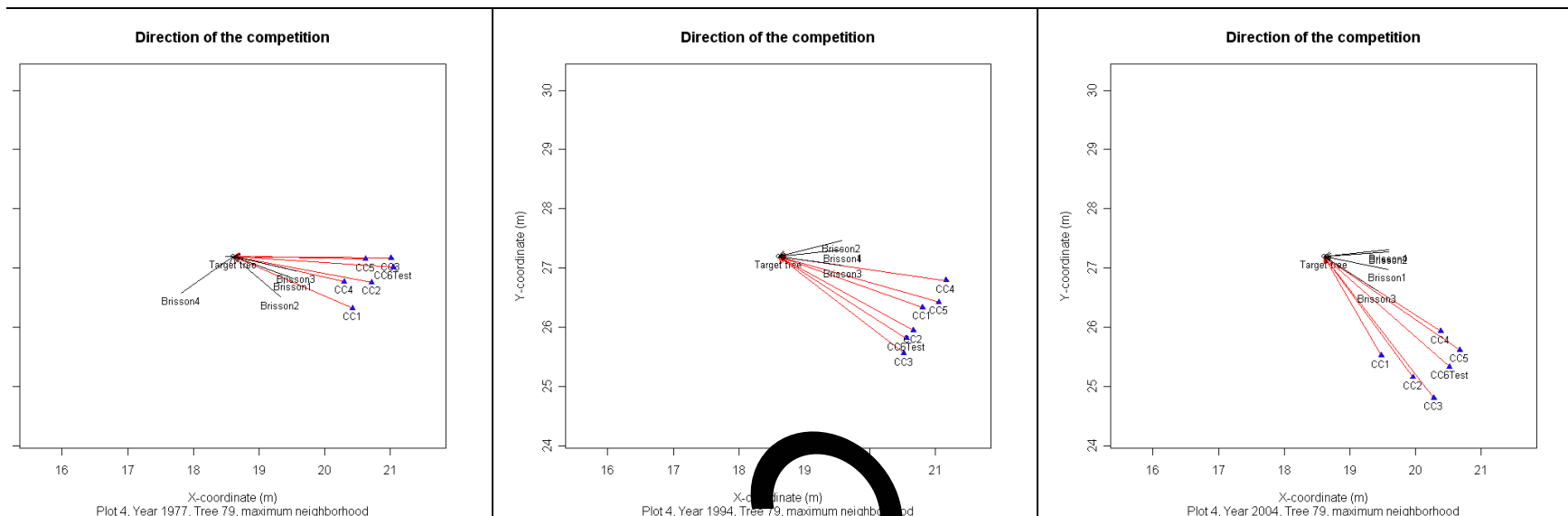
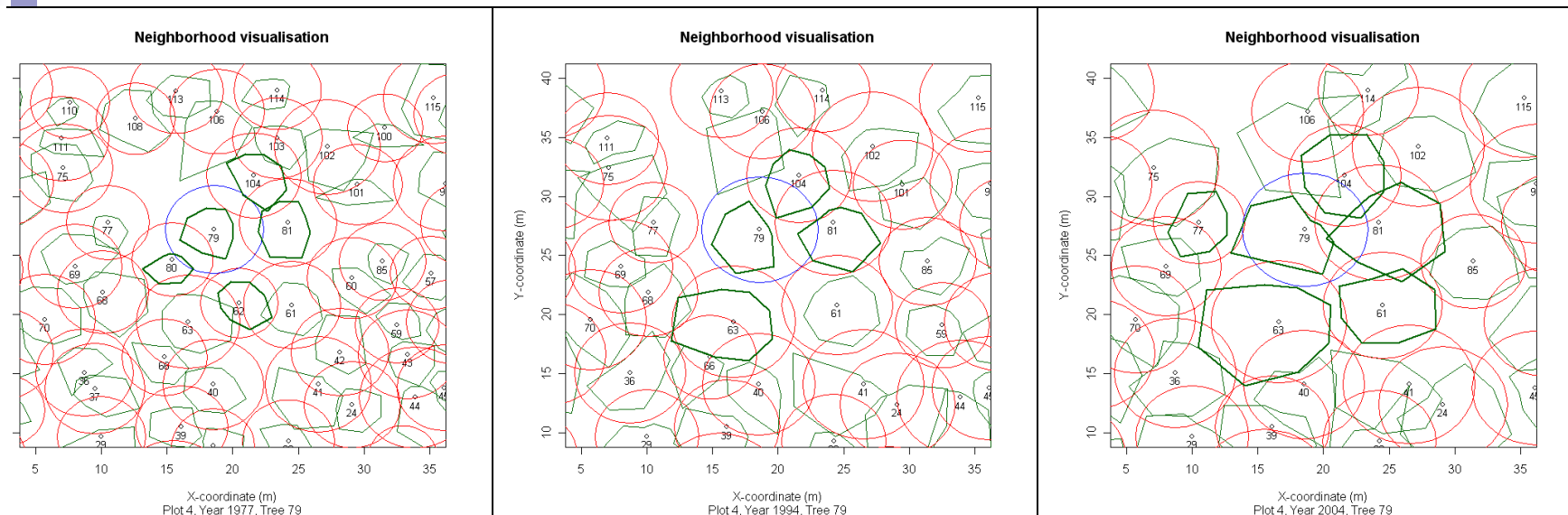
Plot 3, Year 1994, Tree 55, maximum neighborhood

Direction of the competition



Plot 3, Year 2004, Tree 55, maximum neighborhood

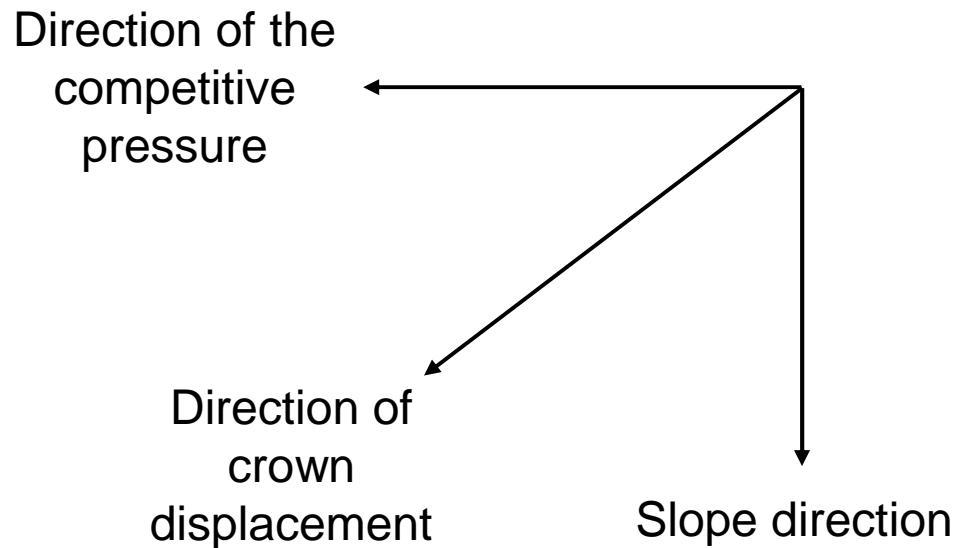




### ■ 3. Direction of the crown displacement:

Direction of crown displacement=

$a \times (\text{direction of competition}) + b \times (\text{direction of slope})$  with  $a > 0$  and  $b > 0$



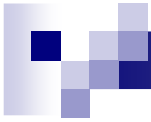
- I tested the different competition indexes:  $a$  and  $b$  estimated are always  $> 0$ ;

- The weight of the slope is always greater than the weight of the competition;

- Best results were obtained with the **sum of the competitive vectors** of each neighbour  $j$  (Brisson) of length  **$DBH_j / \text{distance}_j$**  or  **$DBH_j / \text{distance}_j^2$**

$a = 0.23$  ( $p < 0.0001$ ) and  $b = 0.38$

( $p < 0.0001$ )



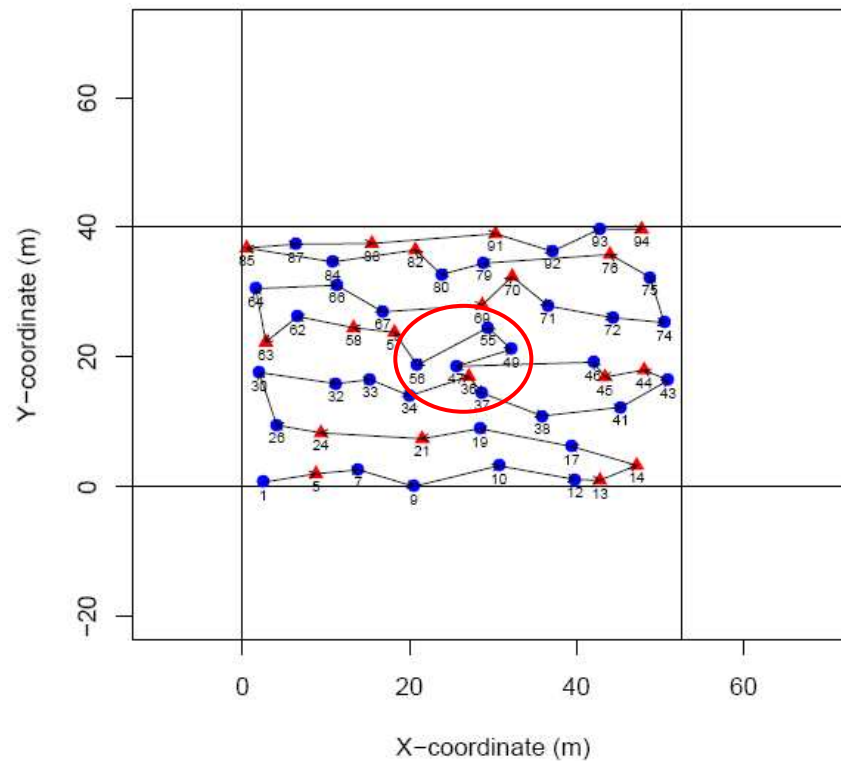
To be continued ...



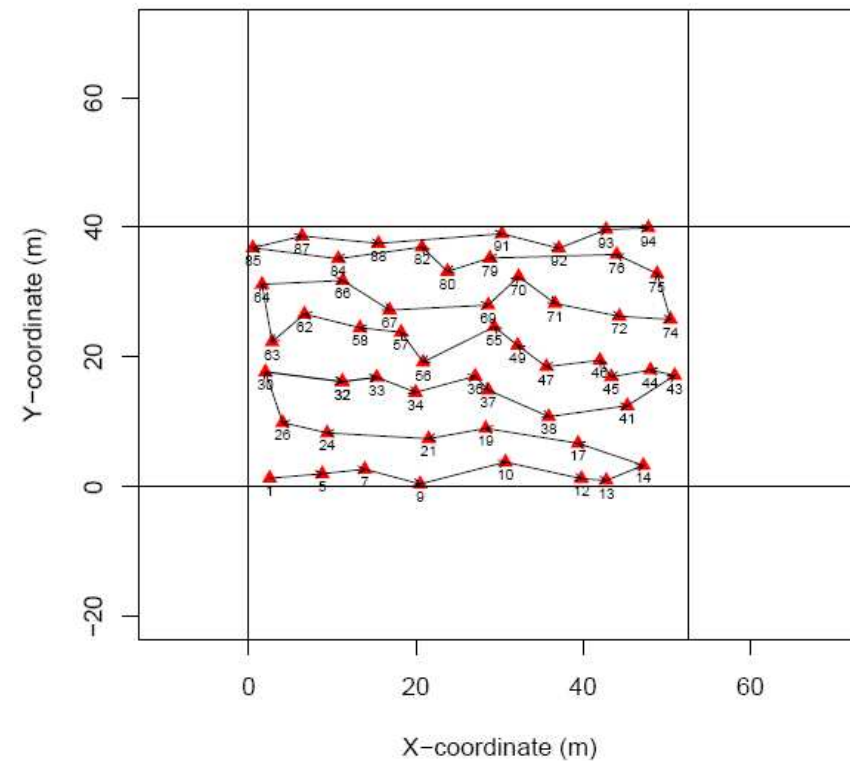
# Annexes

# ■ Errors in theodolite measurements

Plot n° 3, Year = 1977, circles are theodolite measurements

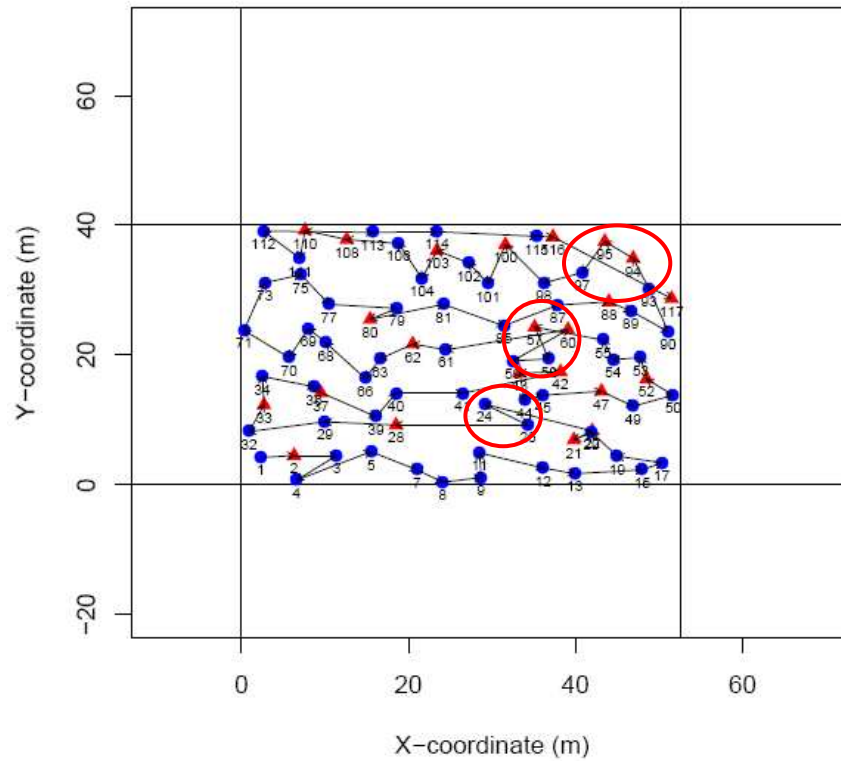


Plot n° 3, Year = 1977, Lutz measurements 1978

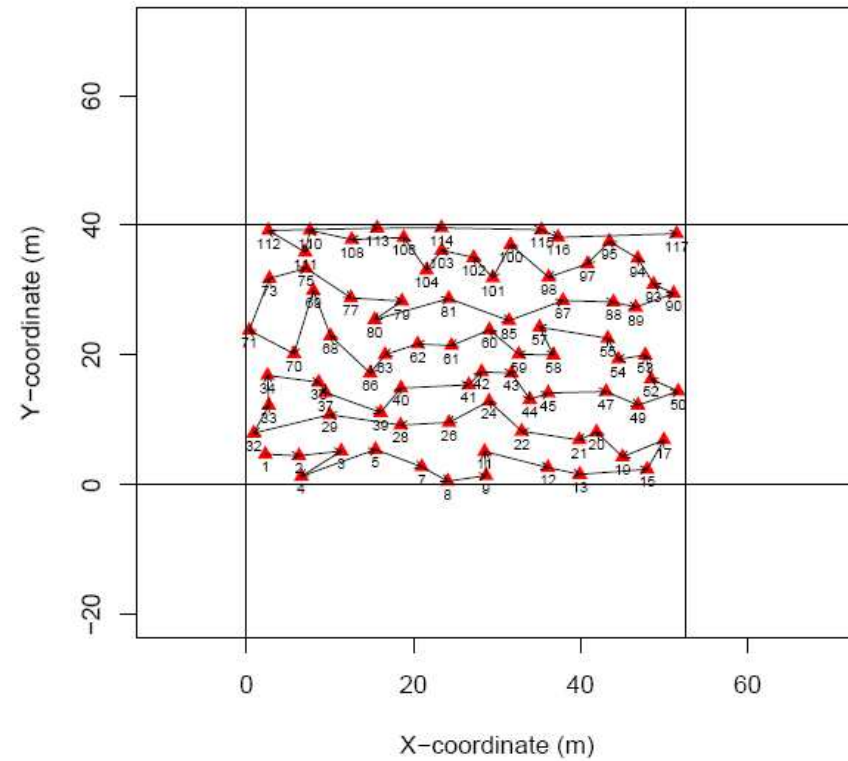




Plot n° 4, Year = 1977, circles are theodolite measurements

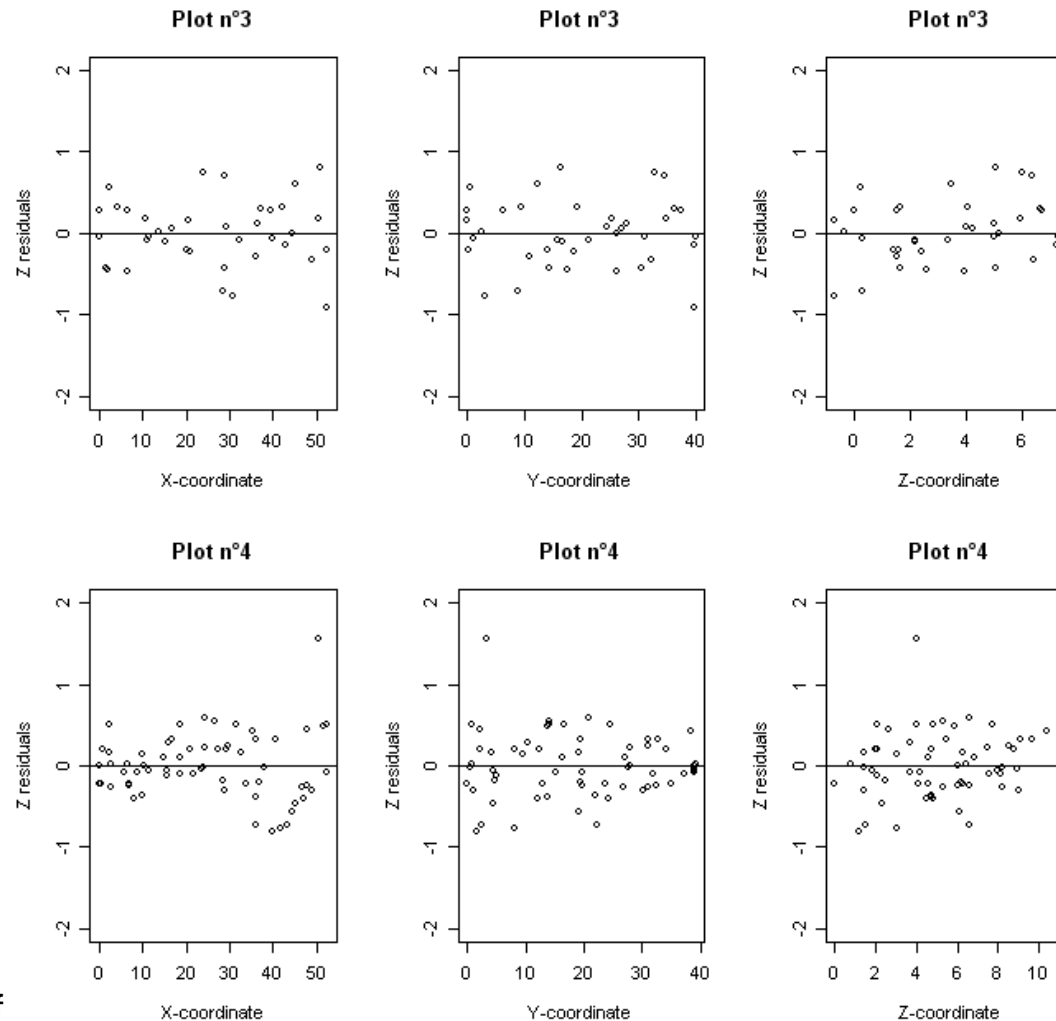


Plot n° 4, Year = 1977, Lutz measurements 1978



# Residuals for the estimation of Z by the 2d order equation

Residuals for estimation of Z-coordinate



# Choice of the method for computing the gravity centres of the projections

