# 5 Designing experiments—keeping it simple

## 5.1 Three fundamental principles of experimental design

The concept of blocking in experimental design is introduced. To analyse a blocked experiment, the categorical variable BLOCK is included in the model formula. In this example, we compare two analyses: one in which BLOCK has been statistically eliminated, and one in which it has not. The second of these examples illustrates how to include two categorical variables in a model.

SPSS COMMANDS FOR BOX 5.1 **Analysis of bean yields**

| | |
|---|---|
| Syntax | `glm YIELD by BEAN`<br>`/design BEAN.` |
| Menu route | Analyze > General Linear Model >Univariate<br>YIELD → Dependent Variable<br>BEAN → Fixed Factor(s) |

SPSS OUTPUT FOR BOX 5.1 **Analysis of bean yields assuming a fully randomised design**

## General linear model

**Between-Subjects Factors**

| | | N |
|---|---|---|
| BEAN | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |
| | 5 | 4 |
| | 6 | 4 |

**Tests of Between-Subjects Effects**

Dependent Variable: YIELD

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 444.435[a] | 5 | 88.887 | 14.586 | .000 |
| Intercept | 6673.335 | 1 | 6673.335 | 1095.086 | .000 |
| BEAN | 444.435 | 5 | 88.887 | 14.586 | .000 |
| Error | 109.690 | 18 | 6.094 | | |
| Total | 7227.460 | 24 | | | |
| Corrected Total | 554.125 | 23 | | | |

a. R Squared = .802 (Adjusted R Squared = .747)

When we move to include BLOCK, the menu route becomes more complicated, and we need to learn a bit more about how SPSS works. So far, we have just added variables to the Covariate(s) and Fixed Factor(s) panes, but behind the scenes SPSS has been constructing a default model from those choices. Up to now, that default model has been the one we want, but now it is not, and to specify the model we need to use the Model subdialog, as follows: We pick the explanatory variables we wish to include in the model from the *Factors & Covariates* pane, and transfer them to the *model* pane via *the build terms* arrow. In this way we can fit the simple model of BLOCK + BEAN (SPSS would automatically build a more complex model, as we will see later). The Model subdialog is the equivalent of the DESIGN subcommand in the syntax route.

SPSS COMMANDS FOR BOX 5.2 **Analysis of a blocked experiment**

| | |
|---|---|
| Syntax | `glm YIELD by BLOCK BEAN`<br>`/design BLOCK BEAN.` |
| Menu route | Analyze > General Linear Model > Univariate<br>`YIELD` → Dependent Variable<br>`BLOCK BEAN` → Fixed Factor(s)<br>[Model]<br>⊙ Custom<br>Factors & Covariates → Build Terms → Model<br>`BLOCK` → `BLOCK`<br>`BEAN` → `BEAN` |

SPSS OUTPUT FOR BOX 5.2 **Analysis of bean yields assuming a randomised block design**

## General linear model

**Between-Subjects Factors**

| | | N |
|---|---|---|
| BLOCK | 1 | 6 |
| | 2 | 6 |
| | 3 | 6 |
| | 4 | 6 |
| BEAN | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |
| | 5 | 4 |
| | 6 | 4 |

**Tests of Between-Subjects Effects**

Dependent Variable: YIELD

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 497.330[a] | 8 | 62.166 | 16.419 | .000 |
| Intercept | 6673.335 | 1 | 6673.335 | 1762.480 | .000 |
| BLOCK | 52.895 | 3 | 17.632 | 4.657 | .017 |
| BEAN | 444.435 | 5 | 88.887 | 23.476 | .000 |
| Error | 56.795 | 15 | 3.786 | | |
| Total | 7227.460 | 24 | | | |
| Corrected Total | 554.125 | 23 | | | |

a. R Squared = .898 (Adjusted R Squared = .843)

A Latin Square design is an example of using two blocking factors in an experimental design. Both categorical blocking variables are added to the model formula. The following analysis uses the *oilseed rape* dataset.

SPSS COMMANDS FOR BOX 5.3 **Analysis of a latin square design**

Syntax

```
glm SEEDS by COLUMN ROW TREATMT
  /design COLUMN ROW TREATMT.
```

Menu route

Analyze > General Linear Model > Univariate

SEEDS → Dependent Variable

COLUMN ROW TREATMT → Fixed Factor(s)

[Model]

⦿ Custom

Factors & Covariates → Build Terms → Model

COLUMN → COLUMN

ROW → ROW

TREATMT → TREATMT

SPSS OUTPUT FOR BOX 5.3 **Analysis of a latin square design**

## General linear model

### Between-Subjects Factors

| | | N |
|---|---|---|
| COLUMN | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |
| ROW | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |
| TREATMT | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |

### Tests of Between-Subjects Effects

Dependent Variable: SEEDS

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 5072.750[a] | 9 | 563.639 | 11.161 | .004 |
| Intercept | 189660.250 | 1 | 189660.250 | 3755.649 | .000 |
| COLUMN | 1332.250 | 3 | 444.083 | 8.794 | .013 |
| ROW | 1090.250 | 3 | 363.417 | 7.196 | .021 |
| TREATMT | 2650.250 | 3 | 883.417 | 17.493 | .002 |
| Error | 303.000 | 6 | 50.500 | | |
| Total | 195036.000 | 16 | | | |
| Corrected Total | 5375.750 | 15 | | | |

a. R Squared = .944 (Adjusted R Squared = .859)

## 5.2 The geometrical analogy for blocking

### Calculating the fitted model for two categorical variables

Revisiting the *Beans* dataset, the full coefficient table can be obtained by altering the level of output requested (see SPSS supplement chapter 3 and below).

SPSS COMMANDS FOR BOX 5.4 **Coefficients table for two categorical variables**

Syntax

```
glm YIELD by BLOCK BEAN
  /print parameters
  /design BLOCK BEAN.
```

Menu route Analyze > General Linear Model > Univariate

YIELD → Dependent Variable

BLOCK BEAN → Fixed Factor(s)

Model

⦿ Custom

Factors & Covariates → Build Terms → Model

BLOCK → BLOCK

BEAN → BEAN

Options

☑ Parameter estimates

This would give the following ANOVA and coefficients table:

SPSS OUTPUT FOR BOX 5.4 **ANOVA and coefficient tables for a randomised blocked design**

## General linear model

### Between-Subjects Factors

| | | N |
|---|---|---|
| BLOCK | 1 | 6 |
| | 2 | 6 |
| | 3 | 6 |
| | 4 | 6 |
| BEAN | 1 | 4 |
| | 2 | 4 |
| | 3 | 4 |
| | 4 | 4 |
| | 5 | 4 |
| | 6 | 4 |

### Tests of Between-Subjects Effects

Dependent Variable: YIELD

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 497.330[a] | 8 | 62.166 | 16.419 | .000 |
| Intercept | 6673.335 | 1 | 6673.335 | 1762.480 | .000 |
| BLOCK | 52.895 | 3 | 17.632 | 4.657 | .017 |
| BEAN | 444.435 | 5 | 88.887 | 23.476 | .000 |
| Error | 56.795 | 15 | 3.786 | | |
| Total | 7227.460 | 24 | | | |
| Corrected Total | 554.125 | 23 | | | |

a. R Squared = .898 (Adjusted R Squared = .843)

### Parameter Estimates

Dependent Variable: YIELD

| | | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| Parameter | B | Std. | t | Sig | Lower Bound | Upper Bound |
| Intercept | 9.492 | 1.192 | 7.966 | .000 | 6.952 | 12.031 |
| [BLOCK=1] | 1.000 | 1.123 | .890 | .387 | –1.395 | 3.395 |
| [BLOCK=2] | 3.350 | 1.123 | 2.982 | .009 | .955 | 5.745 |
| [BLOCK=3] | –.517 | 1.123 | –.460 | .652 | –2.911 | 1.878 |
| [BLOCK=4] | 0[a] | . | . | . | . | . |
| [BEAN=1] | 11.300 | 1.376 | 8.213 | .000 | 8.367 | 14.233 |
| [BEAN=2] | 11.925 | 1.376 | 8.667 | .000 | 8.992 | 14.858 |
| [BEAN=3] | 5.625 | 1.376 | 4.088 | .001 | 2.692 | 8.558 |
| [BEAN=4] | 5.975 | 1.376 | 4.343 | .001 | 3.042 | 8.908 |
| [BEAN=5] | 2.525 | 1.376 | 1.835 | .086 | –.408 | 5.458 |
| [BEAN=6] | 0[a] | . | . | . | . | . |

a. This parameter is set to zero because it is redundant

There are four blocks and six varieties of bean, and a coefficient is given for each level, but that for the final level of each variable equals zero exactly and is assigned no standard error. This is because the final level of each categorical variable is aliassed (as first discussed in chapter 3). The aliassing convention followed in the main text is the not the same as that followed by SPSS. To calculate the full set of fitted values, we therefore need a small amendment to the method of the text. The amendment is the way in which the aliassed value is calculated and used in subsequent fitted value calculations.

The coefficients for each level are given with reference to the last aliassed value. In other words, in this example, block 2 has a mean 3.35 units higher than block 4, and variety 3 has a mean 5.625 units higher than variety 6. This allows a rapid visual inspection of the means of all other blocks with reference to the last block, and all other varieties of bean with reference to variety 6. With only one categorical variable, the reference level represented by the final level of a variable is simply the grand mean, as we saw earlier. But with two categorical variables, the reference level for each variable is a bit more complicated. We need to go into this a bit further in order to show how the coefficients are linked to the fitted values.

Table 5.1 illustrates the derivation of the fitted value coefficients for this particular example. The fourth coefficient for `BLOCK` is actually the mean of the deviations of the variety coefficients from variety 6; and the sixth coefficient for `BEAN` is the mean of the deviations of the block coefficients from block 4. This seems rather counterintuitive. However, a little algebra illustrates how this works.

Let B1 = the mean of block 1; B2 for block 2; V1 = the mean for variety 1 etc. Then the grand mean may be expressed as:

$$\frac{V1 + V2 + V3 + V4 + V5 + V6}{6}$$

or alternatively as

$$\frac{B1 + B2 + B3 + B4}{4}.$$

However, we choose to make B4 and V6 our reference points. Every other block mean can be expressed as a function of B4: e.g. B2 = B4 + $\alpha_2$, and similarly V3 = V6 + $\beta_3$. If we substitute these functions into our two expressions for the grand mean, we find

$$B4 + \frac{\alpha_1 + \alpha_2 + \alpha_3}{4} = V6 + \frac{\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5}{6}.$$

Re-arranging for B4, we get

$$B4 = \left\{V6 - \frac{\alpha_1 + \alpha_2 + \alpha_3}{4}\right\} + \frac{\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5}{6}$$

or re-arranging for V6, we get

$$V6 = \left\{B4 - \frac{\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5}{6}\right\} + \frac{\alpha_1 + \alpha_2 + \alpha_3}{4}.$$

However, the expressions inside the curly brackets are equal — so these are set to $\mu$. This gives us the same expression for the fitted values of B4 and V6 as in SPSS Table 5.1. The intercept, $\mu$, can be thought of as the mean of variety 6 adjusted for differences between the blocks, or the mean for block 4, adjusted for differences between the varieties. Setting the coefficient for the final level of a variable to zero is therefore not always as simple as it seems!
To summarise Table 5.1 as a fitted value equation equivalent to the version given on page 87 of the main text, we have:

$$y = \mu + \frac{\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5}{6} + \begin{pmatrix} \textit{Block} & \\ 1 & \alpha_1 \\ 2 & \alpha_2 \\ 3 & \alpha_3 \\ 4 & 0 \end{pmatrix} + \frac{\alpha_1 + \alpha_2 + \alpha_3}{4} + \begin{pmatrix} \textit{Variety} & \\ 1 & \beta_1 \\ 2 & \beta_2 \\ 3 & \beta_3 \\ 4 & \beta_4 \\ 5 & \beta_5 \\ 6 & 0 \end{pmatrix} + \varepsilon$$

The following table shows how this formula works numerically for our example. It is convenient to introduce the symbols $\alpha_{ave}$ and $\beta_{ave}$ for the average values of $\alpha$ and $\beta$, making this general expression as follows:

$$y = \mu + \alpha_{ave} + \beta_{ave} + \begin{pmatrix} \textit{Block} & \\ 1 & \alpha_1 \\ 2 & \alpha_2 \\ 3 & \alpha_3 \\ 4 & 0 \end{pmatrix} + \begin{bmatrix} \textit{Variety} & \\ 1 & \beta_1 \\ 2 & \beta_2 \\ 3 & \beta_3 \\ 4 & \beta_4 \\ 5 & \beta_5 \\ 6 & 0 \end{bmatrix} + \varepsilon$$

SPSS OUTPUT FOR TABLE 5.1

| Term | Level | Coefficient from SPSS output | | Fitted Value |
|---|---|---|---|---|
| Intercept | | $\mu$ | 9.492 | |
| Block | 1 | $\alpha_1$ | 1.000 | $\mu + \beta_{ave} + \alpha_1 =$ 9.492 + 6.225 + 1 |
| | 2 | $\alpha_2$ | 3.350 | $\mu + \beta_{ave} + \alpha_2 =$ 9.492 + 6.225 + 3.35 |
| | 3 | $\alpha_3$ | –0.517 | $\mu + \beta_{ave} + \alpha_3 =$ 9.492 + 6.225 – 0.517 |
| | 4 | $\alpha_4$ (aliassed) | 0 | $\mu + \beta_{ave} + \alpha_4 =$ 9.492 + 6.225 + 0 |
| | | $\alpha_{ave}$ | $= \dfrac{1 + 3.35 - 0.517 + 0}{4} = 0.958$ | |
| Bean | 1 | $\beta_1$ | 11.300 | $\mu + \alpha_{ave} + \beta_1 =$ 9.492 + 0.958 + 11.3 |
| | 2 | $\beta_2$ | 11.925 | $\mu + \alpha_{ave} + \beta_2 =$ 9.492 + 0.958 +11.925 |
| | 3 | $\beta_3$ | 5.625 | $\mu + \alpha_{ave} + \beta_3 =$ 9.492 + 0.958 + 5.625 |
| | 4 | $\beta_4$ | 5.975 | $\mu + \alpha_{ave} + \beta_4 =$ 9.492 + 0.958 + 5.975 |
| | 5 | $\beta_5$ | 2.525 | $\mu + \alpha_{ave} + \beta_5 =$ 9.492 + 0.958 + 2.525 |
| | 6 | $\beta_6$ (aliassed) | 0 | $\mu + \alpha_{ave} + \beta_6 =$ 9.492 + 0.958 + 0 |
| | | $\beta_{ave}$ | $= \dfrac{11.3 + 11.925 + 5.625 + 5.975 + 2.525 + 0}{6}$ = 6.225 | |

## 5.3 The concept of orthogonality

Loss of orthogonality leads to differences in adjusted and sequential SS for a variable. This may be illustrated by the *Beans* data set in which the variables `MYIELD`, `MBLOCK` and `MBEAN` are shortened versions of the original variables, leading to loss of orthogonality. The analysis must be done twice, once for each type of sum of squares. On this occasion we explicitly lay out the instructions for both analyses. In the output, however, only the ANOVA table is repeated, as the title and coefficients table are the same.

SPSS COMMANDS FOR BOX 5.5 **Loss of orthogonality for two categorical variables**

Syntax

```
glm MYIELD by MBLOCK MBEAN
  /print parameters
  /design MBLOCK MBEAN.

glm MYIELD by MBLOCK MBEAN
  /print parameters
  /method sstype(1)
  /design MBLOCK MBEAN.
```

Menu route

Analyze > General Linear Model > Univariate

MYIELD → Dependent Variable

MBLOCK MBEAN → Fixed Factor(s)

[Model]

⊙ Custom

Factors & Covariates → Build Terms → Model

MBLOCK → MBLOCK

MBEAN → MBEAN

[Options]

☑ Parameter estimates

Analyze > General Linear Model > Univariate

MYIELD → Dependent Variable

MBLOCK MBEAN → Fixed Factor(s)

[Model]

⊙ Custom

Factors & Covariates → Build Terms → Model

MBLOCK → MBLOCK

MBEAN → MBEAN

Sum of Squares: [Type I ▼]

[Options]

☑ Parameter estimates

SPSS OUTPUT FOR BOX 5.5 **Slight loss of orthogonality in a randomised block design**

## General linear model

**Between-Subjects Factors**

| | | N |
|---|---|---|
| MBLOCK | 1 | 6 |
| | 2 | 6 |
| | 3 | 6 |
| | 4 | 4 |
| MBEAN | 1 | 4 |
| | 2 | 3 |
| | 3 | 4 |
| | 4 | 4 |
| | 5 | 4 |
| | 6 | 3 |

**Tests of Between-Subjects Effects**

Dependent Variable: MYIELD

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 498.704[a] | 8 | 62.338 | 24.339 | .000 |
| Intercept | 5737.643 | 1 | 5737.643 | 2240.178 | .000 |
| MBLOCK | 49.690 | 3 | 16.563 | 6.467 | .006 |
| MBEAN | 449.413 | 5 | 89.883 | 35.093 | .000 |
| Error | 33.296 | 13 | 2.561 | | |
| Total | 6741.280 | 22 | | | |
| Corrected Total | 532.000 | 21 | | | |

a. R Squared = .937 (Adjusted R Squared = .899)

(*Contd.*)

SPSS OUTPUT FOR BOX 5.5 (*Contd.*)

**Parameter Estimates**

Dependent Variable: MYIELD

| Parameter | B | Std. Error | t | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Intercept | 8.658 | 1.307 | 6.626 | .000 | 5.835 | 11.481 |
| [MBLOCK=1] | .897 | 1.067 | .841 | .416 | –1.408 | 3.202 |
| [MBLOCK=2] | 3.247 | 1.067 | 3.044 | .009 | .942 | 5.552 |
| [MBLOCK=3] | –.619 | 1.067 | –.581 | .571 | –2.924 | 1.686 |
| [MBLOCK=4] | 0[a] | . | . | . | . | . |
| [MBEAN=1] | 12.210 | 1.244 | 9.816 | .000 | 9.523 | 14.898 |
| [MBEAN=2] | 13.900 | 1.307 | 10.637 | .000 | 11.077 | 16.723 |
| [MBEAN=3] | 6.535 | 1.244 | 5.254 | .000 | 3.848 | 9.223 |
| [MBEAN=4] | 6.885 | 1.244 | 5.535 | .000 | 4.198 | 9.573 |
| [MBEAN=5] | 3.435 | 1.244 | 2.762 | .016 | .748 | 6.123 |
| [MBEAN=6] | 0[a] | . | . | . | . | . |

a. This parameter is set to zero because it is redundant.

*and the second analysis produces this ANOVA table instead*

**Tests of Between-Subjects Effects**

Dependent Variable: MYIELD

| Source | Type I Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 498.704[a] | 8 | 62.338 | 24.339 | .000 |
| Intercept | 6209.280 | 1 | 6209.280 | 2424.321 | .000 |
| MBLOCK | 49.291 | 3 | 16.430 | 6.415 | .007 |
| MBEAN | 449.413 | 5 | 89.883 | 35.093 | .000 |
| Error | 33.296 | 13 | 2.561 | | |
| Total | 6741.280 | 22 | | | |
| Corrected Total | 532.000 | 21 | | | |

a. R Squared = .937 (Adjusted R Squared = .899)

## 5.5 Exercises

### Growing carnations

SPSS COMMANDS FOR BOX 5.6
**Analysis of the number of carnation blooms with bed, water and shade**

Syntax

```
glm SQBLOOMS by BED WATER SHADE
  /print parameters
  /design BED WATER SHADE.

glm SQBLOOMS by BED WATER SHADE
  /print parameters
  /method sstype(1)
  /design BED WATER SHADE.
```

Menu route

Analyze > General Linear Model > Univariate

SQBLOOMS → Dependent Variable

BED WATER SHADE → Fixed Factor(s)

Model

⦿ Custom

Factors & Covariates → Build Terms → Model

BED → BED

WATER → WATER

SHADE → SHADE

Options

☑ Parameter estimates

Analyze > General Linear Model > Univariate

SQBLOOMS → Dependent Variable

BED WATER SHADE → Fixed Factor(s)

Model

⦿ Custom

Factors & Covariates → Build Terms → Model

BED → BED

WATER → WATER

SHADE → SHADE

Sum of Squares: Type I ▼

Options

☑ Parameter estimates

SPSS OUTPUT FOR BOX 5.6

**Analvsis of the number of carnation blooms with bed, water and shade**

## General linear model

**Between-Subjects Factors**

| | | N |
|---|---|---|
| BED | 1 | 12 |
| | 2 | 12 |
| | 3 | 12 |
| WATER | 1 | 12 |
| | 2 | 12 |
| | 3 | 12 |
| SHADE | 1 | 9 |
| | 2 | 9 |
| | 3 | 9 |
| | 4 | 9 |

**Tests of Between-Subjects Effects**

Dependent Variable: SQBLOOMS

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 9.494[a] | 7 | 1.356 | 6.208 | .000 |
| Intercept | 584.390 | 1 | 584.390 | 2674.844 | .000 |
| BED | 4.132 | 2 | 2.066 | 9.457 | .001 |
| WATER | 3.715 | 2 | 1.858 | 8.503 | .001 |
| SHADE | 1.646 | 3 | .549 | 2.512 | .079 |
| Error | 6.117 | 28 | .218 | | |
| Total | 600.002 | 36 | | | |
| Corrected Total | 15.611 | 35 | | | |

a. R Squared = .608 (Adjusted R Squared = .510)

(*Contd.*)

SPSS OUTPUT FOR BOX 5.6 (*Contd.*)

**Parameter Estimates**

Dependent Variable: SQBLOOMS

| Parameter | B | Std. | t | Sig. | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| Intercept | 3.354 | .220 | 15.220 | .000 | 2.902 | 3.805 |
| [BED=1] | .504 | .191 | 2.643 | .013 | .114 | .895 |
| [BED=2] | .823 | .191 | 4.313 | .000 | .432 | 1.214 |
| [BED=3] | 0[a] | . | . | . | . | . |
| [WATER=1] | –.449 | .191 | –2.353 | .026 | –.840 | –5.804E-02 |
| [WATER=2] | .335 | .191 | 1.757 | .090 | –5.563E-02 | .726 |
| [WATER=3] | 0[a] | . | . | . | . | . |
| [SHADE=1] | .367 | .220 | 1.667 | .107 | –8.402E-02 | .819 |
| [SHADE=2] | .564 | .220 | 2.561 | .016 | .113 | 1.016 |
| [SHADE=3] | .152 | .220 | .688 | .497 | –.300 | .603 |
| [SHADE=4] | 0[a] | . | . | . | . | . |

a. This parameter is set to zero because it is redundant

*and the second analysis produces the following ANOVA table instead…*

**Tests of Between-Subjects Effects**

Dependent Variable: SQBLOOMS

| Source | Type I Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 9.494[a] | 7 | 1.356 | 6.208 | .000 |
| Intercept | 584.390 | 1 | 584.390 | 2674.844 | .000 |
| BED | 4.132 | 2 | 2.066 | 9.457 | .001 |
| WATER | 3.715 | 2 | 1.858 | 8.503 | .001 |
| SHADE | 1.646 | 3 | .549 | 2.512 | .079 |
| Error | 6.117 | 28 | .218 | | |
| Total | 600.002 | 36 | | | |
| Corrected Total | 15.611 | 35 | | | |

a. R Squared = .608 (Adjusted R Squared = .510)

The next analysis does not include BED as a block.

**SPSS COMMANDS FOR BOX 5.7 The carnation bloom analysis without bed used as a block**

Syntax

```
glm SQBLOOMS by WATER SHADE
  /print parameters
  /design WATER SHADE.
```

Menu route

Analyze > General Linear Model > Univariate

SQBLOOMS → Dependent Variable

WATER SHADE → Fixed Factor(s)

[Model]

⊙ Custom

Factors & Covariates → Build Terms → Model

WATER → WATER

SHADE → SHADE

[Options]

☑ Parameter estimates

SPSS OUTPUT FOR BOX 5.7 **The carnation bloom analysis without bed used as a block**

## General linear model

### Between-Subjects Factors

| | | N |
|---|---|---|
| WATER | 1 | 12 |
| | 2 | 12 |
| | 3 | 12 |
| SHADE | 1 | 9 |
| | 2 | 9 |
| | 3 | 9 |
| | 4 | 9 |

### Tests of Between-Subjects Effects

Dependent Variable: SQBLOOMS

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 5.362[a] | 5 | 1.072 | 3.139 | .021 |
| Intercept | 584.390 | 1 | 584.390 | 1710.474 | .000 |
| WATER | 3.715 | 2 | 1.858 | 5.437 | .010 |
| SHADE | 1.646 | 3 | .549 | 1.606 | .209 |
| Error | 10.250 | 30 | .342 | | |
| Total | 600.002 | 36 | | | |
| Corrected Total | 15.611 | 35 | | | |

a. R Squared = .343 (Adjusted R Squared = .234)

### Parameter Estimates

Dependent Variable: SQBLOOMS

| Parameter | B | Std. Error | t | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| Intercept | 3.796 | .239 | 15.908 | .000 | 3.309 | 4.283 |
| [WATER=1] | –.449 | .239 | –1.881 | .070 | –.936 | 3.842E-02 |
| [WATER=2] | .335 | .239 | 1.405 | .170 | –.152 | .823 |
| [WATER=3] | 0[a] | . | . | . | . | . |
| [SHADE=1] | .367 | .276 | 1.333 | .193 | –.195 | .930 |
| [SHADE=2] | .564 | .276 | 2.048 | .049 | 1.491E-03 | 1.127 |
| [SHADE=3] | .152 | .276 | .550 | .586 | –.411 | .714 |
| [SHADE=4] | 0[a] | . | . | . | . | . |

a. This parameter is set to zero because it is redundant

In the third analysis, three plots have been removed.

SPSS COMMANDS FOR BOX 5.8

**Analysis of the carnation blooms with three plot values removed**

Syntax

```
glm SQ2 by B2 W2 S2
  /design B2 W2 S2.

glm SQ2 by B2 W2 S2
  /method sstype(1)
  /design B2 W2 S2.
```

Menu route

Analyze > General Linear Model > Univariate

SQ2 → Dependent Variable

B2 W2 S2 → Fixed Factor(s)

[Model]

⊙ Custom

Factors & Covariates → Build Terms → Model

| | | |
|---|---|---|
| B2 | → | B2 |
| W2 | → | W2 |
| S2 | → | S2 |

Analyze > General Linear Model > Univariate

SQ2 → Dependent Variable

B2 W2 S2 → Fixed Factor(s)

[Model]

⊙ Custom

Factors & Covariates → Build Terms → Model

| | | |
|---|---|---|
| B2 | → | B2 |
| W2 | → | W2 |
| S2 | → | S2 |

Sum of Squares: [Type I ▼]

SPSS OUTPUT FOR BOX 5.8

**Analysis of the carnation blooms with three plot values removed**

## General linear model

**Between-Subjects Factors**

| | | N |
|---|---|---|
| B2 | 1 | 11 |
| | 2 | 12 |
| | 3 | 10 |
| W2 | 1 | 11 |
| | 2 | 11 |
| | 3 | 11 |
| S2 | 1 | 9 |
| | 2 | 8 |
| | 3 | 9 |
| | 4 | 7 |

**Tests of Between-Subjects Effects**

Dependent Variable: SQ2

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 8.649[a] | 7 | 1.236 | 7.495 | .000 |
| Intercept | 537.900 | 1 | 537.900 | 3262.928 | .000 |
| B2 | 2.649 | 2 | 1.325 | 8.035 | .002 |
| W2 | 4.676 | 2 | 2.338 | 14.184 | .000 |
| S2 | .807 | 3 | .269 | 1.632 | .207 |
| Error | 4.121 | 25 | .165 | | |
| Total | 566.001 | 33 | | | |
| Corrected Total | 12.770 | 32 | | | |

a. R Squared = .677 (Adjusted R Squared = .587)

*and the second analysis produces the following ANOVA table instead.*

**Tests of Between-Subjects Effects**

Dependent Variable: SQ2

| Source | Type I Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 8.649[a] | 7 | 1.236 | 7.495 | .000 |
| Intercept | 553.230 | 1 | 553.230 | 3355.924 | .000 |
| B2 | 2.763 | 2 | 1.381 | 8.379 | .002 |
| W2 | 5.079 | 2 | 2.540 | 15.406 | .000 |
| S2 | .807 | 3 | .269 | 1.632 | .207 |
| Error | 4.121 | 25 | .165 | | |
| Total | 566.001 | 33 | | | |
| Corrected Total | 12.770 | 32 | | | |

a. R Squared = .677 (Adjusted R Squared = .587)

### The dorsal crest of the male smooth newt

See SPSS output for this exercise in the answers for exercises.