# DESIGN AND MIXED-MODEL ANALYSIS OF EXPERIMENTS

# XII. Repeated measurements experiments

(Payne, 1996; Mead, sec. 14.5)



## XII.A Introduction to repeated measurements experiments

**Definition XII.1**: A **repeated measurements experiment** is one in which a sequence of measurements is made under constant treatment conditions. Generally, there will be *u* units (plots, animals and so) each of which is observed for $s_k$ times. ■

Thus repeated measurement experiments are distinguished from split-plot experiments in which each unit is observed only once and from cross-over experiments in which each unit is observed more than once but the treatment conditions are not the same for all observations. Also, experiments involving the observation of different plots at different times are not repeated measurements experiments. That is, just because an experiment involves observations at different times, does not mean that it is necessarily a repeated measurements experiment.

**Definition XII.2**: A repeated measures experiment in which all units are observed for the same time intervals relative to the start of the experiment is called a **balanced repeated measurements experiment**. ■

**Definition XII.3**: The set of measurements made on a unit is called the unit's **profile**. ■

The design of repeated measurement experiments involves no special consideration. One has only to decide on the design to be applied to the units, most likely using one of the designs covered in the other chapters of this subject. For example, one might choose to run a factorial experiment laid out using an RCBD. This having been decided the experiment is laid out according to the chosen design and the repeated observations made on each unit.

There are now available several methods for the analysis of repeated measurements. These vary from an analysis of variance to complicated analyses allowing for non-linear fitting of trends and complex covariance structures between the observations from different times. We will be focussing on analysis of variance methods, although these have the limitation of often involving over-simplified models.

## XII.B Repeated measurements versus split-plot experiments

In this section we consider the application of the analysis of variance to repeated measurements experiments and explore how this differs from that for split-plot experiments. In many textbooks you will see suggested that the analysis of variance for a repeated measurements experiment is a split-plot-in-time, with times being regarded as randomized to hypothetical subplots. For example, suppose that the experiment was laid out as an RCBD and then repeated measurements were made on each plot. The suggested analysis would be that for the standard split-plot experiment with the plots from the RCBD being treated as main plot and the times as being randomized to hypothetical subplots. However, the times are not randomized — they are the result of systematic observation of the plots. Further times are not nested within subplots, as is often the case with split-plot experiments, but time is crossed with plots in that each time is the same for all units. So this type of experiment is not of the split-plot kind.

First we consider experiments in which time is randomized. The first two exercises for chapter XI are examples of such experiments as they involved time factors that were randomized to subplots using a split-plot design.

**Example XII.1 Celery experiment**

Exercise XI.1 involved an experiment to investigate the effect on the yield of three methods of seedling propagation, two levels of nutrient and four harvest dates. The six combinations of propagation methods and nutrients were applied to main plots using a completely randomized design with three replicates of each treatment combination. The harvest dates were to be randomized to the four subplots within each main plot. The analysis of variance that was derived for this experiment was of the following form:

| Source | df | E[MSq] |
|---|---|---|
| MainPlots | 17 | |
| Propagation | 2 | $\sigma^2_{\mathrm{MS}} + 4\sigma^2_{\mathrm{M}} + f_{\mathrm{P}}(\psi)$ |
| Nutrient | 1 | $\sigma^2_{\mathrm{MS}} + 4\sigma^2_{\mathrm{M}} + f_{\mathrm{N}}(\psi)$ |
| Propagation.Nutrient | 2 | $\sigma^2_{\mathrm{MS}} + 4\sigma^2_{\mathrm{M}} + f_{\mathrm{PN}}(\psi)$ |
| Residual | 12 | $\sigma^2_{\mathrm{MS}} + 4\sigma^2_{\mathrm{M}}$ |
| MainPlots.Subplots | 54 | |
| Harvests | 3 | $\sigma^2_{\mathrm{MS}} + f_{\mathrm{H}}(\psi)$ |
| Propagation.Harvests | 6 | $\sigma^2_{\mathrm{MS}} + f_{\mathrm{PH}}(\psi)$ |
| Nutrient.Harvests | 3 | $\sigma^2_{\mathrm{MS}} + f_{\mathrm{NH}}(\psi)$ |
| Propagation.Nutrient.Harvests | 6 | $\sigma^2_{\mathrm{MS}} + f_{\mathrm{PNH}}(\psi)$ |
| Residual | 36 | $\sigma^2_{\mathrm{MS}}$ |
| Total | 71 | |

Here the factor Harvests corresponds to times of harvest so that the experiment involves tracing the response variable, yield, over a period of time. However, the experiment is not a repeated measurements experiment because we did not repeatedly observe the same plot.

We next consider a repeated measurements experiment.

**Example XII.2 Clones observed over several years**

Consider a randomized complete block experiment in which several clones of some perennial crop are to be compared. The yield for each plot is measured in successive years without any change in the experimental layout. Generated data for such an experiment are given in the table below.

**Layout and results for the repeated measurements experiment**

| | | Plots | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | |
| Blocks | Years | Clone | Yield | Clone | Yield | Clone | Yield |
| 1 | 1 | 1 | 148.8 | 2 | 152.7 | 3 | 159.9 |
| | 2 | | 142.4 | | 142.3 | | 150.6 |
| | 3 | | 146.9 | | 141.9 | | 157.7 |
| | 4 | | 155.4 | | 142.9 | | 152.2 |
| 2 | 1 | 3 | 160.5 | 1 | 160.5 | 2 | 156.2 |
| | 2 | | 152.1 | | 162.0 | | 150.9 |
| | 3 | | 136.7 | | 148.1 | | 135.0 |
| | 4 | | 151.9 | | 164.4 | | 149.8 |
| 3 | 1 | 3 | 158.6 | 2 | 151.2 | 1 | 152.3 |
| | 2 | | 157.5 | | 145.1 | | 156.6 |
| | 3 | | 145.6 | | 135.7 | | 145.6 |
| | 4 | | 163.1 | | 154.6 | | 165.3 |
| 4 | 1 | 1 | 152.5 | 3 | 159.0 | 2 | 151.4 |
| | 2 | | 154.4 | | 158.0 | | 145.7 |
| | 3 | | 162.7 | | 166.5 | | 151.6 |
| | 4 | | 162.3 | | 164.0 | | 147.5 |
| 5 | 1 | 1 | 152.1 | 3 | 153.2 | 2 | 148.5 |
| | 2 | | 158.4 | | 149.1 | | 144.4 |
| | 3 | | 168.3 | | 157.4 | | 153.6 |
| | 4 | | 168.2 | | 151.7 | | 144.7 |

The split-plot-in-time analysis for the generated set of data is presented in table below. In working out the expected mean squares for this analysis, Years is taken to be a fixed factor as it is unlikely that Years will display the necessary homogeneity to be regarded as a variation factor. From this analysis we conclude that there is no interaction between Clones and Years and no overall differences between the Years but that there are overall differences between the Clones.

**Split-plot-in-time analysis**
**for the repeated measurements experiment**

| Source | df | MSq | E[MSq] | F | Prob |
|---|---|---|---|---|---|
| Blocks | 4 | 75.38 | $\sigma^2_{\mathrm{BPY}} + 4\sigma^2_{\mathrm{BP}} + 12\sigma^2_{\mathrm{B}}$ | 1.35 | 0.332 |
| Blocks.Plots | 10 | | | | |
| Clones | 2 | 490.52 | $\sigma^2_{\mathrm{BPY}} + 4\sigma^2_{\mathrm{BP}} + f_{\mathrm{C}}(\psi)$ | 8.77 | 0.010 |
| Residual | 8 | 55.96 | $\sigma^2_{\mathrm{BPY}} + 4\sigma^2_{\mathrm{BP}}$ | 1.50 | 0.192 |
| Blocks.Plots.SubPlots | 45 | | | | |
| Years | 3 | 105.57 | $\sigma^2_{\mathrm{BPY}} + f_{\mathrm{Y}}(\psi)$ | 2.84 | 0.051 |
| Clones.Years | 6 | 48.52 | $\sigma^2_{\mathrm{BPY}} + f_{\mathrm{CY}}(\psi)$ | 1.30 | 0.282 |
| Residual | 36 | 37.22 | $\sigma^2_{\mathrm{BPY}}$ | | |

## a) Determining the analysis of variance table

We now derive the analysis for a repeated measurements experiment using the rules for determining the analysis of variance table.

**Example XII.2 Clones observed over several years** (continued)

What are the components of the study?

1. Observational unit – a plot in a year
2. Response variable – Yield
3. Unrandomized factors – Blocks, Plots, Years
4. Randomized factors – Clones
5. Type of study – Repeated measurements on an RCBD

The experimental structure is:

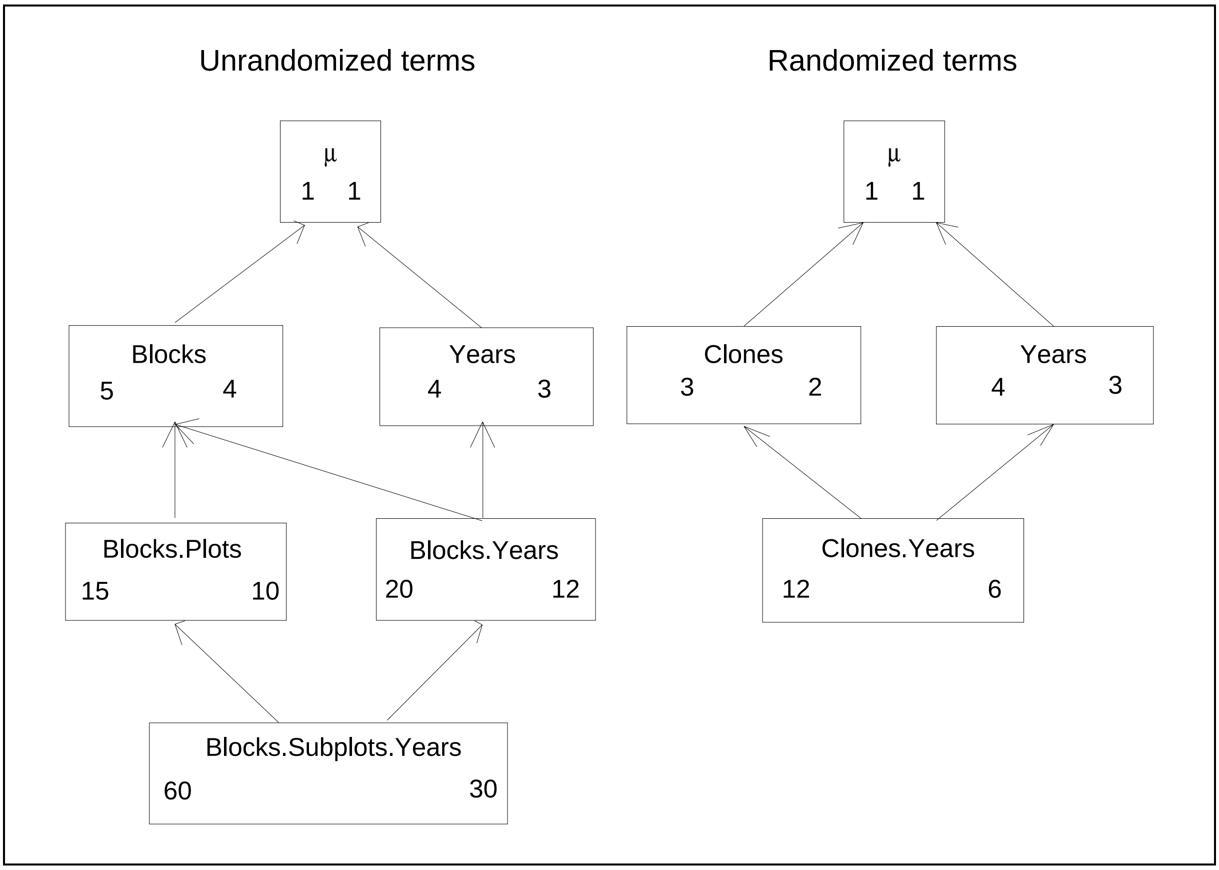
| Structure | Formula |
|---|---|
| unrandomized | (*5* Blocks/*3* Plots)**4* Years |
| randomized | *3* Clones*Years |

Note that we have included the factor Years in the randomized structure because we are interested its interaction with Clones.

The formulae expand to give:

(Blocks/Plots)*Years
= (Blocks + Blocks.Plots)*Years
= Blocks + Blocks.Plots + Years + Blocks.Years + Blocks.Plots.Years

and Clones*Years = Clones + Years + Clones.Years




Note, that in working out the degrees of freedom for the terms from the randomized structure, the rule for a set of crossed factors can be used. That is, for each factor in the term, calculate the number of levels minus one and multiply these together.

The models for this experiment, based on Blocks and Plots being random factors and Clones and Years being fixed factors are:

E[Y] = Clones.Years

and var[Y] = Blocks + Blocks.Plots + Blocks.Years + Blocks.Plots.Years.

The analysis of variance table for this experiment has the following form:

**Skeleton analysis of variance table for the repeated measurements experiment**

| Source | df | E[MSq] | | | |
|---|---|---|---|---|---|
| Blocks | 4 | $\sigma^2_{BPY}$ | $+4\sigma^2_{BP}$ | $+3\sigma^2_{BY}$ | $+12\sigma^2_{B}$ |
| Blocks.Plots | 10 | | | | |
| Clones | 2 | $\sigma^2_{BPY}$ | $+4\sigma^2_{BP}$ | | $+f_{C}(\psi)$ |
| Residual | 8 | $\sigma^2_{BPY}$ | $+4\sigma^2_{BP}$ | | |
| Years | 3 | $\sigma^2_{BPY}$ | | $+3\sigma^2_{BY}$ | $+f_{Y}(\psi)$ |
| Blocks.Years | 12 | $\sigma^2_{BPY}$ | | $+3\sigma^2_{BY}$ | |
| Blocks.Plots.Years | 30 | | | | |
| Clones.Years | 6 | $\sigma^2_{BPY}$ | | | $+f_{CY}(\psi)$ |
| Residual | 24 | $\sigma^2_{BPY}$ | | | |
| Total | 59 | | | | |

The analysis of variance table includes a source for Blocks.Years, a term that was not included in the split-plot-in-time analysis. It should be included unless one is willing to argue that it is unlikely to occur. If this is an appreciable source of variability, one may get quite different results from an analysis that separates this term compared to one that does not. Further it is noted that a test for Years has Blocks.Years as the denominator, rather than Blocks.Plots.Years. However, this would not be the case if both Blocks and Years were designated as fixed factors.

### b) Analysis of the example

The analysis in Genstat will start with plots of the profiles using the DREPMEASURES procedure. The analysis of variance will be conducted on the data and the usual diagnostic checking performed. Because time is a quantitative factor, we will investigate whether a linear trend can be used to describe the time trend for this data.

**Example XII.2 Clones observed over several years** (continued)

The Genstat output file for analyzing this experiment is:

```
Genstat 5  Release 4.1  (PC/Windows NT)              29 April 2000 11:30:52
Copyright 1998, Lawes Agricultural Trust (Rothamsted Experimental Station)

                 ______________________________________________

                 Genstat 5 Fourth Edition - (for Windows)
                 Genstat 5 Procedure Library Release PL11
                 ______________________________________________

   3  "Data taken from File: D:/ANALYSES/LM/REPEATMEASURE/RMECLONE.GSH"
   4  DELETE [redefine=yes] Blocks,Plots,Years,Clones,Yields
   5  FACTOR [modify=yes;nvalues=60;levels=5] Blocks
   6  READ Blocks; frepresentation=ordinal

    Identifier    Values   Missing    Levels
        Blocks        60         0         5

   9  FACTOR [modify=yes;nvalues=60;levels=3] Plots
  10  READ Plots; frepresentation=ordinal

    Identifier    Values   Missing    Levels
         Plots        60         0         3

  13  FACTOR [modify=yes;nvalues=60;levels=4] Years
  14  READ Years; frepresentation=ordinal

    Identifier    Values   Missing    Levels
         Years        60         0         4

  17  FACTOR [modify=yes;nvalues=60;levels=3] Clones
  18  READ Clones; frepresentation=ordinal

    Identifier    Values   Missing    Levels
        Clones        60         0         3

  21  VARIATE [nvalues=60] Yields
  22  READ Yields

    Identifier   Minimum      Mean   Maximum    Values   Missing
        Yields     135.0     153.0     168.3        60         0

  28
  29  PRINT Blocks,Plots,Years,Clones,Yields

      Blocks       Plots       Years      Clones      Yields
           1           1           1           1       148.8
           1           2           1           2       152.7
           1           3           1           3       159.9
           1           1           2           1       142.4
           1           2           2           2       142.3
           1           3           2           3       150.6
           1           1           3           1       146.9
           1           2           3           2       141.9
           1           3           3           3       157.7
           1           1           4           1       155.4
           1           2           4           2       142.9
           1           3           4           3       152.2
           2           1           1           3       160.5
           2           2           1           1       160.5
           2           3           1           2       156.2
           2           1           2           3       152.1
           2           2           2           1       162.0
           2           3           2           2       150.9
           2           1           3           3       136.7
           2           2           3           1       148.1
           2           3           3           2       135.0
           2           1           4           3       151.9
           2           2           4           1       164.4
           2           3           4           2       149.8
           3           1           1           3       158.6
           3           2           1           2       151.2
           3           3           1           1       152.3
```

| | | | | |
|---|---|---|---|---|
| 3 | 1 | 2 | 3 | 157.5 |
| 3 | 2 | 2 | 2 | 145.1 |
| 3 | 3 | 2 | 1 | 156.6 |
| 3 | 1 | 3 | 3 | 145.6 |
| 3 | 2 | 3 | 2 | 135.7 |
| 3 | 3 | 3 | 1 | 145.6 |
| 3 | 1 | 4 | 3 | 163.1 |
| 3 | 2 | 4 | 2 | 154.6 |
| 3 | 3 | 4 | 1 | 165.3 |
| 4 | 1 | 1 | 1 | 152.5 |
| 4 | 2 | 1 | 3 | 159.0 |
| 4 | 3 | 1 | 2 | 151.4 |
| 4 | 1 | 2 | 1 | 154.4 |
| 4 | 2 | 2 | 3 | 158.0 |
| 4 | 3 | 2 | 2 | 145.7 |
| 4 | 1 | 3 | 1 | 162.7 |
| 4 | 2 | 3 | 3 | 166.5 |
| 4 | 3 | 3 | 2 | 151.6 |
| 4 | 1 | 4 | 1 | 162.3 |
| 4 | 2 | 4 | 3 | 164.0 |
| 4 | 3 | 4 | 2 | 147.5 |
| 5 | 1 | 1 | 1 | 152.1 |
| 5 | 2 | 1 | 3 | 153.2 |
| 5 | 3 | 1 | 2 | 148.5 |
| 5 | 1 | 2 | 1 | 158.4 |
| 5 | 2 | 2 | 3 | 149.1 |
| 5 | 3 | 2 | 2 | 144.4 |
| 5 | 1 | 3 | 1 | 168.3 |
| 5 | 2 | 3 | 3 | 157.4 |
| 5 | 3 | 3 | 2 | 153.6 |
| 5 | 1 | 4 | 1 | 168.2 |
| 5 | 2 | 4 | 3 | 151.7 |
| 5 | 3 | 4 | 2 | 144.7 |

```
"
**** separate data for years and plot profiles
"
SUBSET [CONDITION=Years==1] OLD=Blocks,Plots,Clones; \
                            NEW=Block,Plot,Clone
FOR i=1...4
    SUBSET [CONDITION=Years==i] OLD=Yields; NEW=Yield[i]
ENDFOR
PRINT Block,Plot,Clone,Yield[1...4]; FIELD=9; DEC=1
```

| Block | Plot | Clone | Yield[1] | Yield[2] | Yield[3] | Yield[4] |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 148.8 | 142.4 | 146.9 | 155.4 |
| 1 | 2 | 2 | 152.7 | 142.3 | 141.9 | 142.9 |
| 1 | 3 | 3 | 159.9 | 150.6 | 157.7 | 152.2 |
| 2 | 1 | 3 | 160.5 | 152.1 | 136.7 | 151.9 |
| 2 | 2 | 1 | 160.5 | 162.0 | 148.1 | 164.4 |
| 2 | 3 | 2 | 156.2 | 150.9 | 135.0 | 149.8 |
| 3 | 1 | 3 | 158.6 | 157.5 | 145.6 | 163.1 |
| 3 | 2 | 2 | 151.2 | 145.1 | 135.7 | 154.6 |
| 3 | 3 | 1 | 152.3 | 156.6 | 145.6 | 165.3 |
| 4 | 1 | 1 | 152.5 | 154.4 | 162.7 | 162.3 |
| 4 | 2 | 3 | 159.0 | 158.0 | 166.5 | 164.0 |
| 4 | 3 | 2 | 151.4 | 145.7 | 151.6 | 147.5 |
| 5 | 1 | 1 | 152.1 | 158.4 | 168.3 | 168.2 |
| 5 | 2 | 3 | 153.2 | 149.1 | 157.4 | 151.7 |
| 5 | 3 | 2 | 148.5 | 144.4 | 153.6 | 144.7 |

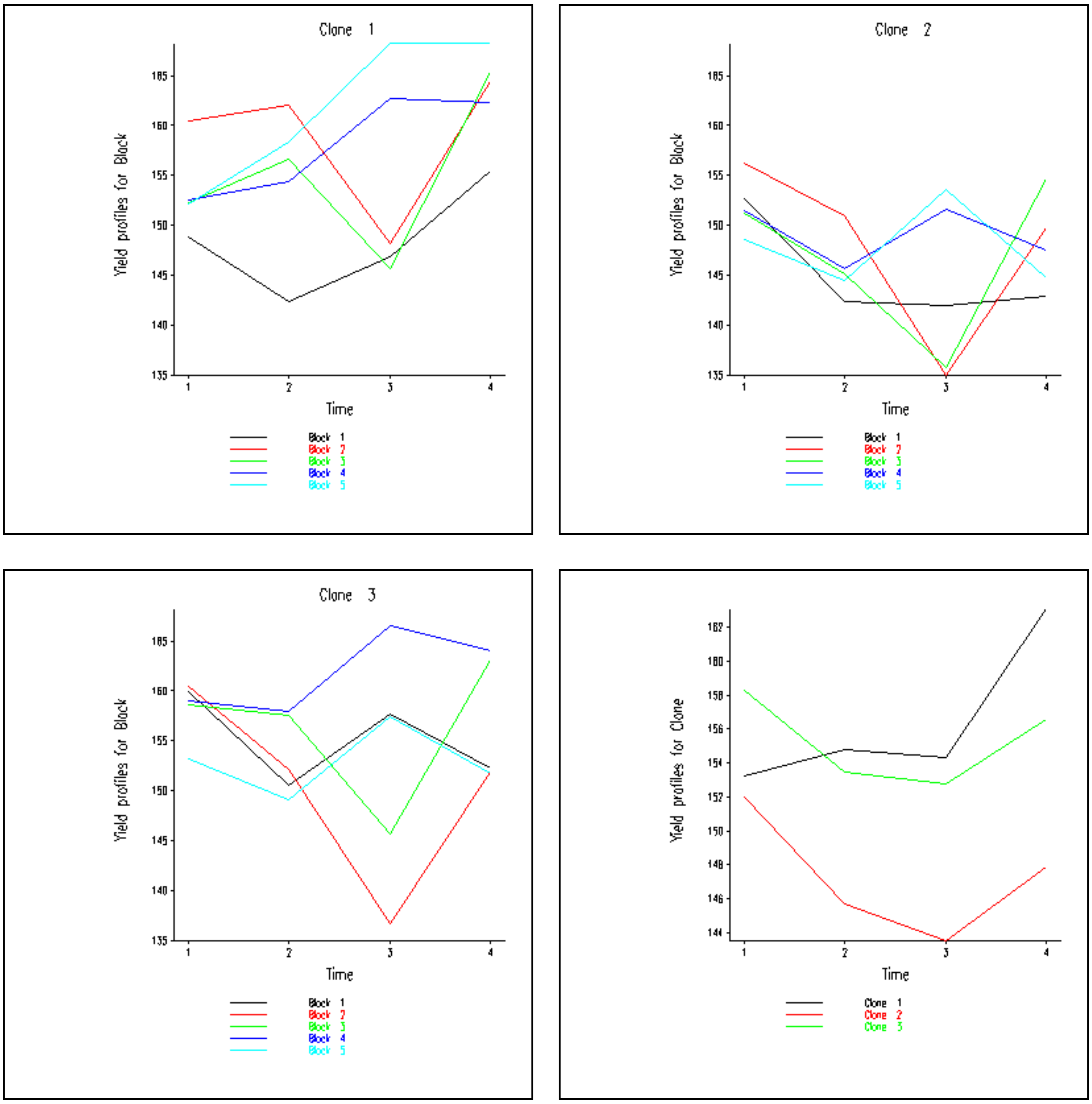
```
DREPMEASURES [GROUPS=Clone,Block] DATA=Yield
DREPMEASURES [GROUPS=Clone] DATA=Yield
"
**** perform repeated measurements ANOVA
"
DUPLICATE OLD=Years; NEW=Year
BLOCK (Blocks/Plots)*Years
TREAT Clones*POL(Year;2)
ANOVA [FPROB=Y; PSE=LSD] Yields
```

```
47.............................................................................

***** Analysis of variance *****

Variate: Yields

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Blocks stratum             4    302.268     75.567

Years stratum
Year                       3    315.939    105.313
  Lin                      1      6.931      6.931
  Quad                     1    293.046    293.046
  Deviations               1     15.962     15.962

Blocks.Plots stratum
Clones                     2    981.567    490.783    8.74  0.010
Residual                   8    449.371     56.171   14.76

Blocks.Years stratum      12   1247.572    103.964   27.33

Blocks.Plots.Years stratum
Clones.Year                6    290.200     48.367   12.71  <.001
  Clones.Lin               2    266.222    133.111   34.99  <.001
  Clones.Quad              2      7.267      3.633    0.96  0.399
  Deviations               2     16.711      8.355    2.20  0.133
Residual                  24     91.309      3.805

Total                     59   3678.226


* MESSAGE: the following units have large residuals.

Blocks 2    Years 3           -9.66   s.e. 4.56

Blocks 1    Plots 3    Years 3            2.98   s.e. 1.23


***** Tables of means *****

Variate: Yields

Grand mean  152.97

   Clones        1        2        3
            156.36   147.29   155.27

     Year        1        2        3        4
            154.49   151.30   150.22   155.87

   Clones     Year        1        2        3        4
        1            153.24   154.76   154.32   163.12
        2            152.00   145.68   143.56   147.90
        3            158.24   153.46   152.78   156.58


*** Least significant differences of means (5% level) ***

Table               Clones        Year      Clones
                                              Year
rep.                    20          15           5
l.s.d.               5.465           *           *
d.f.                     8           *           *
Except when comparing means with the same level(s) of
 Year                                        5.696
 d.f.                                        11.42
```

```
  48  CALC pBP=1-FPROB(56.171/3.805; 8; 24)
  49  &    pBY=1-FPROB(103.964/3.805; 12; 24)
  50  PRINT pBP,pBY

         pBP         pBY
 0.000000148  0.4532E-10

  51  APLOT METHOD=fit,normal


             -
             I
             I
             I                                      *
         2.5 I                                   *
r            I                                            *     *
e            I              *                 *  *                     *
s            I                         *  * * * *    *
i            I                           *             *
d            I    * *               *    *     **              *       *
u        0.0 I                     * *     * 2**   *      2      **       *
a            I                   *    *        2           *  *
l            I                           *       *            *
s            I          *        *                         *      *   *
             I                    *   *  *               *
             I                         *           2                     *
        -2.5 I                                                 *
             -+---------+---------+---------+---------+---------+---------+---
          132.0     138.0     144.0     150.0     156.0     162.0     168.0

                                         fitted values


                                          Normal plot

             -
             I
         3.0 I                                                           *
r            I                                                      *
e            I                                             * *** *
s            I                                            *
i            I                                       2**2*
d            I                                   222*
u        0.0 I                           2222222*
a            I                       222*
l            I                    *2*
s            I             * ***2*
             I      *  * **
             I *
        -3.0 I
             -+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles

  52  "
 -53  **** Tukey’’s one-degree-of-freedom-for-non-additivity.
 -54  **** It is the term designated covariate in the following analysis
 -55  "
  56  TREAT Clones*Year
  57  AKEEP [FIT=Fit]
  58  CALC ResSq=Fit*Fit
  59  ANOVA [PRINT=*]  ResSq; RES=ResSq
  60  COVAR ResSq                            "A computational trick"
  61  ANOVA [PRINT=A; FPROB=Y] Yields

******** Warning (Code AN 40). Statement 1 on Line 61
Command: ANOVA [PRINT=A; FPROB=Y] Yields
Stratum variance cannot be estimated
Years stratum has zero residual sum of squares or degrees of freedom
```

```
61.................................................................................

***** Analysis of variance (adjusted for covariate) *****

Variate: Yields
Covariate: ResSq

Source of variation     d.f.       s.s.       m.s.    v.r. cov.ef.  F pr.

Blocks stratum             4    302.268     75.567

Years stratum
Year                       3    315.939    105.313            1.00

Blocks.Plots stratum
Clones                     2    981.567    490.783    8.74    1.00  0.010
Residual                   8    449.371     56.171   14.49    1.00

Blocks.Years stratum      12   1247.572    103.964   26.81

Blocks.Plots.Years stratum
Clones.Year                6    290.200     48.367   12.47    1.00  <.001
Covariate                  1      2.135      2.135    0.55          0.466
Residual                  23     89.174      3.877            0.98

Total                     59   3678.226

  62  COVAR
  63  "
 -64  **** obtain fitted equations
 -65  "
  66  VARI Yr
  67  CALC Yr=Year
  68  MODEL Yields
  69  TERMS Clones/Yr
  70  FIT Clones/Yr


70.................................................................................


***** Regression Analysis *****

 Response variate: Yields
     Fitted terms: Constant + Clones + Yr.Clones


*** Summary of analysis ***

              d.f.         s.s.         m.s.      v.r.
Regression       5        1255.       250.94      5.59
Residual        54        2424.        44.88
Total           59        3678.        62.34

Percentage variance accounted for 28.0
Standard error of observations is estimated to be 6.70
* MESSAGE: The following units have large standardized residuals:
         Unit     Response    Residual
           19       136.70       -2.81


*** Estimates of parameters ***

                              estimate         s.e.     t(54)
Constant                        149.06         3.67     40.62
Clones 2                          1.83         5.19      0.35
Clones 3                          7.62         5.19      1.47
Yr.Clones 1                       2.92         1.34      2.18
Yr.Clones 2                      -1.44         1.34     -1.08
Yr.Clones 3                      -0.57         1.34     -0.42
```

The plots of the profiles are given in the following figures:




These plots indicate that there is considerable variability amongst the individual profiles for a particular clone. However, it also appears that the clones differ in their pattern over the years.

As far as diagnostic checking is concerned, there are no problems apparent. The residual-versus-fitted-values plot is displaying a homogenous pattern, the normal probability plot looks like a roughly linear pattern and Tukey's test for nonadditivity is nonsignificant.

The analysis of variance indicates that

1. The Deviations term for Clones.Times is not significant;
2. The Clones.Quad term is not significant;
3. The Clones.Lin term is significant.

That is, a linear trend describes the pattern over time, but that the slope of the trend differs between the clones. Regression was used to obtain the fitted equations and these are as follows:

$$\text{For clone 1}, \mathit{Yield} = 149.06 + 2.92\,\mathit{Year}$$
$$\text{For clone 2}, \mathit{Yield} = 150.89 - 1.44\,\mathit{Year}$$
$$\text{For clone 3}, \mathit{Yield} = 156.68 - 0.57\,\mathit{Year}$$

We note that the Clones.Years term was not significant in the split-plot-in-time analysis, but is in this analysis. This is because the Blocks.Years term is highly significant and in the split-plot-in-time analysis it included in the Residual MSq of 37.22.

### c) Computation in Genstat

The following commands were used in analyzing the example:

```
PRINT Blocks,Plots,Years,Clones,Yields
"
**** separate data for years and plot profiles
"
SUBSET [CONDITION=Years==1] OLD=Blocks,Plots,Clones; \
                            NEW=Block,Plot,Clone
FOR i=1...4
    SUBSET [CONDITION=Years==i] OLD=Yields; NEW=Yield[i]
ENDFOR
PRINT Block,Plot,Clone,Yield[1...4]; FIELD=9; DEC=1
DREPMEASURES [GROUPS=Clone,Block] DATA=Yield
DREPMEASURES [GROUPS=Clone] DATA=Yield
"
**** perform repeated measurements ANOVA
"
DUPLICATE OLD=Years; NEW=Year
BLOCK (Blocks/Plots)*Years
TREAT Clones*POL(Year;2)
ANOVA [FPROB=Y; PSE=LSD] Yields
CALC pBP=1-FPROB(56.171/3.805; 8; 24)
&    pBY=1-FPROB(103.964/3.805; 12; 24)
PRINT pBP,pBY
APLOT METHOD=fit,normal
"
**** Tukey''s one-degree-of-freedom-for-non-additivity.
**** It is the term designated covariate in the following analysis
"
TREAT Clones*Year
AKEEP [FIT=Fit]
CALC ResSq=Fit*Fit
ANOVA [PRINT=*]  ResSq; RES=ResSq
COVAR ResSq                          "A computational trick"
ANOVA [PRINT=A; FPROB=Y] Yields
COVAR
"
**** obtain fitted equations
"
VARI Yr
CALC Yr=Year
MODEL Yields
TERMS Clones/Yr
FIT Clones/Yr
```

## XII.C Problems with ANOVA on individual measurements for all timepoints

The major problem with using an ANOVA on the individual measurements for all timepoints is that it is very likely that the assumptions are not met. In practice it is assumed that variances at the different timepoints are equal and the correlations between pairs of timepoints are the same for all timepoints. That is the variance matrix for times should have the following form:

$$\begin{array}{cc} & \begin{array}{ccccc} 1 & 2 & 3 & \dots & t \end{array} \\ \sigma^2 & \begin{bmatrix} 1 & \rho & \rho & \dots & \rho \\ \rho & 1 & \rho & \dots & \rho \\ \rho & \rho & 1 & \dots & \rho \\ \vdots & \vdots & \vdots & & \vdots \\ \rho & \rho & \rho & \dots & 1 \end{bmatrix} \end{array}$$

This pattern is known as **uniform covariance structure** and the matrix is said to show **compound symmetry**. Further the values of $\sigma^2$ and $\rho$ in this matrix must be the same for each of the terms not involving times in the analysis. Tests are available for compound symmetry and equality of variance matrices.

There will be situations in which these assumptions are met and the single ANOVA on the individual measurements for all timepoints is appropriate. However, when the observations are made over a period of time during which there is a considerable change in the organisms being observed, it is very likely that these assumptions will not be met. If they are not met, alternative analyses must be used instead. Some of the possible alternative analyses are:

a) separate analyses of each timepoint
b) ad hoc summary statistics over timepoints
c) summary statistics from fitted curves
d) Greenhouse-Geisser and Huyhn-Feldt adjustments to the degrees of freedom of ANOVA on individual measurements for all timepoints
e) multivariate ANOVA
f) analysis assuming ante-dependence structure
g) nonlinear-mixed models
h) more general covariance models and nonparametric smoothing of time trends

Of these, only the first three will be discussed in this course.

## XII.D Separate analyses of each timepoint

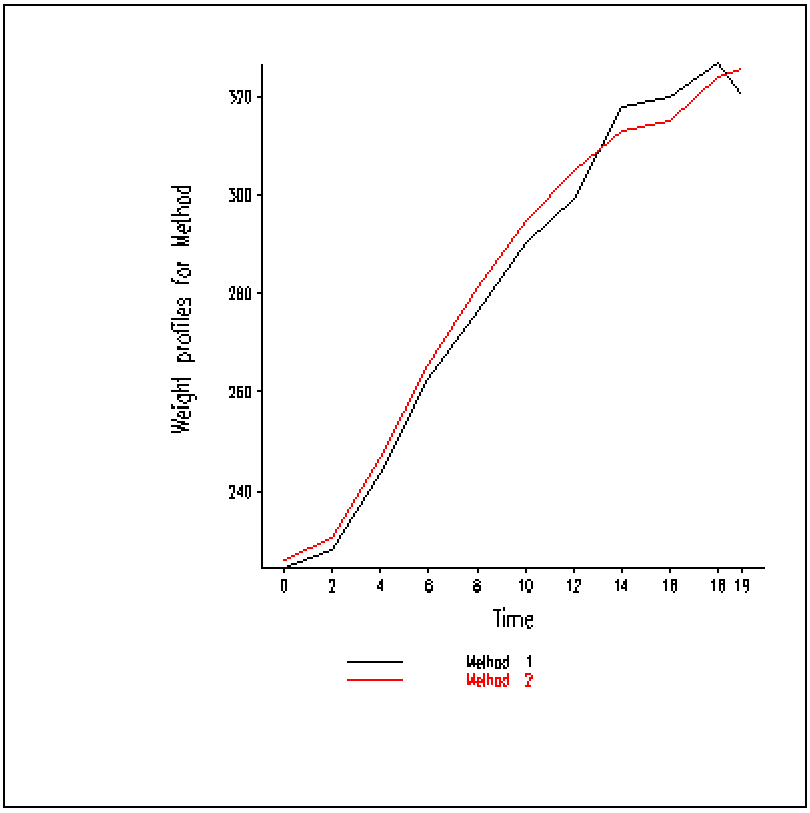
Often the data from repeated measurements experiments is analysed using separate analyses of the data from each timepoint. This is not invalid but separate tests must be interpreted correctly, and this means in a very limited sense. The major errors that occur in the use of this procedure are:

- The tests are incorrectly used to assess changes over time. These tests ignore the successive nature of the observations. They are based on *between-unit* comparisons. The test examines whether the group means over different units at a particular time are different using variability in the response variable between units within a group. On the other hand assessment of change requires *within-unit* comparisons. That is, a comparison of the means of the time differences computed for each unit using the variability of the within-unit time differences. The variability of within-unit time differences is likely to be quite different to the variability between units at a particular time. *Further, a change in statistical significance is **not** equivalent to a statistically significant change*.
- The tests may not detect differences because they are very inefficient. They ignore the within-unit correlations and treat each timepoint as independent.
- It is inappropriate to simply divide timepoints into those that are "significant" and those that are "not significant" for a process that is essentially continuous in time.

**Example XII.3 Internal parasites in calves**

An experiment to compare two methods for the control of intestinal parasites in calves involved 60 calves. At the start of the grazing season the calves were randomly assigned to the two methods so that 30 calves received each method. The weights of each calf were measured at weeks 0, 2, 4, 6, 8, 10,12, 14, 16, 18 and 19.

The plot of the mean profile for the two methods is shown in the following diagram.



There are only two treatments and so it is a simple matter to perform t-tests on the data for each timepoint (very easy to do in Excel). The results of the t-tests are shown in the following output:

| | test | d.f. | prob |
|---|---|---|---|
| ttest[0] | -0.60 | 58.00 | 0.55 |
| ttest[2] | -0.82 | 58.00 | 0.42 |
| ttest[4] | -1.03 | 58.00 | 0.31 |
| ttest[6] | -0.88 | 58.00 | 0.38 |
| ttest[8] | -1.21 | 58.00 | 0.23 |
| ttest[10] | -1.12 | 58.00 | 0.27 |
| ttest[12] | -1.28 | 58.00 | 0.21 |
| ttest[14] | 1.10 | 58.00 | 0.28 |
| ttest[16] | 0.95 | 58.00 | 0.34 |
| ttest[18] | 0.53 | 58.00 | 0.60 |
| ttest[19] | -0.85 | 58.00 | 0.40 |

These tests indicate that there are no differences between the methods over time. We will see how alternative analyses can give more useful information about the effects of treatments in this experiment.

## XII.E Analyses of summary statistics

The summary statistic approach to the analysis of repeated measurements experiments is, in principle, very simple. A small number of statistics is computed for each unit from the observations over time for that unit.

The analysis of these summary statistics is generally straightforward. Each statistics is treated a single response and analyzed using conventional techniques, for example analysis of variance, regression or even a nonparametric test. If there is more than one-statistic from each subject then these will usually not be independent and multivariate analyses can be used, for example multivariate analysis of variance. So this method moves the problem from the realm of repeated measurements into that of more conventional methodology.

The advantage of this approach is that the unlikely-to-be-met assumptions about the behaviour through time are avoided. The choice of summary statistic depends very much on the context and there exist many possible alternatives. It is important that the chosen statistics have some meaning or interpretation in terms of the experiment. However, it is not critical that all information in a unit's profile is extracted, provided that features believed to be relevant are examined.

It is likely that in choosing the statistics there will be some trade-off between exploratory and confirmatory analysis. It is preferable that the statistics be chosen in the planning stage of the experiment. However, this may require knowledge in advance about the form of the profile and this may well not be the case. If there is insufficient knowledge available in the planning stage, one may be forced into a more exploratory analysis where an examination of the observed profiles is used to choose a suitable summary statistic.

The summary statistic approach is particularly valuable when

- individual profiles vary considerably;
- the repeated measurements are unbalanced because not all units are measured at the same set of timepoints, provided the differences between units are not too great.

We distinguish between two forms of summary statistics: a) ad hoc summary statistics and b) summary statistics from fitted curves.

**a) Ad hoc summary statistics**

Often a profile will not follow a simple functional form and many types of ad hoc statistics can be considered. Some commonly used ones are:

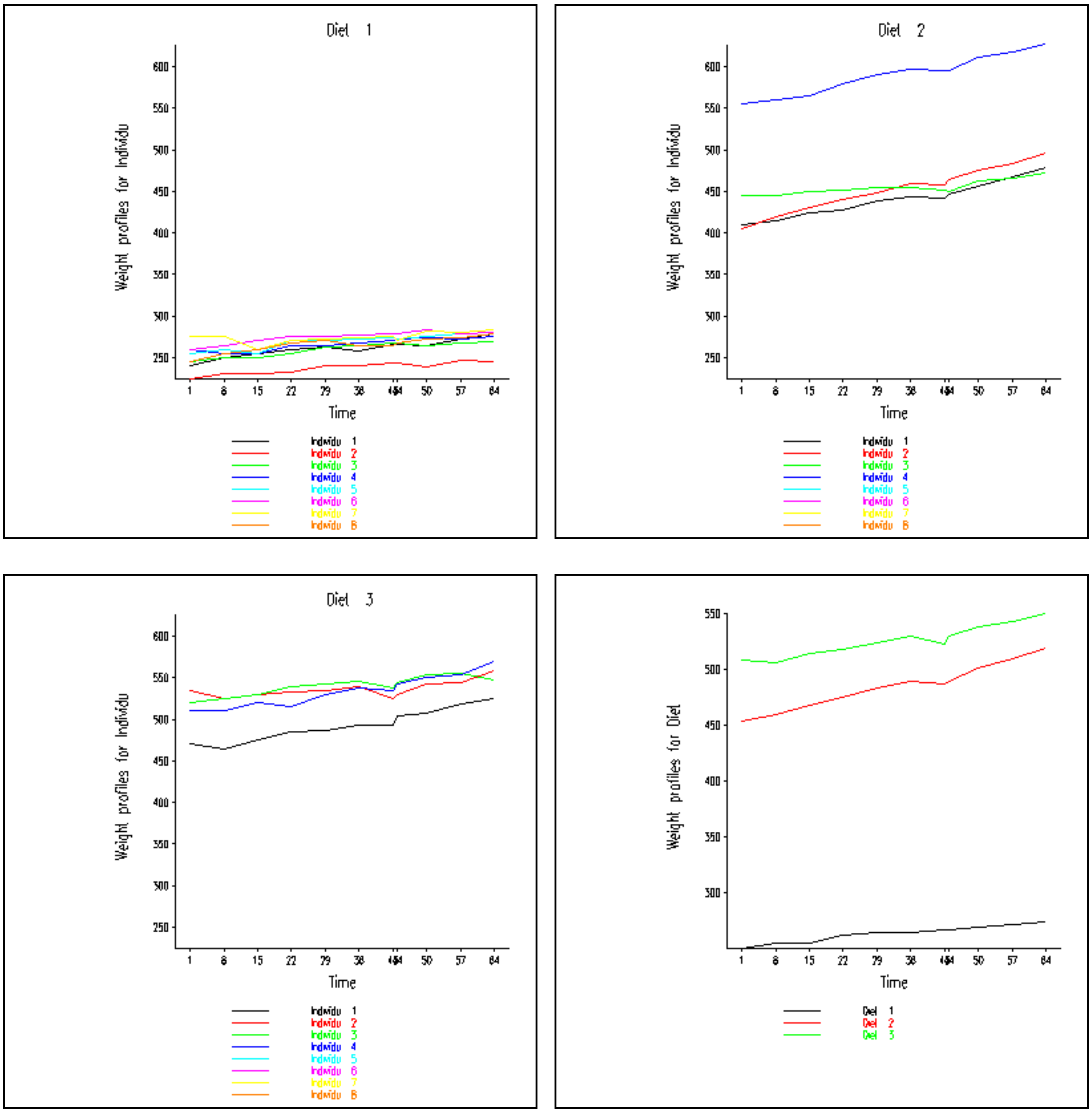
- particular end point(s)
- mean over the whole or part of the profile
- area under the profile
- maximum or minimum during the whole, or part, of the period of measurement
- change between two times
- time to a pre-defined threshold, to return to a baseline or to the maximum/minimum
- the number of events or changes
- proportion of successes

The great advantage of summary statistics is that they provide a way of handling categorical (particularly binary) repeated measurements without the need for sophisticated modelling. However, some summary statistics may be far from normally distributed whatever the distribution of the original measurements. Examples are extrema or times to particular events when there are only a few timepoints.

One danger with this approach is to create a very large number of statistics and to analyse them all. It is unlikely that all the statistics will be independent. Consequently, the analysis and interpretation of the results would not be independent and the statistical properties of the analyses would be compromised.

**Example XII.4 Rat weight**

An experiment to investigate the effects of 3 diets is described in Crowder and Hand (1996). It involved 16 rats, eight randomly assigned to diet 1 and four to each of diets 2 and 3. The body weights, in grams, were measured over 64 days. The profiles are plotted in the following diagrams.




The profiles show a roughly linear pattern with all rats having parallel patterns — rather well-behaved profiles.

In this case, the weight gain over the 64 days is likely to be of interest to the experiment and so we choose it as our summary statistic for analysis. Below is the Genstat output that contains the commands to produce the profiles and analyses and the output from these commands.

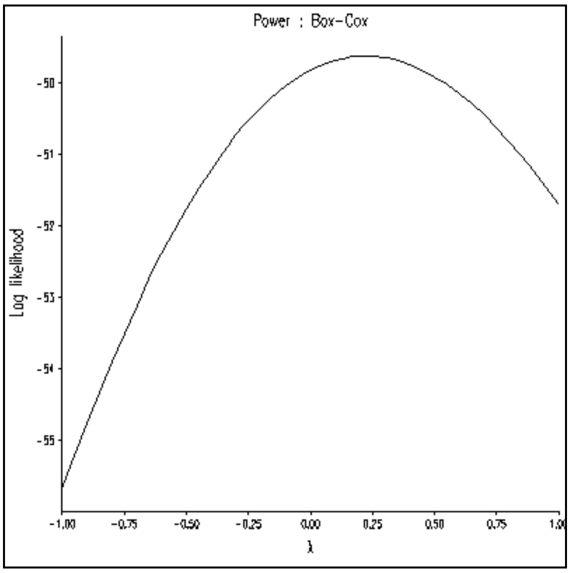
```
Genstat 5  Release 4.1  (PC/Windows NT)              30 April 2000 12:14:48
Copyright 1998, Lawes Agricultural Trust (Rothamsted Experimental Station)

                 ____________________________________________

                 Genstat 5 Fourth Edition - (for Windows)
                 Genstat 5 Procedure Library Release PL11
                 ____________________________________________

   3  "Data taken from File: D:/ANALYSES/LM/REPEATMEASURE/RMERAT.GSH"
   4  DELETE [redefine=yes] Days,Rats,Diets,Weights
   5  FACTOR [modify=yes;nvalues=176;levels=!(1,8,15,22,29,36,43,44,50,57,64)\
   6  ] Days
   7  READ Days; frepresentation=ordinal
```

```
   Identifier    Values   Missing    Levels
         Days       176         0        11

 14  FACTOR [modify=yes;nvalues=176;levels=16] Rats
 15  READ Rats; frepresentation=ordinal

   Identifier    Values   Missing    Levels
         Rats       176         0        16

 22  FACTOR [modify=yes;nvalues=176;levels=3] Diets
 23  READ Diets; frepresentation=ordinal

   Identifier    Values   Missing    Levels
        Diets       176         0         3

 29  VARIATE [nvalues=176] Weights
 30  READ Weights

   Identifier   Minimum      Mean   Maximum    Values   Missing
      Weights     225.0     384.5     628.0       176         0

 41
 42  "
-43  **** separate data for Days and Rat profiles
-44  "
 45  SUBSET [CONDITION=Days==1] OLD=Rats,Diets; \
 46                                NEW=Rat,Diet
 47  FOR i=1,8...43,44,50,57,64
 48      SUBSET [CONDITION=Days==i] OLD=Weights; NEW=Weight[i]
 49  ENDFOR
 50  PRINT Rat,Diet,Weight[1,8...43,44,50,57,64]; FIELD=9; DEC=0

     Rat     Diet Weight[1] Weight[8] Weight[15] Weight[22] Weight[29] Weight[36]
       1        1      240       250       255       260       262       258
       2        1      225       230       230       232       240       240
       3        1      245       250       250       255       262       265
       4        1      260       255       255       265       265       268
       5        1      255       260       255       270       270       273
       6        1      260       265       270       275       275       277
       7        1      275       275       260       270       273       274
       8        1      245       255       260       268       270       265
       9        2      410       415       425       428       438       443
      10        2      405       420       430       440       448       460
      11        2      445       445       450       452       455       455
      12        2      555       560       565       580       590       597
      13        3      470       465       475       485       487       493
      14        3      535       525       530       533       535       540
      15        3      520       525       530       540       543       546
      16        3      510       510       520       515       530       538


Weight[43] Weight[44] Weight[50] Weight[57] Weight[64]
     266       266       265       272       278
     243       244       238       247       245
     267       267       264       268       269
     270       272       274       273       275
     274       273       276       278       280
     278       278       284       279       281
     276       271       282       281       284
     265       267       273       274       278
     442       446       456       468       478
     458       464       475       484       496
     451       450       462       466       472
     595       595       612       618       628
     493       504       507       518       525
     525       530       543       544       559
     538       544       553       555       548
     535       542       550       553       569

 51  FACTOR [LEV=30] Individuals
 52  CALC Individuals=NEWLEVELS(Rat; !v(1...8,(1...4)2))
```

```
  53  DREPMEASURES [GROUPS=Diet,Individuals] DATA=Weight
* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

  54  DREPMEASURES [GROUPS=Diet] DATA=Weight
  55  "
 -56  **** analyse weight gain
 -57  "
  58  CALC WtGain=Weight[64]-Weight[1]
  59  BLOCK Rat
  60  TREAT Diet
  61  ANOVA [FPROB=Y; PSE=LSD] WtGain


61................................................................................

***** Analysis of variance *****

Variate: WtGain

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rat stratum
Diet                       2     4681.1     2340.6    8.07  0.005
Residual                  13     3772.6      290.2
Total                     15     8453.7


* MESSAGE: the following units have large residuals.

Rat 11          -37.7   s.e. 15.4


***** Tables of means *****

Variate: WtGain

Grand mean  38.1

     Diet        1        2        3
              23.1     64.7     41.5
     rep.        8        4        4


*** Least significant differences of means (5% level) ***

Table                  Diet
rep.                unequal
d.f.                     13
l.s.d.                26.02  min.rep
                      22.54  max-min
                      18.40X max.rep

(No comparisons in categories where s.e.d. marked with an X)
```

```
62  APLOT METHOD=fit,normal


             -
             I
             I
             I
        40.0 I
r            I
e            I                                                             *
s            I                                *
i            I         *                      *
d            I         *                                                   *
u        0.0 I         4                                                   *
a            I         *
l            I         *                      *
s            I                                *
             I
             I
       -40.0 I                                                             *
             -+---------+---------+---------+---------+---------+---------+---
           16.0      24.0      32.0      40.0      48.0      56.0      64.0

                                        fitted values


                                         Normal plot
             -
             I
        40.0 I
r            I
e            I                                                           *
s            I                                                   *
i            I                                           *  *
d            I                                     * *
u        0.0 I                       *  *  * *  *
a            I                     *
l            I              *  *
s            I         *
             I
             I
       -40.0 I *
             -+---------+---------+---------+---------+---------+---------+---
           -1.8      -1.2      -0.6       0.0       0.6       1.2       1.8

                                  expected Normal quantiles
```

The assumptions underlying the analysis of weight gain appear not to be met in that the variance appears to be increasing with the weight gain. So we need to find modify the analysis to take this into account. The following diagram contains the plot produced by YTRANSFORM to identify a power transformation. The log transformation was chosen because it is close to the maximum and is interpretable. The output below shows the analysis of the natural logarithm of the weight gain.




```
  63  YTRANSFORM [TERMS=Diet; LOWER=-1; UPPER=1] WtGain; SAVE=s
  64  CALC TWtGain=LOG(WtGain)
  65  ANOVA [FPROB=Y; PSE=LSD] TWtGain


65................................................................................

***** Analysis of variance *****

Variate: TWtGain

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rat stratum
Diet                       2     2.9587     1.4794    6.55  0.011
Residual                  13     2.9344     0.2257
Total                     15     5.8932


* MESSAGE: the following units have large residuals.

Rat 7           -0.86   s.e. 0.43


***** Tables of means *****

Variate: TWtGain

Grand mean  3.46

     Diet        1        2        3
              3.06     4.08     3.65
     rep.        8        4        4


*** Least significant differences of means (5% level) ***

Table                 Diet
rep.               unequal
d.f.                    13
l.s.d.               0.726  min.rep
                     0.629  max-min
                     0.513X max.rep

(No comparisons in categories where s.e.d. marked with an X)
```

```
  66  APLOT METHOD=fit,normal


             -
             I
             I
             I
         1.0 I
r            I
e            I
s            I   2                            *                     *
i            I                                *
d            I   2                                                  2
u        0.0 I   2
a            I
l            I   *                            *
s            I                                *
             I
             I   *                                                  *
        -1.0 I
             -+---------+---------+---------+---------+---------+---------+---
            3.0       3.2       3.4       3.6       3.8       4.0       4.2

                                         fitted values


                                          Normal plot

             -
             I
         1.0 I
r            I
e            I
s            I                                           *  *    *       *
i            I                                       *
d            I                             * *  *  *
u        0.0 I                       *  *
a            I
l            I                 *   *
s            I              *
             I
             I *       *
        -1.0 I
             -+---------+---------+---------+---------+---------+---------+---
           -1.8      -1.2      -0.6       0.0       0.6       1.2       1.8

                                   expected Normal quantiles

  67  AKEEP Diet; MEANS=DietMn
  68  CALC DietMn=EXP(DietMn)
  69  PRINT DietMn

                   DietMn
         Diet
            1       21.32
            2       59.10
            3       38.43
```

This analysis indicates a significant difference between the weight gains under the different diets ($p = 0.011$). To determine the differences between the diet we examine the table of log weight gain means and use the LSD; the relevant part of the output is given below.

```
***** Tables of means *****

Variate: TWtGain

Grand mean  3.46

     Diet         1         2         3
               3.06      4.08      3.65
     rep.         8         4         4


*** Least significant differences of means (5% level) ***

Table                Diet
rep.              unequal
d.f.                   13
l.s.d.              0.726  min.rep
                    0.629  max-min
                    0.513X max.rep

(No comparisons in categories where s.e.d. marked with an X)
```

Note to compare diet 1 with the other diets, use the max-min LSD as these comparisons involve a mean of 8 with a mean of 4; for diet 2 versus 3, use the min-min LSD as these two means are both based on 4 observations. Using the max-min LSD we see that diet 1 results in less weight gain than diet 3 but is not significantly different to diet 2. Nor is there a significant difference between the mean weight gains of diets 2 and 3.

The back-transformed means have also been computed and are given at the end of the output — they are the geometric means of the original data. We can interpret the results from using the LSD as indicating which ratios of geometric means are significantly different. In this case, the only significant difference is between diets 1 and 2 and the ratio of diet 2 to diet 1 is $59.1/21.32 = 2.77$.

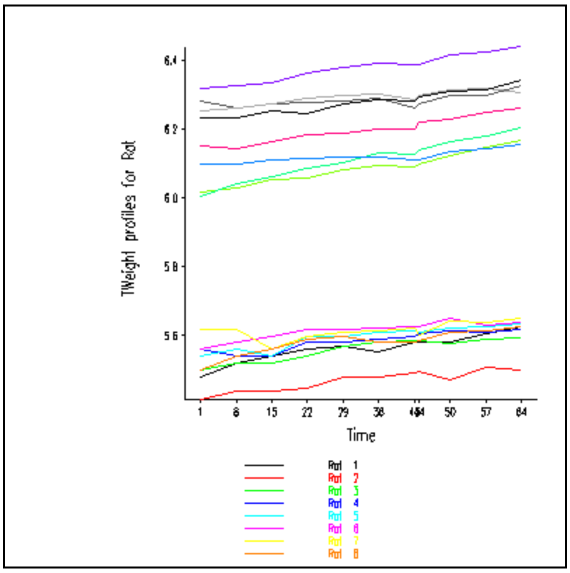
### b) Summary statistics from fitted curves

If the individual profiles are smooth, it may be possible to summarize an individual profile with a response function. In general, this response function can be any suitable function and the parameters of the fitted equation provide the summary statistics for analysis. We will examine the use of low-degree polynomials for this purpose.

Although the measurements at different timepoints for a subject are not independent, it is still suggested that ordinary, unweighted, least-squares estimates be used, possibly after transformation of the response. Provided that the variability of the repeated measurements does not change much over time (a transformation may be needed to ensure this), the ordinary, unweighted, least-squares estimates will be as efficient, or nearly as efficient, as more sophisticated methods that take into account the correlations between the timepoints. The ordinary, unweighted, least-squares estimates will always be valid, in the sense that they will be consistent, and they have the great advantage of simplicity. However, standard errors, $R^2$ and other inferential, regression procedures, in particular the use of differences in the residual mean squares to compare models, are **not** valid and can be very misleading. Here it is to be emphasized that we merely computed fitted parameters as summary statistics describing particular aspects of the behaviour of the data. The analysis that we then perform on these statistics involves assumptions about a model for the distribution of the values of the fitted parameters over the sample of units, and not the distribution of the residuals from the fit of a curve to an individual's profile. One consequence of this is that it is not even required that the curves are particularly good fit to the data, although clearly this may be a desirable aid to interpretation.

**Example XII.4 Rat weight** (continued)

In the previous section we described an experiment involving 16 rats to investigate the effects of 3 diets. The weight gain over the period of observation was used as an ad hoc summary statistic to analyse this data. However, it was found that a log transformation was needed to stabilise the variance. A plot of the profiles is the natural logarithms of the weights is shown in the diagram below.




From this plot it is concluded that the trend remains linear, as would be expected if the range of the weight gains for each rat covers a narrow range $(\max/\min < 3)$. Given this approximately linear trend, another possible summary statistic is the slope of a fitted straight line. Genstat's VORTHPOL procedure can be used to compute the coefficients of orthogonal polynomials. The degree of the polynomials to be fitted is specified by the option MAXDEGREE and the coefficients are saved in variates specified by the CONTRAST parameter. For example CONTRAST=pol saves the mean for each unit in pol[0], the slope for each in pol[1], the quadratic coefficient for each in pol[2] and so on. The following Genstat output contains the commands to compute the mean and linear and quadratic coefficients and to analyse them. The output of these commands is also given.

```
Genstat 5  Release 4.1  (PC/Windows NT)              30 April 2000 13:11:19
Copyright 1998, Lawes Agricultural Trust (Rothamsted Experimental Station)

                 ______________________________________________

                 Genstat 5 Fourth Edition - (for Windows)
                 Genstat 5 Procedure Library Release PL11
                 ______________________________________________

   3  "Data taken from File: D:/ANALYSES/LM/REPEATMEASURE/RMERAT.GSH"
   4  DELETE [redefine=yes] Days,Rats,Diets,Weights
```

```
FACTOR [modify=yes;nvalues=176;levels=!(1,8,15,22,29,36,43,44,50,57,64)\
] Days
READ Days; frepresentation=ordinal

  Identifier    Values   Missing    Levels
        Days       176         0        11

FACTOR [modify=yes;nvalues=176;levels=16] Rats
READ Rats; frepresentation=ordinal

  Identifier    Values   Missing    Levels
        Rats       176         0        16

FACTOR [modify=yes;nvalues=176;levels=3] Diets
READ Diets; frepresentation=ordinal

  Identifier    Values   Missing    Levels
       Diets       176         0         3

VARIATE [nvalues=176] Weights
READ Weights

  Identifier   Minimum      Mean   Maximum    Values   Missing
     Weights     225.0     384.5     628.0       176         0


"
**** separate data for Days and Rat profiles
"
SUBSET [CONDITION=Days==1] OLD=Rats,Diets; \
                            NEW=Rat,Diet
FOR i=1,8...43,44,50,57,64
    SUBSET [CONDITION=Days==i] OLD=Weights; NEW=Weight[i]
ENDFOR
PRINT Rat,Diet,Weight[1,8...43,44,50,57,64]; FIELD=9; DEC=0

      Rat     Diet Weight[1] Weight[8] Weight[15] Weight[22] Weight[29] Weight[3
6]
        1        1       240       250       255       260       262       258
        2        1       225       230       230       232       240       240
        3        1       245       250       250       255       262       265
        4        1       260       255       255       265       265       268
        5        1       255       260       255       270       270       273
        6        1       260       265       270       275       275       277
        7        1       275       275       260       270       273       274
        8        1       245       255       260       268       270       265
        9        2       410       415       425       428       438       443
       10        2       405       420       430       440       448       460
       11        2       445       445       450       452       455       455
       12        2       555       560       565       580       590       597
       13        3       470       465       475       485       487       493
       14        3       535       525       530       533       535       540
       15        3       520       525       530       540       543       546
       16        3       510       510       520       515       530       538


 Weight[43] Weight[44] Weight[50] Weight[57] Weight[64]
      266       266       265       272       278
      243       244       238       247       245
      267       267       264       268       269
      270       272       274       273       275
      274       273       276       278       280
      278       278       284       279       281
      276       271       282       281       284
      265       267       273       274       278
      442       446       456       468       478
      458       464       475       484       496
      451       450       462       466       472
      595       595       612       618       628
      493       504       507       518       525
      525       530       543       544       559
      538       544       553       555       548
```

```
      535      542      550      553      569

  51  "
 -52  **** analyse means, linear and quadratic coefficients
 -53  "
  54  DUPLICATE OLD=Weight; NEW=TWeight
  55  CALC #TWeight=LOG(#Weight)
  56  DREPMEASURES [GROUP=Rat] DATA=TWeight

******** Warning (Code HG 20). Statement 96 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

  57  VORTHPOL [MAXDEGREE=2] TWeight; CONTRAST=pol
  58  BLOCK Rat
  59  TREAT Diet
  60  ANOVA [FPROB=Y; PSE=LSD] pol[0]


60................................................................................

***** Analysis of variance *****

Variate: pol[0]

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rat stratum
Diet                       2   1.685232   0.842616  141.88  <.001
Residual                  13   0.077208   0.005939
Total                     15   1.762440


* MESSAGE: the following units have large residuals.

Rat 12          0.205   s.e. 0.069


***** Tables of means *****

Variate: pol[0]

Grand mean  5.897

     Diet        1        2        3
             5.573    6.175    6.264
     rep.        8        4        4


*** Least significant differences of means (5% level) ***

Table                 Diet
rep.               unequal
d.f.                    13
l.s.d.              0.1177  min.rep
                    0.1020  max-min
                    0.0832X max.rep

(No comparisons in categories where s.e.d. marked with an X)


  61  APLOT METHOD=fit,normal
```

```
             -
             I
             I                                                       *
             I
        0.15 I
r            I
e            I
s            I
i            I    2
d            I    *                                                         3
u       0.00 I    3
a            I    *
l            I                                                       2
s            I                                                              *
             I    *                                                  *
             I
       -0.15 I
             -+---------+---------+---------+---------+---------+---------+---
           5.52      5.64      5.76      5.88      6.00      6.12      6.24

                                         fitted values


                                          Normal plot

             -
             I
         0.2 I                                                           *
r            I
e            I
s            I
i            I
d            I                                     * *   *  *    *
u        0.0 I                       *  *  * *  *
a            I
l            I              *  *   *
s            I *       *
             I
             I
        -0.2 I
             -+---------+---------+---------+---------+---------+---------+---
           -1.8      -1.2      -0.6       0.0       0.6       1.2       1.8

                                   expected Normal quantiles
```

```
  62  ANOVA [FPROB=Y; PSE=LSD] pol[1]

62..............................................................................

***** Analysis of variance *****

Variate: pol[1]

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rat stratum
Diet                       2  0.136E-05  0.678E-06    1.99  0.177
Residual                  13  0.443E-05  0.341E-06
Total                     15  0.579E-05


* MESSAGE: the following units have large residuals.

Rat 11       -0.00121   s.e. 0.00053
```

```
***** Tables of means *****

Variate: pol[1]

Grand mean  0.00151

     Diet        1        2        3
           0.00138  0.00200  0.00126
     rep.        8        4        4


*** Least significant differences of means (5% level) ***

Table                Diet
rep.              unequal
d.f.                   13
l.s.d.           0.000892  min.rep
                 0.000773  max-min
                 0.000631X max.rep

(No comparisons in categories where s.e.d. marked with an X)


  63  APLOT METHOD=fit,normal

             -
             I
             I
             I
      0.0015 I
r            I
e            I                                                      *
s            I
i            I    2       *
d            I            3                                         *
u     0.0000 I            *                                         *
a            I    *       2
l            I
s            I    *       *
             I
             I                                                      *
     -0.0015 I
             -+---------+---------+---------+---------+---------+---------+---
        0.00120   0.00135   0.00150   0.00165   0.00180   0.00195   0.00210

                                         fitted values


                                          Normal plot

             -
             I
      0.0015 I
r            I
e            I                                                           *
s            I
i            I                                           *  *    *
d            I                               *  *  * *
u     0.0000 I                          *  *
a            I                 *   * *
l            I
s            I         *    *
             I
             I *
     -0.0015 I
             -+---------+---------+---------+---------+---------+---------+---
           -1.8      -1.2      -0.6       0.0       0.6       1.2       1.8

                                   expected Normal quantiles
```

```
  64  ANOVA [FPROB=Y; PSE=LSD] pol[2]

64..............................................................................

***** Analysis of variance *****

Variate: pol[2]

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.

Rat stratum
Diet                        2  0.117E-08  0.587E-09    2.31  0.138
Residual                   13  0.330E-08  0.254E-09
Total                      15  0.448E-08


* MESSAGE: the following units have large residuals.

Rat 7       0.0000401   s.e. 0.0000144


***** Tables of means *****

Variate: pol[2]

Grand mean  -0.0000013

     Diet            1            2            3
          -0.975903E-05 0.511111E-05 0.916205E-05
     rep.            8            4            4


*** Least significant differences of means (5% level) ***

Table                 Diet
rep.               unequal
d.f.                    13
l.s.d.          0.00002435  min.rep
                0.00002109  max-min
                0.00001722X max.rep

(No comparisons in categories where s.e.d. marked with an X)


  65  APLOT METHOD=fit,normal



             -
             I
             I      *
             I
     0.00003 I
r            I
e            I
s            I                                                     *
i            I      *                                    *
d            I                                           *         2
u    0.00000 I      *
a            I      2                                    *
l            I      *                                    *
s            I      2
             I
             I                                                     *
    -0.00003 I
             -+---------+---------+---------+---------+---------+---------+---
      -0.000012 -0.000008 -0.000004  0.000000  0.000004  0.000008  0.000012

                                         fitted values
```

```
                                          Normal plot

             -
             I
     0.00004 I                                                           *
r            I
e            I
s            I
i            I                                                   *
d            I                                  *  * *   *  *
u    0.00000 I                               *
a            I                       *  *  *
l            I         *    *  *   *
s            I
             I *
             I
    -0.00004 I
             -+---------+---------+---------+---------+---------+---------+---
           -1.8      -1.2      -0.6       0.0       0.6       1.2       1.8

                                   expected Normal quantiles
```

The assumptions underlying these analyses appear to be met, although there is an outlier in the mean values that would require investigation to see if a reason could be established for it. The analyses indicate that there are significant differences between the diets in the overall rat means ($p < 0.001$) and that there are not significant differences between the diets in the slopes ($p = 0.177$) nor in the quadratic coefficients ($p = 0.138$). That is all the information about the differences between the diets appears to be contained in the overall rat means. The advantage of the overall rat means, compared to the weight gains, is that the overall rat means are based on all the observations for a rat. However, the final choice must be based on what is most important to the experimenter.

The diet means computed from the overall rat means are given in the following table. Again the exponential of these means is the geometric mean of the observations for that diet and the ratios of these could be reported.

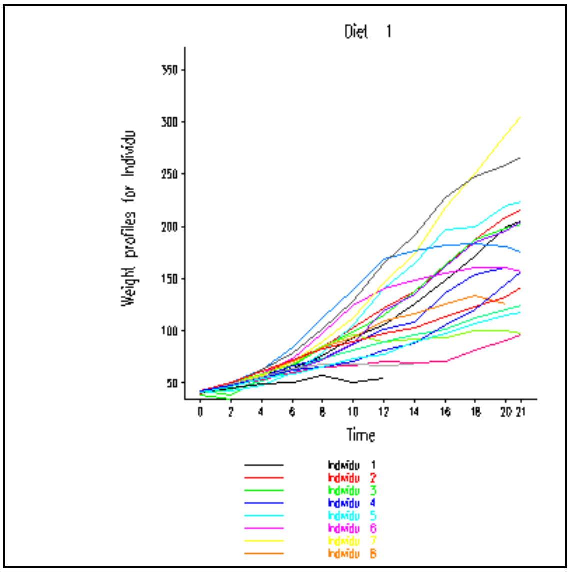
```
***** Tables of means *****

Variate: pol[0]

Grand mean  5.897

     Diet        1        2        3
             5.573    6.175    6.264
     rep.        8        4        4


*** Least significant differences of means (5% level) ***

Table                 Diet
rep.               unequal
d.f.                    13
l.s.d.              0.1177  min.rep
                    0.1020  max-min
                    0.0832X max.rep

(No comparisons in categories where s.e.d. marked with an X)
```

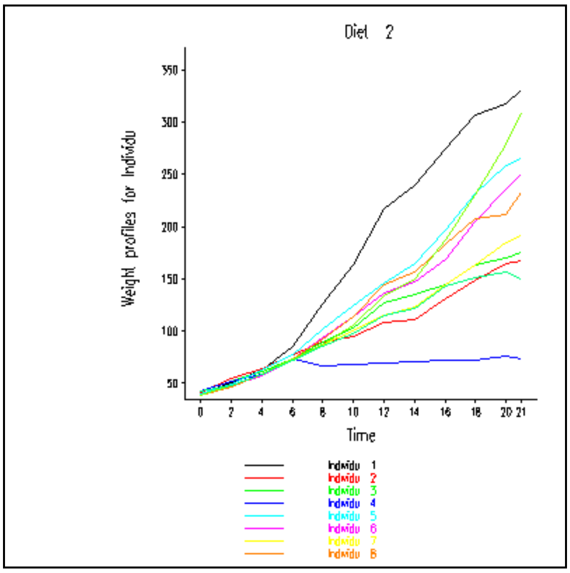
In this case diet 1 is significantly different to diets 2 and 3, the latter two diets not being significantly different. The back-transformed diet means and ratios are given in the following table.

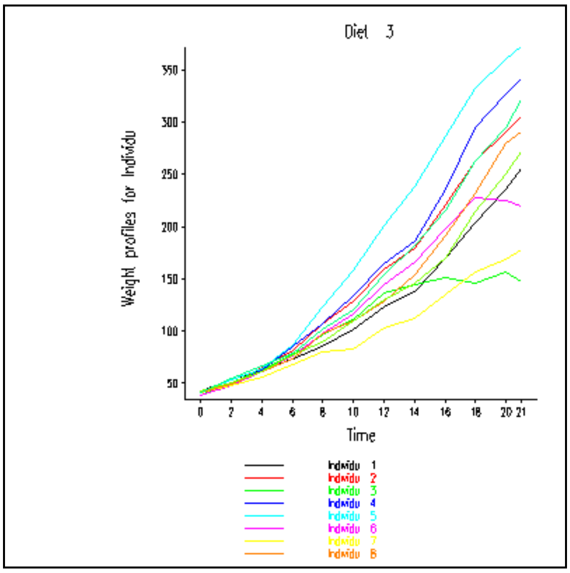
| Diet | Geometric mean | Ratio to diet 1 |
|---|---|---|
| 1 | 263.4 | |
| 2 | 480.7 | 1.82 |
| 3 | 525.2 | 1.99 |

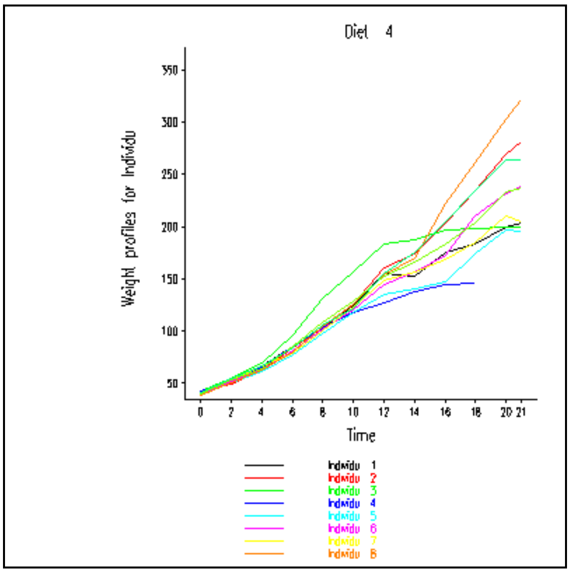
**Example XII.5 Chick body weights under 4 diets**

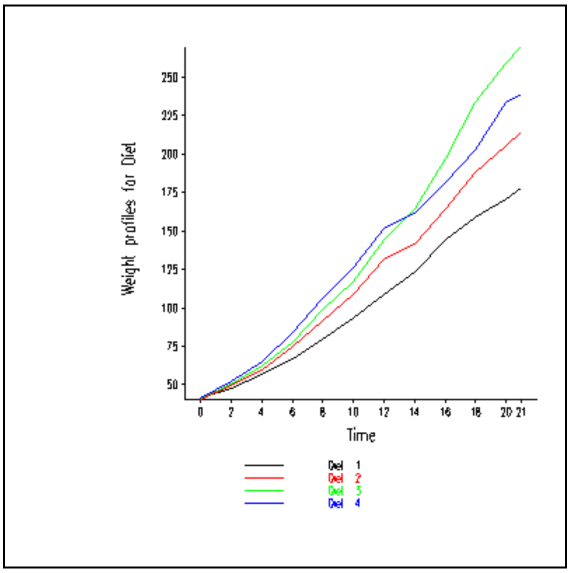
Fifty chicks were involved in the study of the effect of four diets on the body weight of chicks. The chicks were observed on alternative days over a 3-week period. The plots of the individual profiles are shown in the following diagrams.






To analyse this data polynomials of order 6 are fitted. The results are shown in the following Genstat output.

```
Genstat 5  Release 4.1  (PC/Windows NT)              30 April 2000 21:36:45
Copyright 1998, Lawes Agricultural Trust (Rothamsted Experimental Station)

                 _____________________________________________

                 Genstat 5 Fourth Edition - (for Windows)
                 Genstat 5 Procedure Library Release PL11
                 _____________________________________________

   3  "Data taken from File: D:/ANALYSES/LM/REPEATMEASURE/RMECHICKDIET.GSH"
   4  DELETE [redefine=yes] Days,Chicks,Diets,Weights
   5  FACTOR [modify=yes;nvalues=600;levels=!(0,2,4,6,8,10,12,14,16,18,20,21)\
   6  ] Days
   7  READ Days; frepresentation=ordinal

    Identifier     Values    Missing     Levels
          Days        600          0         12

  26  FACTOR [modify=yes;nvalues=600;levels=50] Chicks
  27  READ Chicks; frepresentation=ordinal

    Identifier     Values    Missing     Levels
        Chicks        600          0         50

  51  FACTOR [modify=yes;nvalues=600;levels=4] Diets
  52  READ Diets; frepresentation=ordinal

    Identifier     Values    Missing     Levels
         Diets        600          0          4

  69  VARIATE [nvalues=600] Weights
  70  READ Weights

    Identifier    Minimum       Mean    Maximum     Values    Missing
       Weights       35.0      121.8      373.0        600         22

  99
 100  "
-101  **** separate data for Days and Chick profiles
-102  "
 103  SUBSET [CONDITION=Days==0] OLD=Chicks,Diets; \
 104                              NEW=Chick,Diet
 105  FOR i=0,2...20,21
 106      SUBSET [CONDITION=Days==i] OLD=Weights; NEW=Weight[i]
```

```
107  ENDFOR
108  PRINT Chick,Diet,Weight[0,2...20,21]; FIELD=9; DEC=0
```

| Chick | Diet | Weight[0] | Weight[2] | Weight[4] | Weight[6] | Weight[8] | Weight[10] |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 42 | 51 | 59 | 64 | 76 | 93 |
| 2 | 1 | 40 | 49 | 58 | 72 | 84 | 103 |
| 3 | 1 | 43 | 39 | 55 | 67 | 84 | 99 |
| 4 | 1 | 42 | 49 | 56 | 67 | 74 | 87 |
| 5 | 1 | 41 | 42 | 48 | 60 | 79 | 106 |
| 6 | 1 | 41 | 49 | 59 | 74 | 97 | 124 |
| 7 | 1 | 41 | 49 | 57 | 71 | 89 | 112 |
| 8 | 1 | 42 | 50 | 61 | 71 | 84 | 93 |
| 9 | 1 | 42 | 51 | 59 | 68 | 85 | 96 |
| 10 | 1 | 41 | 44 | 52 | 63 | 74 | 81 |
| 11 | 1 | 43 | 51 | 63 | 84 | 112 | 139 |
| 12 | 1 | 41 | 49 | 56 | 62 | 72 | 88 |
| 13 | 1 | 41 | 48 | 53 | 60 | 65 | 67 |
| 14 | 1 | 41 | 49 | 62 | 79 | 101 | 128 |
| 15 | 1 | 41 | 49 | 56 | 64 | 68 | 68 |
| 16 | 1 | 41 | 45 | 49 | 51 | 57 | 51 |
| 17 | 1 | 42 | 51 | 61 | 72 | 83 | 89 |
| 18 | 1 | 39 | 35 | * | * | * | * |
| 19 | 1 | 43 | 48 | 55 | 62 | 65 | 71 |
| 20 | 1 | 41 | 47 | 54 | 58 | 65 | 73 |
| 21 | 2 | 40 | 50 | 62 | 86 | 125 | 163 |
| 22 | 2 | 41 | 55 | 64 | 77 | 90 | 95 |
| 23 | 2 | 43 | 52 | 61 | 73 | 90 | 103 |
| 24 | 2 | 42 | 52 | 58 | 74 | 66 | 68 |
| 25 | 2 | 40 | 49 | 62 | 78 | 102 | 124 |
| 26 | 2 | 42 | 48 | 57 | 74 | 93 | 114 |
| 27 | 2 | 39 | 46 | 58 | 73 | 87 | 100 |
| 28 | 2 | 39 | 46 | 58 | 73 | 92 | 114 |
| 29 | 2 | 39 | 48 | 59 | 74 | 87 | 106 |
| 30 | 2 | 42 | 48 | 59 | 72 | 85 | 98 |
| 31 | 3 | 42 | 53 | 62 | 73 | 85 | 102 |
| 32 | 3 | 41 | 49 | 65 | 82 | 107 | 129 |
| 33 | 3 | 39 | 50 | 63 | 77 | 96 | 111 |
| 34 | 3 | 41 | 49 | 63 | 85 | 107 | 134 |
| 35 | 3 | 41 | 53 | 64 | 87 | 123 | 158 |
| 36 | 3 | 39 | 48 | 61 | 76 | 98 | 116 |
| 37 | 3 | 41 | 48 | 56 | 68 | 80 | 83 |
| 38 | 3 | 41 | 49 | 61 | 74 | 98 | 109 |
| 39 | 3 | 42 | 50 | 61 | 78 | 89 | 109 |
| 40 | 3 | 41 | 55 | 66 | 79 | 101 | 120 |
| 41 | 4 | 42 | 51 | 66 | 85 | 103 | 124 |
| 42 | 4 | 42 | 49 | 63 | 84 | 103 | 126 |
| 43 | 4 | 42 | 55 | 69 | 96 | 131 | 157 |
| 44 | 4 | 42 | 51 | 65 | 86 | 103 | 118 |
| 45 | 4 | 41 | 50 | 61 | 78 | 98 | 117 |
| 46 | 4 | 40 | 52 | 62 | 82 | 101 | 120 |
| 47 | 4 | 41 | 53 | 66 | 79 | 100 | 123 |
| 48 | 4 | 39 | 50 | 62 | 80 | 104 | 125 |
| 49 | 4 | 40 | 53 | 64 | 85 | 108 | 128 |
| 50 | 4 | 41 | 54 | 67 | 84 | 105 | 122 |

| Weight[12] | Weight[14] | Weight[16] | Weight[18] | Weight[20] | Weight[21] |
|---|---|---|---|---|---|
| 106 | 125 | 149 | 171 | 199 | 205 |
| 122 | 138 | 162 | 187 | 209 | 215 |
| 115 | 138 | 163 | 187 | 198 | 202 |
| 102 | 108 | 136 | 154 | 160 | 157 |
| 141 | 164 | 197 | 199 | 220 | 223 |
| 141 | 148 | 155 | 160 | 160 | 157 |
| 146 | 174 | 218 | 250 | 288 | 305 |
| 110 | 116 | 126 | 134 | 125 | * |
| 90 | 92 | 93 | 100 | 100 | 98 |
| 89 | 96 | 101 | 112 | 120 | 124 |
| 168 | 177 | 182 | 184 | 181 | 175 |
| 119 | 135 | 162 | 185 | 195 | 205 |
| 71 | 70 | 71 | 81 | 91 | 96 |
| 164 | 192 | 227 | 248 | 259 | 266 |
| 67 | 68 | * | * | * | * |

```
      54        *        *        *        *        *
      98      103      113      123      133      142
       *        *        *        *        *        *
      82       88      106      120      144      157
      77       89       98      107      115      117
     217      240      275      307      318      331
     108      111      131      148      164      167
     127      135      145      163      170      175
      70       71       72       72       76       74
     146      164      197      231      259      265
     136      147      169      205      236      251
     115      123      144      163      185      192
     145      156      184      207      212      233
     134      150      187      230      279      309
     115      122      143      151      157      150
     123      138      170      204      235      256
     159      179      221      263      291      305
     137      144      151      146      156      147
     164      186      235      294      327      341
     201      238      287      332      361      373
     145      166      198      227      225      220
     103      112      135      157      169      178
     128      154      192      232      280      290
     130      146      170      214      250      272
     154      182      215      262      295      321
     155      153      175      184      199      204
     160      174      204      234      269      281
     184      188      197      198      199      200
     127      138      145      146        *        *
     135      141      147      174      197      196
     144      156      173      210      231      238
     148      157      168      185      210      205
     154      170      222      261      303      322
     152      166      184      203      233      237
     155      175      205      234      264      264

 109  FACTOR [LEV=30] Individuals
 110  CALC Individuals=NEWLEVELS(Chick; !v(1...20,(1...10)3))
 111  DREPMEASURES [GROUPS=Diet,Individuals] DATA=Weight

******** WARNING message from procedure DREPMEAS :
There are missing values in the DATA pointer
Plots of means can be misleading

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full

* MESSAGE: There are missing values in the plot


******** Warning (Code HG 20). Statement 130 in Procedure DREPMEAS
Command:  DGRAPH [WINDOW= window; KEYWINDOW= keywindow; TITLE= Title_]  GroupMns
Key window full
```

```
 112  DREPMEASURES [GROUPS=Diet] DATA=Weight

******** WARNING message from procedure DREPMEAS :
There are missing values in the DATA pointer
Plots of means can be misleading

 113  "
-114  **** analyse polynomial coefficients to degree 6
-115  "
 116  VORTHPOL [MAXDEGREE=6] Weight; CONTRAST=pol
 117  BLOCK Chick
 118  TREAT Diet
 119  FOR k=0...6
 120    ANOVA [PRINT=aov; FPROB=Y; PSE=LSD] pol[k]
 121    APLOT METHOD=fit,normal
 122  ENDFOR


122...............................................................................

***** Analysis of variance *****

Variate: pol[0]

Source of variation     d.f.(m.v.)      s.s.       m.s.    v.r.  F pr.

Chick stratum
Diet                        3         11015.2     3671.7    5.76  0.002
Residual                  41(5)       26124.6      637.2
Total                     44(5)       35824.9

                                                                                         5
             I
             I
             I
        60.0 I                        *
r            I                                                         *
e            I     2
s            I                                                         *
i            I     2                  2                          *
d            I     4                  2                          2     2
u        0.0 I     *                                             3     *
a            I     *                  2                          2     3
l            I     3                  2                          *
s            I     2                                                   *
             I     *                                                   *
             I
       -60.0 I                        *
             -+---------+---------+---------+---------+---------+---------+---
           104.0     112.0     120.0     128.0     136.0     144.0     152.0
                                          fitted values

                                           Normal plot
                                                                                         5
             I
        60.0 I                                                                  *
r            I                                                             *
e            I                                                        * *
s            I                                                      *
i            I                                                *****
d            I                                        **2**2**
u        0.0 I                                     2*2
a            I                               2**2**
l            I                         ******
s            I                    * * *
             I               *  *
             I
       -60.0 I  *
             -+---------+---------+---------+---------+---------+---------+---
            -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4
                                    expected Normal quantiles
```

```
122.............................................................................

***** Analysis of variance *****

Variate: pol[1]

Source of variation     d.f.(m.v.)      s.s.       m.s.    v.r.  F pr.

Chick stratum
Diet                         3          149.15      49.72    4.57  0.007
Residual                    41(5)       445.85      10.87
Total                       44(5)       579.84
```

```
                                                                              5
             -
             I
             I
             I
         8.0 I
r            I         *                *
e            I         *                                            *
s            I                          *            *              *
i            I         *                *                           *
d            I         4                2            2              *
u        0.0 I         2                             2              *
a            I         2                2            3              3
l            I         3                2            *
s            I         *
             I         *                                            2
             I
        -8.0 I                          *
             -+---------+---------+---------+---------+---------+---------+---
            6.0       7.0       8.0       9.0      10.0      11.0      12.0

                                         fitted values
```

```
                                          Normal plot
                                                                              5
             -
             I
         8.0 I
r            I                                                     *    *
e            I                                                999* *
s            I                                           ** *
i            I                                        ***
d            I                                 *2**2**
u        0.0 I                             **2*
a            I                      *2**2***
l            I                ******
s            I              *
             I       *  * *
             I
        -8.0 I  *
             -+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles
```

```
122..............................................................................

***** Analysis of variance *****

Variate: pol[2]

Source of variation     d.f.(m.v.)      s.s.       m.s.    v.r.  F pr.

Chick stratum
Diet                        3         0.35795    0.11932    2.54  0.069
Residual                   41(5)      1.92227    0.04688
Total                      44(5)      2.26415


                                                                              5
             -
             I
             I
             I
         0.6 I
r            I
e            I               **         *
s            I
i            I               *3         *                                3
d            I               23         *                                4
u        0.0 I               *3         2
a            I               33         3                                *
l            I                          2                                *
s            I                2
             I                *
             I               *                                           *
        -0.6 I
             -+---------+---------+---------+---------+---------+---------+---
           0.00      0.05      0.10      0.15      0.20      0.25      0.30

                                         fitted values


                                          Normal plot
                                                                              5
             -
             I
         0.6 I
r            I
e            I                                                  *  *    *
s            I
i            I                                       ****** * *
d            I                               ***2**2*
u        0.0 I                           **2**
a            I                   ****2**2
l            I                ***
s            I            * *
             I          *
             I  *    *
        -0.6 I
             -+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles
```

122.........................................................................

***** Analysis of variance *****

Variate: pol[3]

| Source of variation | d.f.(m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Chick stratum | | | | | |
| Diet | 3 | 0.0003445 | 0.0001148 | 0.28 | 0.841 |
| Residual | 41(5) | 0.0169446 | 0.0004133 | | |
| Total | 44(5) | 0.0172501 | | | |

```
                                                                              5
             -
             I
             I
             I
        0.06 I
r            I
e            I
s            I        2                                           *        *
i            I        2                                           2        2
d            I        4                           3               2        2
u       0.00 I        2                           4               2        *
a            I        2                           *                        3
l            I        *                                           *
s            I        2                           *               2
             I        *
             I                                                             *
       -0.06 I
             -+---------+---------+---------+---------+---------+---------+---
        -0.0144   -0.0132   -0.0120   -0.0108   -0.0096   -0.0084   -0.0072

                                         fitted values
```

```
                                          Normal plot
                                                                              5
             -
             I
        0.06 I
r            I
e            I
s            I                                                * *  *    *
i            I                                        ***** *
d            I                               ***2**2**
u       0.00 I                         *2**2**
a            I                    ***2*
l            I                  **
s            I          * * * **
             I       *
             I  *
       -0.06 I
             -+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles
```

```
122..............................................................................

***** Analysis of variance *****

Variate: pol[4]

Source of variation     d.f.(m.v.)      s.s.       m.s.    v.r.  F pr.

Chick stratum
Diet                        3       0.323E-04  0.108E-04    4.44  0.009
Residual                   41(5)    0.994E-04  0.242E-05
Total                      44(5)    0.130E-03


                                                                              5
             -
             I
             I
             I
       0.004 I
r            I                                                          *
e            I                          2
s            I         2                *          *
i            I                          3                               *
d            I         *                *          3                    2
u      0.000 I         4                *          2                    2
a            I         2                3          3                    *
l            I                          2          *
s            I                          *                               *
             I         *                2
             I                                                          *
      -0.004 I
             -+---------+---------+---------+---------+---------+---------+---
        -0.0015   -0.0010   -0.0005    0.0000    0.0005    0.0010    0.0015

                                         fitted values


                                          Normal plot
                                                                              5
             -
             I
       0.004 I
r            I                                                          *
e            I                                                  *  *
s            I                                           ** * *
i            I                                       ****
d            I                                  2**2*
u      0.000 I                           **2*2**
a            I                    ***2**2
l            I                 ***
s            I              * *
             I       *  * *
             I  *
      -0.004 I
             -+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles
```

122...........................................................................

***** Analysis of variance *****

Variate: pol[5]

| Source of variation | d.f.(m.v.) | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Chick stratum | | | | | |
| Diet | 3 | 0.292E-06 | 0.974E-07 | 1.65 | 0.194 |
| Residual | 41(5) | 0.243E-05 | 0.592E-07 | | |
| Total | 44(5) | 0.270E-05 | | | |

```
                                                                              5
             -
             I
             I
             I
      0.0005 I    *                                                    *
r            I                                     *
e            I    *
s            I                                     * *                2
i            I    2                                * 2                2
d            I                                     * *                *
u     0.0000 I    2                                  *                3
a            I                                     2 *                3
l            I    2                                3 2                *
s            I                                     * *                *
             I    *                                                   *
             I                                                        *
     -0.0005 I    *
             -+---------+---------+---------+---------+---------+---------+---------+---
      -0.000248 -0.000208 -0.000168 -0.000128 -0.000088 -0.000048 -0.000008

                                         fitted values
```

```
                                          Normal plot
                                                                              5
             -
             I
      0.0005 I                                                     *    *
r            I                                                  *
e            I                                                *
s            I                                          *** *
i            I                                    *2****
d            I                                  2*
u     0.0000 I                             **2**
a            I                         *2***
l            I                  *****2*
s            I              * **
             I          * *
             I       *
     -0.0005 I  *
             -+---------+---------+---------+---------+---------+---------+---------+---
           -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                   expected Normal quantiles
```

122...........................................................................

```
***** Analysis of variance *****

Variate: pol[6]

Source of variation     d.f.(m.v.)      s.s.       m.s.    v.r.  F pr.

Chick stratum
Diet                      3       0.189E-07  0.630E-08    6.69  <.001
Residual                41(5)     0.386E-07  0.942E-09
Total                   44(5)     0.551E-07
```

```
                                                                              5
             -
             I
             I
             I
     0.00006 I
r            I                                            2              *
e            I                                           *               *
s            I     3                                                     3
i            I     *                                     2               2
d            I                                           *2              *
u    0.00000 I     2                                     2*              *
a            I                                           *2              *
l            I     *                                     2*              3
s            I
             I     *                                     **              *
             I     *                                      *
    -0.00006 I                                                           2
             -+---------+---------+---------+---------+---------+---------+---
         -0.00007  -0.00006  -0.00005  -0.00004  -0.00003  -0.00002  -0.00001

                                       fitted values
```

```
                                        Normal plot
                                                                              5
             -
             I
     0.00006 I
r            I                                                        *   *    *
e            I                                                    * *
s            I                                              ******
i            I                                          **2*
d            I                                       **2
u    0.00000 I                                   *2*2
a            I                                *2*
l            I                          ****2*
s            I
             I                     * ***
             I                 * *
    -0.00006 I  *    *
             -+---------+---------+---------+---------+---------+---------+---
            -2.4      -1.6      -0.8       0.0       0.8       1.6       2.4

                                 expected Normal quantiles
```

While the assumptions for the analysis appear to be met, the fourth- and sixth-degree polynomial coefficients are significant. The analysis of polynomial coefficients does not appear to be appropriate for this example. Perhaps non-linear models would provide a more satisfactory basis for analysis of this example. In fitting nonlinear models one has to be particularly careful about the normality of the coefficients and very high correlations between the estimates of different parameters.

## c) Computation in Genstat

**Example XII.4 Rat weight** (continued)

The commands used in the analysis of summary statistics for this example are as follows:

```
"
**** separate data for Days and Rat profiles
"
SUBSET [CONDITION=Days==1] OLD=Rats,Diets; \
                            NEW=Rat,Diet
FOR i=1,8...43,44,50,57,64
    SUBSET [CONDITION=Days==i] OLD=Weights; NEW=Weight[i]
ENDFOR
PRINT Rat,Diet,Weight[1,8...43,44,50,57,64]; FIELD=9; DEC=0
FACTOR [LEV=30] Individuals
CALC Individuals=NEWLEVELS(Rat; !v(1...8,(1...4)2))
DREPMEASURES [GROUPS=Diet,Individuals] DATA=Weight
DREPMEASURES [GROUPS=Diet] DATA=Weight
"
**** analyse weight gain
"
CALC WtGain=Weight[64]-Weight[1]
BLOCK Rat
TREAT Diet
ANOVA [FPROB=Y; PSE=LSD] WtGain
APLOT METHOD=fit,normal
YTRANSFORM [TERMS=Diet; LOWER=-1; UPPER=1] WtGain; SAVE=s
CALC TWtGain=LOG(WtGain)
ANOVA [FPROB=Y; PSE=LSD] TWtGain
APLOT METHOD=fit,normal
AKEEP Diet; MEANS=DietMn
CALC DietMn=EXP(DietMn)
PRINT DietMn
"
**** analyse means, linear and quadratic coefficients
"
DUPLICATE OLD=Weight; NEW=TWeight
CALC #TWeight=LOG(#Weight)
DREPMEASURES [GROUP=Rat] DATA=TWeight
VORTHPOL [MAXDEGREE=2] TWeight; CONTRAST=pol
BLOCK Rat
TREAT Diet
FOR k=0…2
  ANOVA [FPROB=Y; PSE=LSD] pol[k]
  APLOT METHOD=fit,normal
ENDFOR
```