Chapter 14 : Multifactor studies without replication

Effects of Ozone with Sulfur Dioxide and Water Stress on Soybean Yield

This study involved two different soybean cultivars. The 30 possible combinations of ozone (at five levels), sulfur dioxide (at three levels), and water stress (at two levels) were randomly assigned to 30 open-topped chambers specially constructed to maintain stable conditions. Two soybean cultivars- Forrest and Williams-were randomly assigned to two rows within each chamber, with separate randomizations within each chamber. The soybeans were planted in July; sulfur dioxide and ozone were piped in and monitored daily; soil moisture was maintained by watering and was measured at a depth of 0.25 to 0.45 meters. In September, the crops were harvested, each row producing a quantity of soybean seeds that was converted into kilograms per hectare. (Data from H. E. Heggestad and V. M. Lesser, "Effects of Chronic Doses of Sulfur Dioxide, Ozone, and Drought on Yields and Growth of Soybeans Under Field Conditions," Journal of Environmental Quality 19 (1990): 488-95.)

Seed yields for soybean cultivars *Forrest* and *Williams* from chambers kept under varying conditions of ozone, sulfur dioxide, and water stress

Water stress	SO_2 ($\mu L/L$)	O_3 ($\mu L/L$)	Yields (kg/ha) Forrest	Williams
Well-watered (WW) (−0.05 MPa)	0.0045	0.017	4376	5561
		0.049	4544	5947
		0.067	2806	4273
		0.084	3339	3470
		0.099	3320	3080
	0.0170	0.017	3747	5092
		0.049	4570	4752
		0.067	4635	4232
		0.084	3613	2867
		0.099	3259	3106
	0.0590	0.017	4179	4736
		0.049	5077	3672
		0.067	3401	3386
		0.084	3371	2854
		0.099	2158	2557
Soil moisture stress (SMS) (−0.40 MPa)	0.045	0.017	4977	4520
		0.049	3780	3047
		0.067	3804	3526
		0.084	3941	3357
		0.099	2863	2663
	0.0170	0.017	5573	4869
		0.049	3555	3774
		0.067	3340	2955
		0.084	3243	3513
		0.099	2802	2838
	0.0590	0.017	4589	4056
		0.049	3250	2758
		0.067	3045	3094
		0.084	2827	2398
		0.099	2979	2101

Ideally this study could have been repeated two or three times in time and the time repetitions could have been used as blocks. This would provide ample degrees of freedom for testing. However, this was not feasible and an alternative approach is described below.

Many previous studies had found that ozone and sulfur dioxide reduce yield. Evidence about interactions between ozone and sulfur dioxide had not been consistent, nor was it clear how moisture stress influenced the results. Three questions were of interest in this study: (1) Is there an additional influence of soil moisture stress? (2) Are there interactive effects among the three factors? and (3) Do the stress variables have different effects on the two cultivars?

Linear Models – If all three of the sources are considered "treatments of interest", and if tthey were to be treated as fixed effects the model would be $Y_{ij} = \mu + \tau_{1i} + \tau_{2j} + \tau_{3k} + \tau_{12ij} + \tau_{13ik} + \tau_{23jk} + \tau_{123ijk}$,

where τ_1 is SO_2 level, τ_2 is water stress (well watered and stressed) and τ_3 is O_3 level. Obviously there is a problem here, no error term. In order to have an error term for testing treatments the 5 ozone levels are treated as a quantitative variable. In this way the ozone uses only one degree of freedom (d.f.), so all other degrees of freedom from ozone and its interaction are available as a "deviations from regression" type of error term. The linear model for this is then

$Y_{ij} = \beta_0 + \tau_{1i} + \tau_{2j} + \tau_{12ij} + \beta_1 X_k + \beta_2 X_k \tau_{1ik} + \beta_3 X_k \tau_{2jk} + \beta_4 X_k \tau_{123ijk} + \varepsilon_{ijk}$. In this model all deviation from regression "interaction" terms are pooled into a single error term.

In addition to these terms there was an additional treatment, cultivar. This makes a split-plot within the 30 chambers. It is possible to factor out all interactions of the treatments and the quantitative variable with cultivars. In order to simplify the problem your text does the two cultivars separate analyses.

```
1           ****************************************************;
2           *** STRESS SO2 O3anzee language study                      ***;
3           ****************************************************;
4
5           dm'log;clear;output;clear';
6           options nodate nocenter nonumber ps=512 ls=132 nolabel;
7           *ODS HTML style=minimal rs=none body='C:\Geaghan\Current\EXST3201\Fall2005\SAS\Soybean01.html' ;
8
9           ods html;
NOTE: Writing HTML Body file: sashtml.htm
10          ods graphics on;
NOTE: ODS Statistical Graphics will require a SAS/GRAPH license when it is declared
production.
11
12          Title1 'Chapter 14 : Soybean Yield study';
13          filename input1 'C:\Geaghan\Current\EXST3201\Datasets\ASCII\case1402.csv';
14
15          data Soybean; infile input1 missover DSD dlm="," firstobs=2;
16             input STRESS $ SO2 O3 FORREST WILLIAM;
17               label Yield   = 'Soybean yield'
18                     STRESS  = 'Water stress'
19                     SO2     = 'Sulfur dioxied level'
20                     O3      = 'Ozone level'
21                     Cultivar = 'Cultivar';
22             cultivar = 'Forrest'; yield = FORREST; LogYield = log(Yield); output;
23             cultivar = 'William'; yield = WILLIAM; LogYield = log(Yield); output;
24          datalines;
NOTE: The infile INPUT1 is:
      File Name=C:\Geaghan\Current\EXST3201\Datasets\ASCII\case1402.csv,
      RECFM=V,LRECL=256
NOTE: 30 records were read from the infile INPUT1.
      The minimum record length was 57.
      The maximum record length was 65.
NOTE: The data set WORK.SOYBEAN has 60 observations and 8 variables.
NOTE: DATA statement used (Total process time):
      real time           0.01 seconds
      cpu time            0.02 seconds
25          run;
26
27          PROC PRINT DATA=Soybean; TITLE2 'Data Listing';
28          RUN;
NOTE: There were 60 observations read from the data set WORK.SOYBEAN.
NOTE: The PROCEDURE PRINT printed page 1.
NOTE: PROCEDURE PRINT used (Total process time):
      real time           0.52 seconds
      cpu time            0.10 seconds
```

Chapter 14 : Soybean Yield study
Data Listing

| | | | | | | | | Log |
Obs	STRESS	SO2	O3	FORREST	WILLIAM	Yield	Cultivar	Yield
1	WELL-WAT	0.004500	0.017000	4376	5561	4376	Forrest	8.38389
2	WELL-WAT	0.004500	0.017000	4376	5561	5561	William	8.62353
3	WELL-WAT	0.004500	0.049000	4544	5947	4544	Forrest	8.42156
4	WELL-WAT	0.004500	0.049000	4544	5947	5947	William	8.69064
5	WELL-WAT	0.004500	0.067000	2806	4273	2806	Forrest	7.93952
6	WELL-WAT	0.004500	0.067000	2806	4273	4273	William	8.36007
7	WELL-WAT	0.004500	0.084000	3339	3470	3339	Forrest	8.11343
8	WELL-WAT	0.004500	0.084000	3339	3470	3470	William	8.15191
9	WELL-WAT	0.004500	0.099000	3320	3080	3320	Forrest	8.10772
10	WELL-WAT	0.004500	0.099000	3320	3080	3080	William	8.03268
11	WELL-WAT	0.017000	0.017000	3747	5092	3747	Forrest	8.22871
12	WELL-WAT	0.017000	0.017000	3747	5092	5092	William	8.53543
13	WELL-WAT	0.017000	0.049000	4570	4752	4570	Forrest	8.42727
14	WELL-WAT	0.017000	0.049000	4570	4752	4752	William	8.46632
15	WELL-WAT	0.017000	0.067000	4635	4232	4635	Forrest	8.44139
16	WELL-WAT	0.017000	0.067000	4635	4232	4232	William	8.35043
17	WELL-WAT	0.017000	0.084000	3613	2867	3613	Forrest	8.19229

18	WELL-WAT	0.017000	0.084000	3613	2867	2867	William	7.96102
19	WELL-WAT	0.017000	0.099000	3259	3106	3259	Forrest	8.08918
20	WELL-WAT	0.017000	0.099000	3259	3106	3106	William	8.04109
21	WELL-WAT	0.059000	0.017000	4179	4736	4179	Forrest	8.33783
22	WELL-WAT	0.059000	0.017000	4179	4736	4736	William	8.46295
23	WELL-WAT	0.059000	0.049000	5077	3672	5077	Forrest	8.53248
24	WELL-WAT	0.059000	0.049000	5077	3672	3672	William	8.20849
25	WELL-WAT	0.059000	0.067000	3401	3386	3401	Forrest	8.13182
26	WELL-WAT	0.059000	0.067000	3401	3386	3386	William	8.12740
27	WELL-WAT	0.059000	0.084000	3371	2854	3371	Forrest	8.12296
28	WELL-WAT	0.059000	0.084000	3371	2854	2854	William	7.95648
29	WELL-WAT	0.059000	0.099000	2158	2557	2158	Forrest	7.67694
30	WELL-WAT	0.059000	0.099000	2158	2557	2557	William	7.84659
31	STRESSED	0.004500	0.017000	4977	4520	4977	Forrest	8.51258
32	STRESSED	0.004500	0.017000	4977	4520	4520	William	8.41627
33	STRESSED	0.004500	0.049000	3780	3047	3780	Forrest	8.23748
34	STRESSED	0.004500	0.049000	3780	3047	3047	William	8.02191
35	STRESSED	0.004500	0.067000	3804	3526	3804	Forrest	8.24381
36	STRESSED	0.004500	0.067000	3804	3526	3526	William	8.16792
37	STRESSED	0.004500	0.084000	3941	3357	3941	Forrest	8.27919
38	STRESSED	0.004500	0.084000	3941	3357	3357	William	8.11880
39	STRESSED	0.004500	0.099000	2863	2663	2863	Forrest	7.95963
40	STRESSED	0.004500	0.099000	2863	2663	2663	William	7.88721
41	STRESSED	0.017000	0.017000	5573	4869	5573	Forrest	8.62569
42	STRESSED	0.017000	0.017000	5573	4869	4869	William	8.49064
43	STRESSED	0.017000	0.049000	3555	3774	3555	Forrest	8.17611
44	STRESSED	0.017000	0.049000	3555	3774	3774	William	8.23589
45	STRESSED	0.017000	0.067000	3340	2955	3340	Forrest	8.11373
46	STRESSED	0.017000	0.067000	3340	2955	2955	William	7.99125
47	STRESSED	0.017000	0.084000	3243	3513	3243	Forrest	8.08425
48	STRESSED	0.017000	0.084000	3243	3513	3513	William	8.16423
49	STRESSED	0.017000	0.099000	2802	2838	2802	Forrest	7.93809
50	STRESSED	0.017000	0.099000	2802	2838	2838	William	7.95085
51	STRESSED	0.059000	0.017000	4589	4056	4589	Forrest	8.43142
52	STRESSED	0.059000	0.017000	4589	4056	4056	William	8.30795
53	STRESSED	0.059000	0.049000	3250	2758	3250	Forrest	8.08641
54	STRESSED	0.059000	0.049000	3250	2758	2758	William	7.92226
55	STRESSED	0.059000	0.067000	3045	3094	3045	Forrest	8.02126
56	STRESSED	0.059000	0.067000	3045	3094	3094	William	8.03722
57	STRESSED	0.059000	0.084000	2827	2398	2827	Forrest	7.94697
58	STRESSED	0.059000	0.084000	2827	2398	2398	William	7.78239
59	STRESSED	0.059000	0.099000	2979	2101	2979	Forrest	7.99934
60	STRESSED	0.059000	0.099000	2979	2101	2101	William	7.65017

```
30        PROC mixed DATA=Soybean cl covtest; class STRESS SO2 O3 Cultivar;
31          Title2 'Unreplicated multifactor study - ozone as a class variable';
32          MODEL LogYield = STRESS | SO2 | O3 | Cultivar;
33        RUN;
NOTE: An infinite likelihood is assumed in iteration 0 because of a nonpositive residual
variance estimate.
NOTE: The PROCEDURE MIXED printed page 2.
NOTE: PROCEDURE MIXED used (Total process time):
     real time           0.53 seconds
     cpu time            0.20 seconds
34        QUIT;
```

Chapter 14 : Soybean Yield study
Unreplicated multifactor study - ozone as a class variable

The Mixed Procedure

Model Information
Data Set   WORK.SOYBEAN
Dependent Variable   LogYield
Covariance Structure   Diagonal
Estimation Method   REML
Residual Variance Method   Profile

```
Fixed Effects SE Method        Model-Based
Degrees of Freedom Method      Residual


Class Level Information
Class        Levels    Values
STRESS          2      STRESSED WELL-WAT
SO2             3      0.0044999998 0.0170000009 0.0590000004
O3              5      0.0170000009 0.0489999987 0.0670000017 0.0839999989 0.0989999995
Cultivar        2      Forrest William


Dimensions
Covariance Parameters            1
Columns in X                   216
Columns in Z                     0
Subjects                         1
Max Obs Per Subject             60


Number of Observations
Number of Observations Read            60
Number of Observations Used            60
Number of Observations Not Used         0


Covariance Parameter Estimates
                        Standard         Z
Cov Parm      Estimate    Error       Value         Pr Z      Alpha       Lower       Upper
Residual             0        .         .            .          .           .           .


Fit Statistics
-2 Res Log Likelihood          -18E307
AIC (smaller is better)        -18E307
AICC (smaller is better)       -18E307
BIC (smaller is better)        -18E307


Type 3 Tests of Fixed Effects
                          Num     Den
Effect                     DF      DF     F Value    Pr > F
STRESS                      1       0        .         .
SO2                         2       0        .         .
STRESS*SO2                  2       0        .         .
O3                          4       0        .         .
STRESS*O3                   4       0        .         .
SO2*O3                      8       0        .         .
STRESS*SO2*O3               8       0        .         .
Cultivar                    1       0        .         .
STRESS*Cultivar             1       0        .         .
SO2*Cultivar                2       0        .         .
STRESS*SO2*Cultivar         2       0        .         .
O3*Cultivar                 4       0        .         .
STRESS*O3*Cultivar          4       0        .         .
SO2*O3*Cultivar             8       0        .         .
STRESS*SO2*O3*Cultiv        8       0        .         .


36          PROC mixed DATA=Soybean cl covtest; class STRESS SO2 Cultivar;
37             Title2 'Unreplicated multifactor study';
38            MODEL LogYield = STRESS SO2 O3 cultivar STRESS*SO2 STRESS*O3 STRESS*Cultivar
39                  O3*SO2 O3*Cultivar SO2*Cultivar O3*STRESS*SO2 STRESS*SO2*Cultivar
40                  O3*STRESS*Cultivar O3*SO2*Cultivar O3*STRESS*SO2*Cultivar;
41          RUN;
NOTE: The PROCEDURE MIXED printed page 3.
NOTE: PROCEDURE MIXED used (Total process time):
      real time            0.26 seconds
      cpu time             0.10 seconds
```

I fitted the full model above, and then reduced the model one term at a time to the simplest possible model. I put one restriction on my reduction, that lower order interactions and main effects were not removed if higher order terms containing the effect were significant. The model eventually reduced down to the terms "**STRESS SO2 O3 cultivar STRESS*Cultivar**". There is a big advantage to having no ozone interactions in the model.

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study


The Mixed Procedure


Model Information
Data Set                    WORK.SOYBEAN
Dependent Variable          LogYield
Covariance Structure        Diagonal
Estimation Method           REML
Residual Variance Method    Profile
Fixed Effects SE Method     Model-Based
Degrees of Freedom Method   Residual


Class Level Information
Class      Levels   Values
STRESS        2     STRESSED WELL-WAT
SO2           3     0.0044999998 0.0170000009  0.0590000004
Cultivar      2     Forrest William


Dimensions
Covariance Parameters           1
Columns in X                   72
Columns in Z                    0
Subjects                        1
Max Obs Per Subject            60


Number of Observations
Number of Observations Read          60
Number of Observations Used          60
Number of Observations Not Used       0


Covariance Parameter Estimates
                      Standard        Z
Cov Parm    Estimate     Error    Value      Pr Z      Alpha     Lower      Upper
Residual     0.01832  0.004318     4.24    <.0001      0.05    0.01212    0.03091


Fit Statistics
-2 Res Log Likelihood          -88.6
AIC (smaller is better)        -86.6
AICC (smaller is better)       -86.5
BIC (smaller is better)        -85.0


Type 3 Tests of Fixed Effects
                        Num    Den
Effect                   DF     DF    F Value    Pr > F
STRESS                    1     36       1.49    0.2296
SO2                       2     36       0.28    0.7563
O3                        1     36     100.73    <.0001
Cultivar                  1     36       0.54    0.4688
STRESS*SO2                2     36       0.82    0.4469
O3*STRESS                 1     36       0.00    0.9845
STRESS*Cultivar           1     36       3.80    0.0592
O3*SO2                    2     36       0.51    0.6076
O3*Cultivar               1     36       1.36    0.2513
SO2*Cultivar              2     36       0.44    0.6475
O3*STRESS*SO2             2     36       0.86    0.4301
STRESS*SO2*Cultivar       2     36       1.14    0.3325
O3*STRESS*Cultivar        1     36       1.44    0.2379
O3*SO2*Cultivar           2     36       0.07    0.9338
O3*STRESS*SO2*Cultiv      2     36       1.26    0.2969



43          PROC mixed DATA=Soybean cl covtest; class STRESS SO2 Cultivar;
44            Title2 'Unreplicated multifactor study - reduced model';
45             MODEL LogYield = STRESS SO2 O3 cultivar STRESS*Cultivar / outp=resids solution;
46             lsmeans STRESS SO2 Cultivar STRESS*Cultivar / pdiff adjust=tukey;
47           ods output diffs=ppp lsmeans=mmm;
48           ods listing exclude diffs;* lsmeans; *this is now just a comment;
```

```
49          run;
NOTE: The data set WORK.MMM has 11 observations and 9 variables.
NOTE: The data set WORK.PPP has 11 observations and 14 variables.
NOTE: The data set WORK.RESIDS has 60 observations and 15 variables.
NOTE: The PROCEDURE MIXED printed page 4.
NOTE: PROCEDURE MIXED used (Total process time):
      real time           0.73 seconds
      cpu time            0.46 seconds
50          TITLE3 'Post hoc adjustment with macro by Arnold Saxton';
51          %include 'C:\Geaghan\Current\EXST3201\Fall2005\SAS\pdmix800.sas';
724         %pdmix800(ppp,mmm,alpha=.05,sort=yes);
PDMIX800 08.08.2003 processing
2.8366198946
Tukey  values for STRESS  are 0.0677  (avg) 0.0677  (min) 0.0677  (max).
3.4100482656
Tukey  values for SO2  are 0.09968  (avg) 0.09968  (min) 0.09968  (max).
2.8366198946
Tukey  values for Cultivar  are 0.0677  (avg) 0.0677  (min) 0.0677  (max).
3.7510419993
Tukey  values for STRESS*Cultivar  are 0.12661  (avg) 0.12661  (min) 0.12661  (max).
725         RUN;
726         QUIT;
```

Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model

The Mixed Procedure

Model Information
Data Set   WORK.SOYBEAN
Dependent Variable   LogYield
Covariance Structure   Diagonal
Estimation Method   REML
Residual Variance Method   Profile
Fixed Effects SE Method   Model-Based
Degrees of Freedom Method   Residual

Class Level Information
Class   Levels   Values
STRESS   2   STRESSED WELL-WAT
SO2   3   0.0044999998 0.0170000009
                      0.0590000004
Cultivar   2   Forrest William

Dimensions
Covariance Parameters   1
Columns in X   13
Columns in Z   0
Subjects   1
Max Obs Per Subject   60

Number of Observations
Number of Observations Read   60
Number of Observations Used   60
Number of Observations Not Used   0

Covariance Parameter Estimates

Cov Parm	Estimate	Standard Error	Z Value	Pr Z	Alpha	Lower	Upper
Residual	0.01709	0.003320	5.15	<.0001	0.05	0.01208	0.02604

Fit Statistics
-2 Res Log Likelihood   -52.6
AIC (smaller is better)   -50.6
AICC (smaller is better)   -50.5
BIC (smaller is better)   -48.6

```
Solution for Fixed Effects
                                                        Standard
Effect          STRESS      Cultivar   SO2           Estimate    Error      DF    t Value    Pr > |t|
Intercept                                               8.5432   0.05575    53     153.24     <.0001
STRESS          STRESSED                               -0.1780   0.04773    53      -3.73     0.0005
STRESS          WELL-WAT                                     0        .      .          .          .
SO2                                    0.0044999998      0.1540   0.04134    53       3.73     0.0005
SO2                                    0.0170000009      0.1457   0.04134    53       3.53     0.0009
SO2                                    0.0590000004           0        .      .          .          .
O3                                                     -6.1509   0.5919     53     -10.39     <.0001
Cultivar                    Forrest                    -0.04454  0.04773    53      -0.93     0.3550
Cultivar                    William                          0        .      .          .          .
STRESS*Cultivar STRESSED    Forrest                     0.1453   0.06751    53       2.15     0.0360
STRESS*Cultivar STRESSED    William                          0        .      .          .          .
STRESS*Cultivar WELL-WAT    Forrest                          0        .      .          .          .
STRESS*Cultivar WELL-WAT    William                          0        .      .          .          .


Type 3 Tests of Fixed Effects
                      Num      Den
Effect                 DF       DF     F Value     Pr > F
STRESS                  1       53        9.75     0.0029
SO2                     2       53        8.78     0.0005
O3                      1       53      107.99     <.0001
Cultivar                1       53        0.69     0.4089
STRESS*Cultivar         1       53        4.63     0.0360


Least Squares Means
                                                        Standard
Effect          STRESS      Cultivar   SO2           Estimate    Error      DF    t Value    Pr > |t|
STRESS          STRESSED                               8.1267    0.02387    53     340.50     <.0001
STRESS          WELL-WAT                               8.2321    0.02387    53     344.92     <.0001
SO2                                    0.0044999998     8.2335    0.02923    53     281.67     <.0001
SO2                                    0.0170000009     8.2252    0.02923    53     281.39     <.0001
SO2                                    0.0590000004     8.0795    0.02923    53     276.40     <.0001
Cultivar                    Forrest                     8.1934    0.02387    53     343.30     <.0001
Cultivar                    William                     8.1653    0.02387    53     342.12     <.0001
STRESS*Cultivar STRESSED    Forrest                     8.1771    0.03375    53     242.26     <.0001
STRESS*Cultivar STRESSED    William                     8.0763    0.03375    53     239.28     <.0001
STRESS*Cultivar WELL-WAT    Forrest                     8.2098    0.03375    53     243.23     <.0001
STRESS*Cultivar WELL-WAT    William                     8.2543    0.03375    53     244.55     <.0001



Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model
Post hoc adjustment with macro by Arnold Saxton


Effect=STRESS ADJUSTMENT=Tukey(P<.05) bygroup=1
Obs     STRESS                SO2    Cultivar     Estimate     StdErr     MSGROUP
  1     WELL-WAT               _                    8.2321     0.02387       A
  2     STRESSED               _                    8.1267     0.02387       B


Effect=SO2 ADJUSTMENT=Tukey(P<.05) bygroup=2
Obs     STRESS                SO2    Cultivar     Estimate     StdErr     MSGROUP
  3                  0.0044999998                   8.2335     0.02923       A
  4                  0.0170000009                   8.2252     0.02923       A
  5                  0.0590000004                   8.0795     0.02923       B


Effect=Cultivar ADJUSTMENT=Tukey(P<.05) bygroup=3
Obs     STRESS                SO2    Cultivar     Estimate     StdErr     MSGROUP
  6                           _      Forrest        8.1934     0.02387       A
  7                           _      William        8.1653     0.02387       A


Effect=STRESS*Cultivar ADJUSTMENT=Tukey(P<.05) bygroup=4
Obs     STRESS                SO2    Cultivar     Estimate     StdErr     MSGROUP
  8     WELL-WAT               _     William        8.2543     0.03375       A
  9     WELL-WAT               _     Forrest        8.2098     0.03375       A
 10     STRESSED               _     Forrest        8.1771     0.03375       AB
 11     STRESSED               _     William        8.0763     0.03375       B



728         proc univariate data=resids plot normal; var resid; run;
NOTE: The PROCEDURE UNIVARIATE printed page 6.
NOTE: PROCEDURE UNIVARIATE used (Total process time):
      real time              0.34 seconds
      cpu time               0.15 seconds
```

```
The UNIVARIATE Procedure
Variable:  Resid

Moments
N                            60    Sum Weights                 60
Mean                          0    Sum Observations             0
Std Deviation        0.12389845    Variance            0.01535083
Skewness             -0.0289145    Kurtosis            0.86612602
Uncorrected SS       0.90569877    Corrected SS        0.90569877
Coeff Variation               .    Std Error Mean      0.01599522


Basic Statistical Measures
     Location                 Variability
Mean      0.00000    Std Deviation          0.12390
Median   -0.00250    Variance               0.01535
Mode         .       Range                  0.64632
                     Interquartile Range    0.14003


Tests for Location: Mu0=0
Test            -Statistic-     -----p Value------
Student's t     t        0    Pr > |t|     1.0000
Sign            M       -1    Pr >= |M|    0.8974
Signed Rank     S       11    Pr >= |S|    0.9363


Tests for Normality
Test                 --Statistic---    -----p Value------
Shapiro-Wilk         W    0.980831     Pr < W       0.4647
Kolmogorov-Smirnov   D    0.098054     Pr > D      >0.1500
Cramer-von Mises     W-Sq 0.05966      Pr > W-Sq   >0.2500
Anderson-Darling     A-Sq 0.41113      Pr > A-Sq   >0.2500


Quantiles (Definition 5)
Quantile         Estimate
100% Max       0.33524950
99%            0.33524950
95%            0.19255790
90%            0.14170991
75% Q3         0.07198608
50% Median    -0.00249791
25% Q1        -0.06804495
10%           -0.15284231
5%            -0.21196433
1%            -0.31107206
0% Min        -0.31107206


Extreme Observations
------Lowest------        ------Highest-----
    Value      Obs          Value      Obs
-0.311072       11       0.170023       48
-0.301015        5       0.175961       37
-0.212743       29       0.209155       15
-0.211186       18       0.294858        4
-0.195867       34       0.335249       23

  Stem Leaf  Boxplot                 Normal Probability Plot
     3 4                 1    0        0.325+                                   * +
     2 9                 1    0            |                                  * ++++
     2 1                 1    |            |                                 *+++
     1 78                2    |            |                               +*+*
     1 2244              4    |            |                             ++***
     0 555566677788888  15 +-----+        |                         *******
     0 02334             5  |  +  |        |                       +****
    -0 4333221000       10 *-----*        |                      *****
    -0 99887766655      11 +-----+        |                 *****
    -1 4311              4    |            |                ***+
    -1 6                 1    |            |             ++**
    -2 110               3    |            |         +++**
    -2                            |        | ++++
    -3 10                2    0   -0.325++ *    *
       ----+----+----+----+          +----+----+----+----+----+----+----+----+----+----+
    Multiply Stem.Leaf by 10**-1              -2        -1         0        +1        +2
```
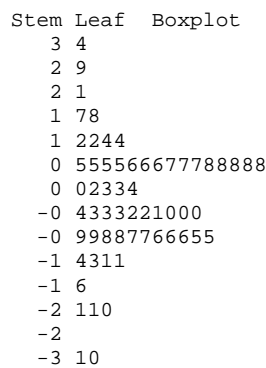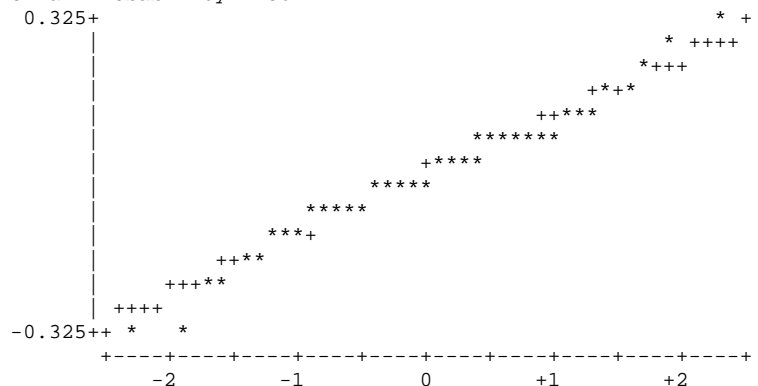
```
729          options ps=52 ls=111;
730          proc plot data=resids; plot resid*pred; run;
731          options ps=512 ls=132;
NOTE: There were 60 observations read from the data set WORK.RESIDS.
NOTE: The PROCEDURE PLOT printed page 7.
NOTE: PROCEDURE PLOT used (Total process time):
      real time           0.27 seconds
      cpu time            0.11 seconds
```

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model
Post hoc adjustment with macro by Arnold Saxton

                     Plot of Resid*Pred.   Legend: A = 1 obs, B = 2 obs, etc.
 Resid |
       |
   0.4 +
       |
       |
       |                                                A
   0.3 +                                                                    A
       |
       |
       |
   0.2 +                                                       A
       |                          A          A
       |                    A          A
       |                               A                                          A
   0.1 +
       |                   A        A        A        A           AA       AAA  A A
       |                 A             A      A A          A
       |                                          B           A
   0.0 +                      A         A   A                      A       A        A
       |              A                                                            A
       |          A                A   AA            A A        A
       |      A              A A  A A           A A           A                 A
  -0.1 +   A              A            A                A
       |
       |                 A
       |                                                          A
  -0.2 +                          A    A
       |        A
       |
       |
  -0.3 +                            A                      A
       |
       |
       |
  -0.4 +
       |
       ---+----------+----------+----------+----------+----------+----------+----------+----------+----------+----------+--
        7.7        7.8        7.9        8.0        8.1        8.2        8.3        8.4        8.5        8.6
                                                  Pred
```

```
733          proc print data=mmm;
734              TITLE3 'LSMeans output dataset of estimates';
735          run;
NOTE: There were 11 observations read from the data set WORK.MMM.
NOTE: The PROCEDURE PRINT printed page 8.
NOTE: PROCEDURE PRINT used (Total process time):
      real time           0.25 seconds
      cpu time            0.10 seconds
```

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model
LSMeans output dataset of estimates
```
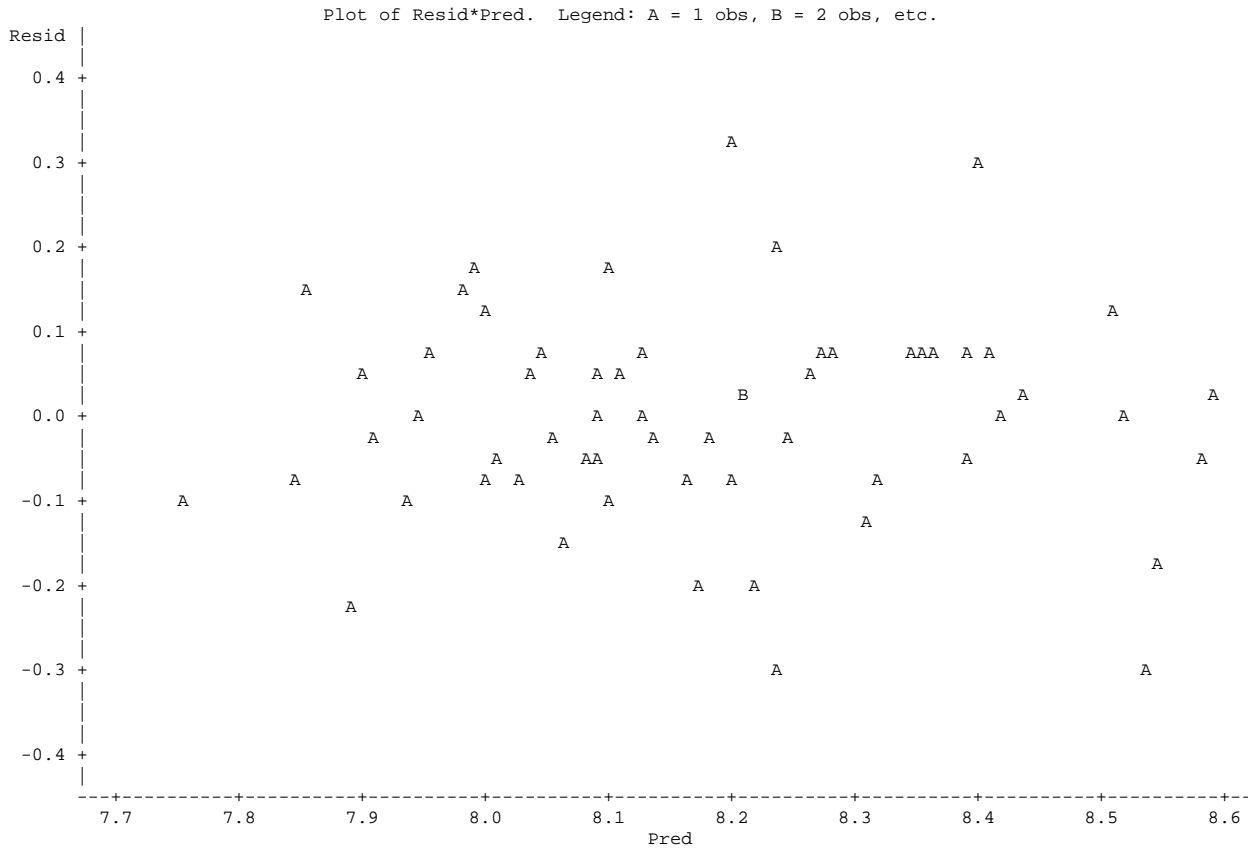
Obs	Effect	STRESS	SO2	Cultivar	Estimate	StdErr	DF	tValue	Probt
1	STRESS	STRESSED	_		8.1267	0.02387	53	340.50	<.0001
2	STRESS	WELL-WAT	_		8.2321	0.02387	53	344.92	<.0001
3	SO2		0.0044999998		8.2335	0.02923	53	281.67	<.0001
4	SO2		0.0170000009		8.2252	0.02923	53	281.39	<.0001
5	SO2		0.0590000004		8.0795	0.02923	53	276.40	<.0001
6	Cultivar			_ Forrest	8.1934	0.02387	53	343.30	<.0001
7	Cultivar			_ William	8.1653	0.02387	53	342.12	<.0001
8	STRESS*Cultivar	STRESSED	_	Forrest	8.1771	0.03375	53	242.26	<.0001
9	STRESS*Cultivar	STRESSED	_	William	8.0763	0.03375	53	239.28	<.0001
10	STRESS*Cultivar	WELL-WAT	_	Forrest	8.2098	0.03375	53	243.23	<.0001
11	STRESS*Cultivar	WELL-WAT	_	William	8.2543	0.03375	53	244.55	<.0001

```
737          data STRESS; set mmm; format estimate f5.1; if effect='STRESS'; run;
NOTE: There were 11 observations read from the data set WORK.MMM.
NOTE: The data set WORK.STRESS has 2 observations and 9 variables.
NOTE: DATA statement used (Total process time):
      real time              0.01 seconds
      cpu time               0.02 seconds
738          data SO2; set mmm; format estimate f5.1; if effect='SO2'; run;
NOTE: There were 11 observations read from the data set WORK.MMM.
NOTE: The data set WORK.SO2 has 3 observations and 9 variables.
NOTE: DATA statement used (Total process time):
      real time              0.01 seconds
      cpu time               0.02 seconds
739          data Cultivar; set mmm; format estimate f5.1; if effect='Cultivar'; run;
NOTE: There were 11 observations read from the data set WORK.MMM.
NOTE: The data set WORK.CULTIVAR has 2 observations and 9 variables.
NOTE: DATA statement used (Total process time):
      real time              0.00 seconds
      cpu time               0.01 seconds
740          data STRESS_Cultivar; set mmm; format estimate f5.1; if effect='STRESS*Cultivar';
run;
NOTE: There were 11 observations read from the data set WORK.MMM.
NOTE: The data set WORK.STRESS_CULTIVAR has 4 observations and 9 variables.
NOTE: DATA statement used (Total process time):
      real time              0.00 seconds
      cpu time               0.01 seconds
741
742          options ps=52 ls=99 nolabel;
743          TITLE3 'Graphics';
744          proc chart data=STRESS; vbar STRESS / sumvar=estimate; run;
NOTE: The PROCEDURE CHART printed page 9.
NOTE: PROCEDURE CHART used (Total process time):
      real time              0.22 seconds
      cpu time               0.07 seconds


Chapter 14 : Soybean Yield study
Unreplicated multifactor study – reduced model
Graphics

Estimate Sum
         |        *****        *****
  8.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  7.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  6.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  5.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  4.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  3.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  2.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
  1.0   +        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         |        *****        *****
         --------------------------------
              STRESSED    WELL-WAT
                    STRESS
```
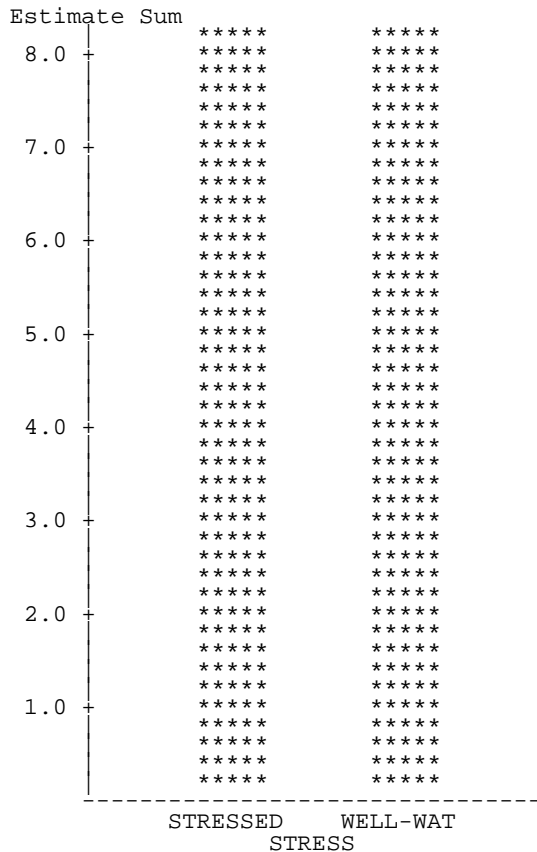
```
745        proc chart data=SO2; vbar SO2 / sumvar=estimate; run;
NOTE: The PROCEDURE CHART printed page 10.
NOTE: PROCEDURE CHART used (Total process time):
      real time            0.27 seconds
      cpu time             0.12 seconds
746        proc chart data=Cultivar; vbar Cultivar / sumvar=estimate; run;
NOTE: The PROCEDURE CHART printed page 11.
NOTE: PROCEDURE CHART used (Total process time):
      real time            0.23 seconds
      cpu time             0.08 seconds
```
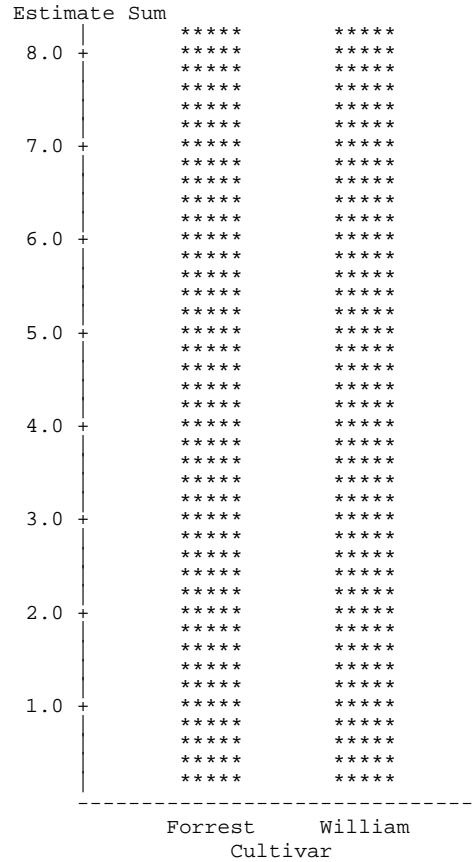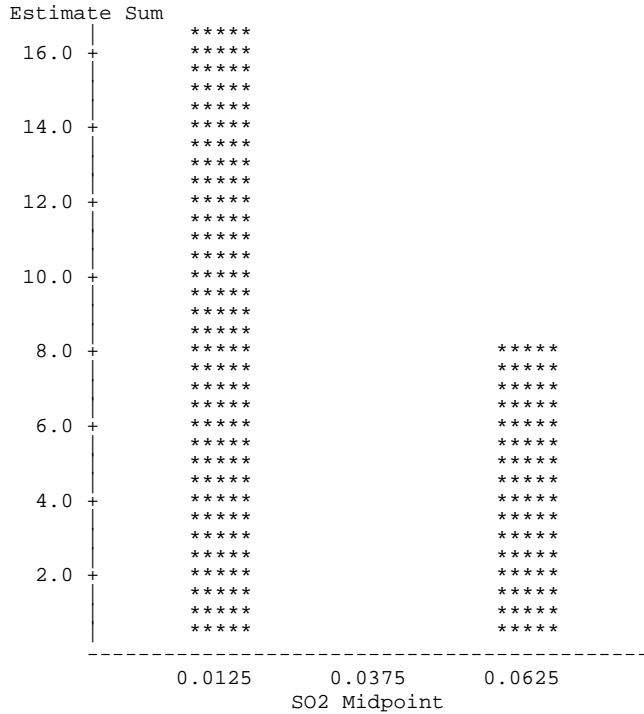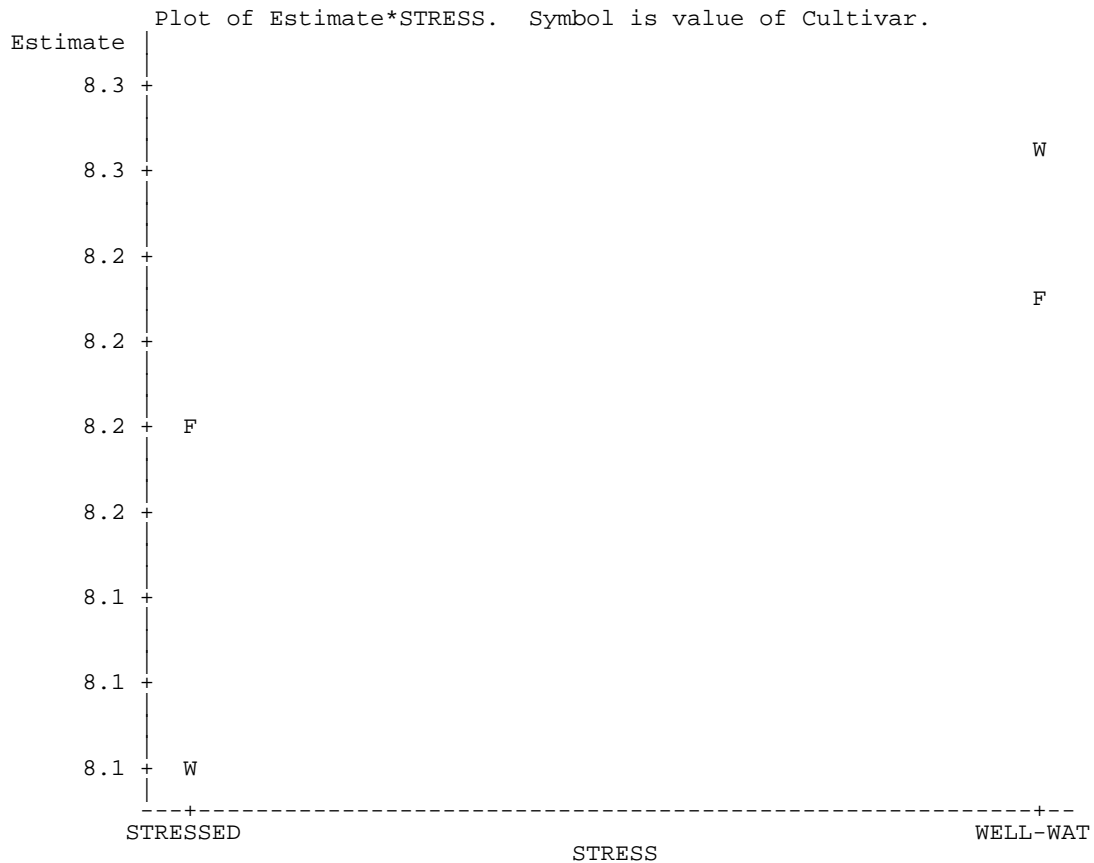
```
Estimate Sum                                    Estimate Sum
     |          *****                                |          *****       *****
16.0 +          *****                           8.0 +          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
14.0 +          *****                           7.0 +          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
12.0 +          *****                                |          *****       *****
     |          *****                           6.0 +          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
10.0 +          *****                                |          *****       *****
     |          *****                           5.0 +          *****       *****
     |          *****                                |          *****       *****
     |          *****                                |          *****       *****
 8.0 +          *****            *****               |          *****       *****
     |          *****            *****               |          *****       *****
     |          *****            *****          4.0 +          *****       *****
     |          *****            *****               |          *****       *****
 6.0 +          *****            *****               |          *****       *****
     |          *****            *****               |          *****       *****
     |          *****            *****          3.0 +          *****       *****
     |          *****            *****               |          *****       *****
 4.0 +          *****            *****               |          *****       *****
     |          *****            *****               |          *****       *****
     |          *****            *****          2.0 +          *****       *****
     |          *****            *****               |          *****       *****
 2.0 +          *****            *****               |          *****       *****
     |          *****            *****               |          *****       *****
     |          *****            *****          1.0 +          *****       *****
     |          *****            *****               |          *****       *****
     ---------------------------------------         |          *****       *****
       0.0125      0.0375     0.0625                 |          *****       *****
              SO2 Midpoint                           -------------------------------
                                                       Forrest     William
                                                              Cultivar
```

```
748        proc plot data=STRESS_Cultivar; plot estimate * stress = cultivar;
749        run;
750
NOTE: There were 4 observations read from the data set WORK.STRESS_CULTIVAR.
NOTE: The PROCEDURE PLOT printed page 12.
NOTE: PROCEDURE PLOT used (Total process time):
      real time            0.33 seconds
      cpu time             0.17 seconds
```

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model
Graphics

                    Plot of Estimate*STRESS.  Symbol is value of Cultivar.
         Estimate |
                  |
           8.3  +
                  |
                  |
                  |
           8.3  +                                                            W
                  |
                  |
                  |
           8.2  +
                  |
                  |                                                           F
                  |
           8.2  +
                  |
                  |
                  |
           8.2  +   F
                  |
                  |
                  |
           8.2  +
                  |
                  |
                  |
           8.1  +
                  |
                  |
                  |
           8.1  +
                  |
                  |
                  |
           8.1  +   W
                  |
                  ---+-------------------------------------------------------+--
                    STRESSED                                              WELL-WAT
                                            STRESS
```

```
751       proc sort data=soybean; by cultivar; run;
NOTE: There were 60 observations read from the data set WORK.SOYBEAN.
NOTE: The data set WORK.SOYBEAN has 60 observations and 8 variables.
NOTE: PROCEDURE SORT used (Total process time):
      real time          0.03 seconds
      cpu time           0.03 seconds
752       PROC mixed DATA=Soybean cl covtest;  by cultivar;
753           class STRESS SO2;
754           Title2 'Unreplicated multifactor study - reduced model';
755           MODEL LogYield = STRESS | SO2 | O3 / outp=resids solution;
756           lsmeans STRESS | SO2 / pdiff adjust=tukey;
757       run;
NOTE: The data set WORK.RESIDS has 60 observations and 15 variables.
NOTE: The PROCEDURE MIXED printed pages 13-20.
NOTE: PROCEDURE MIXED used (Total process time):
      real time           1.02 seconds
      cpu time            0.55 seconds
```

The program above will cause the analyses to be run separately for each cultivar. These analyses will no
   longer have the power gained from pooling the variances across cultivars and not test of cultivar
   interactions can be done. Note that there is an apparent stress by cultivar interaction effect
   above.

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model


Cultivar=Forrest


The Mixed Procedure
Model Information
Data Set                    WORK.SOYBEAN
Dependent Variable          LogYield
Covariance Structure        Diagonal
Estimation Method           REML
Residual Variance Method    Profile
Fixed Effects SE Method     Model-Based
Degrees of Freedom Method   Residual


Class Level Information
Class     Levels   Values
STRESS       2     STRESSED WELL-WAT
SO2          3     0.0044999998 0.0170000009 0.0590000004


Dimensions
Covariance Parameters          1
Columns in X                  24
Columns in Z                   0
Subjects                       1
Max Obs Per Subject           30


Number of Observations
Number of Observations Read           30
Number of Observations Used           30
Number of Observations Not Used        0


Covariance Parameter Estimates
                      Standard      Z
Cov Parm    Estimate     Error    Value      Pr Z     Alpha      Lower      Upper
Residual     0.02340  0.007799     3.00    0.0013      0.05    0.01336    0.05117


Fit Statistics
-2 Res Log Likelihood         -39.9
AIC (smaller is better)       -37.9
AICC (smaller is better)      -37.6
BIC (smaller is better)       -37.0


Solution for Fixed Effects
                                           Standard
Effect          STRESS      SO2           Estimate      Error    DF   t Value   Pr > |t|
Intercept                                   8.6529     0.1663    18     52.02    <.0001
STRESS          STRESSED                    -0.2106     0.2353    18     -0.90    0.3825
STRESS          WELL-WAT                          0          .     .         .         .
SO2                         0.0044999998    -0.1839     0.2353    18     -0.78    0.4445
SO2                         0.0170000009    -0.2564     0.2353    18     -1.09    0.2901
SO2                         0.0590000004          0          .     .         .         .
STRESS*SO2      STRESSED    0.0044999998     0.3266     0.3327    18      0.98    0.3393
STRESS*SO2      STRESSED    0.0170000009     0.4905     0.3327    18      1.47    0.1577
STRESS*SO2      STRESSED    0.0590000004          0          .     .         .         .
STRESS*SO2      WELL-WAT    0.0044999998          0          .     .         .         .
STRESS*SO2      WELL-WAT    0.0170000009          0          .     .         .         .
STRESS*SO2      WELL-WAT    0.0590000004          0          .     .         .         .
O3                                          -7.7927     2.3992    18     -3.25    0.0045
O3*STRESS       STRESSED                     2.3301     3.3930    18      0.69    0.5010
O3*STRESS       WELL-WAT                          0          .     .         .         .
O3*SO2                      0.0044999998     3.4294     3.3930    18      1.01    0.3255
O3*SO2                      0.0170000009     5.8826     3.3930    18      1.73    0.1001
O3*SO2                      0.0590000004          0          .     .         .         .
O3*STRESS*SO2   STRESSED    0.0044999998    -3.3214     4.7984    18     -0.69    0.4977
O3*STRESS*SO2   STRESSED    0.0170000009    -8.1546     4.7984    18     -1.70    0.1065
O3*STRESS*SO2   STRESSED    0.0590000004          0          .     .         .         .
O3*STRESS*SO2   WELL-WAT    0.0044999998          0          .     .         .         .
O3*STRESS*SO2   WELL-WAT    0.0170000009          0          .     .         .         .
O3*STRESS*SO2   WELL-WAT    0.0590000004          0          .     .         .         .
```

```
Type 3 Tests of Fixed Effects
                      Num     Den
Effect                 DF      DF    F Value    Pr > F
STRESS                  1      18      0.21     0.6548
SO2                     2      18      0.01     0.9923
STRESS*SO2              2      18      1.13     0.3459
O3                      1      18     30.81     <.0001
O3*STRESS               1      18      0.58     0.4552
O3*SO2                  2      18      0.37     0.6959
O3*STRESS*SO2           2      18      1.46     0.2583
```

```
Least Squares Means                                      Standard
Effect        STRESS      SO2             Estimate     Error     DF    t Value    Pr > |t|
STRESS        STRESSED                     8.1771      0.03950   18    207.04     <.0001
STRESS        WELL-WAT                     8.2098      0.03950   18    207.87     <.0001
SO2                       0.0044999998     8.2199      0.04837   18    169.93     <.0001
SO2                       0.0170000009     8.2317      0.04837   18    170.18     <.0001
SO2                       0.0590000004     8.1287      0.04837   18    168.05     <.0001
STRESS*SO2    STRESSED    0.0044999998     8.2465      0.06841   18    120.55     <.0001
STRESS*SO2    STRESSED    0.0170000009     8.1876      0.06841   18    119.69     <.0001
STRESS*SO2    STRESSED    0.0590000004     8.0971      0.06841   18    118.37     <.0001
STRESS*SO2    WELL-WAT    0.0044999998     8.1932      0.06841   18    119.77     <.0001
STRESS*SO2    WELL-WAT    0.0170000009     8.2758      0.06841   18    120.98     <.0001
STRESS*SO2    WELL-WAT    0.0590000004     8.1604      0.06841   18    119.29     <.0001
```

```
Differences ofLeast Squares Means                                          Standard
Effect        STRESS      SO2              _STRESS    _SO2             Estimate    Error     DF   t Value
STRESS        STRESSED                     WELL-WAT                    -0.03274    0.05585   18    -0.59
SO2                       0.0044999998                0.0170000009     -0.01179    0.06841   18    -0.17
SO2                       0.0044999998                0.0590000004      0.09114    0.06841   18     1.33
SO2                       0.0170000009                0.0590000004      0.1029     0.06841   18     1.50
STRESS*SO2    STRESSED    0.0044999998     STRESSED   0.0170000009      0.05896    0.09674   18     0.61
STRESS*SO2    STRESSED    0.0044999998     STRESSED   0.0590000004      0.1495     0.09674   18     1.54
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0044999998      0.05331    0.09674   18     0.55
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0170000009     -0.02923    0.09674   18    -0.30
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0590000004      0.08613    0.09674   18     0.89
STRESS*SO2    STRESSED    0.0170000009     STRESSED   0.0590000004      0.09049    0.09674   18     0.94
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0044999998     -0.00565    0.09674   18    -0.06
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0170000009     -0.08819    0.09674   18    -0.91
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0590000004      0.02717    0.09674   18     0.28
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0044999998     -0.09614    0.09674   18    -0.99
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0170000009     -0.1787     0.09674   18    -1.85
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0590000004     -0.06333    0.09674   18    -0.65
STRESS*SO2    WELL-WAT    0.0044999998     WELL-WAT   0.0170000009     -0.08254    0.09674   18    -0.85
STRESS*SO2    WELL-WAT    0.0044999998     WELL-WAT   0.0590000004      0.03282    0.09674   18     0.34
STRESS*SO2    WELL-WAT    0.0170000009     WELL-WAT   0.0590000004      0.1154     0.09674   18     1.19
```

```
Differences ofLeast Squares Means
Effect        STRESS      SO2              _STRESS    _SO2             Pr > |t|   Adjustment    Adj P
STRESS        STRESSED                     WELL-WAT                     0.5651    Tukey        0.5651
SO2                       0.0044999998                0.0170000009      0.8651    Tukey        0.9838
SO2                       0.0044999998                0.0590000004      0.1994    Tukey        0.3963
SO2                       0.0170000009                0.0590000004      0.1498    Tukey        0.3123
STRESS*SO2    STRESSED    0.0044999998     STRESSED   0.0170000009      0.5498    Tukey        0.9889
STRESS*SO2    STRESSED    0.0044999998     STRESSED   0.0590000004      0.1398    Tukey        0.6419
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0044999998      0.5883    Tukey        0.9930
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0170000009      0.7660    Tukey        0.9996
STRESS*SO2    STRESSED    0.0044999998     WELL-WAT   0.0590000004      0.3850    Tukey        0.9440
STRESS*SO2    STRESSED    0.0170000009     STRESSED   0.0590000004      0.3620    Tukey        0.9319
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0044999998      0.9541    Tukey        1.0000
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0170000009      0.3740    Tukey        0.9385
STRESS*SO2    STRESSED    0.0170000009     WELL-WAT   0.0590000004      0.7820    Tukey        0.9997
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0044999998      0.3335    Tukey        0.9140
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0170000009      0.0812    Tukey        0.4629
STRESS*SO2    STRESSED    0.0590000004     WELL-WAT   0.0590000004      0.5210    Tukey        0.9848
STRESS*SO2    WELL-WAT    0.0044999998     WELL-WAT   0.0170000009      0.4047    Tukey        0.9528
EXRSS*SO2     WELL-WAT    0.0044999998     WELL-WAT   0.0590000004      0.7384    Tukey        0.9993
STRESS*SO2    WELL-WAT    0.0170000009     WELL-WAT   0.0590000004      0.2486    Tukey        0.8347
```

```
Chapter 14 : Soybean Yield study
Unreplicated multifactor study - reduced model


Cultivar=William


The Mixed Procedure
Model Information
Data Set                    WORK.SOYBEAN
Dependent Variable          LogYield
Covariance Structure        Diagonal
Estimation Method           REML
Residual Variance Method    Profile
Fixed Effects SE Method     Model-Based
Degrees of Freedom Method   Residual


Class Level Information
Class      Levels   Values
STRESS        2     STRESSED WELL-WAT
SO2           3     0.0044999998 0.0170000009 0.0590000004


Dimensions
Covariance Parameters          1
Columns in X                  24
Columns in Z                   0
Subjects                       1
Max Obs Per Subject           30


Number of Observations
Number of Observations Read           30
Number of Observations Used           30
Number of Observations Not Used        0


Covariance Parameter Estimates
                        Standard       Z
Cov Parm    Estimate      Error     Value      Pr Z     Alpha      Lower       Upper
Residual     0.01324    0.004415     3.00     0.0013     0.05     0.007562    0.02896


Fit Statistics
-2 Res Log Likelihood          -50.1
AIC (smaller is better)        -48.1
AICC (smaller is better)       -47.9
BIC (smaller is better)        -47.2


Solution for Fixed Effects
                                              Standard
Effect          STRESS      SO2          Estimate     Error     DF   t Value   Pr > |t|
Intercept                                  8.5909    0.1252     18    68.64    <.0001
STRESS          STRESSED                  -0.1840    0.1770     18    -1.04    0.3124
STRESS          WELL-WAT                        0         .      .        .         .
SO2                         0.0044999998    0.2927    0.1770     18     1.65    0.1156
SO2                         0.0170000009    0.1366    0.1770     18     0.77    0.4504
SO2                         0.0590000004         0         .      .        .         .
STRESS*SO2      STRESSED    0.0044999998   -0.2589    0.2503     18    -1.03    0.3147
STRESS*SO2      STRESSED    0.0170000009   0.002360    0.2503     18     0.01    0.9926
STRESS*SO2      STRESSED    0.0590000004         0         .      .        .         .
STRESS*SO2      WELL-WAT    0.0044999998         0         .      .        .         .
STRESS*SO2      WELL-WAT    0.0170000009         0         .      .        .         .
STRESS*SO2      WELL-WAT    0.0590000004         0         .      .        .         .
O3                                        -7.4449    1.8051     18    -4.12    0.0006
O3*STRESS       STRESSED                   0.05651    2.5527     18     0.02    0.9826
O3*STRESS       WELL-WAT                         0         .      .        .         .
O3*SO2                      0.0044999998   -0.6530    2.5527     18    -0.26    0.8010
O3*SO2                      0.0170000009    0.2203    2.5527     18     0.09    0.9322
O3*SO2                      0.0590000004         0         .      .        .         .
O3*STRESS*SO2   STRESSED    0.0044999998    3.0051    3.6101     18     0.83    0.4161
O3*STRESS*SO2   STRESSED    0.0170000009    1.1668    3.6101     18     0.32    0.7503
O3*STRESS*SO2   STRESSED    0.0590000004         0         .      .        .         .
O3*STRESS*SO2   WELL-WAT    0.0044999998         0         .      .        .         .
O3*STRESS*SO2   WELL-WAT    0.0170000009         0         .      .        .         .
O3*STRESS*SO2   WELL-WAT    0.0590000004         0         .      .        .         .
```

```
Type 3 Tests of Fixed Effects
                      Num    Den
Effect                DF     DF    F Value   Pr > F
STRESS                1      18    6.95      0.0167
SO2                   2      18    0.98      0.3929
STRESS*SO2            2      18    0.72      0.5004
O3                    1      18    86.80     <.0001
O3*STRESS             1      18    0.96      0.3392
O3*SO2                2      18    0.14      0.8702
O3*STRESS*SO2         2      18    0.35      0.7079
```

```
Least Squares Means                                            Standard
Effect        STRESS      SO2              Estimate   Error     DF   t Value   Pr > |t|
STRESS        STRESSED                     8.0763     0.02971   18   271.80    <.0001
STRESS        WELL-WAT                     8.2543     0.02971   18   277.79    <.0001
SO2                       0.0044999998     8.2471     0.03639   18   226.61    <.0001
SO2                       0.0170000009     8.2187     0.03639   18   225.84    <.0001
SO2                       0.0590000004     8.0302     0.03639   18   220.65    <.0001
STRESS*SO2    STRESSED    0.0044999998     8.1224     0.05147   18   157.82    <.0001
STRESS*SO2    STRESSED    0.0170000009     8.1666     0.05147   18   158.68    <.0001
STRESS*SO2    STRESSED    0.0590000004     7.9400     0.05147   18   154.27    <.0001
STRESS*SO2    WELL-WAT    0.0044999998     8.3718     0.05147   18   162.66    <.0001
STRESS*SO2    WELL-WAT    0.0170000009     8.2709     0.05147   18   160.70    <.0001
STRESS*SO2    WELL-WAT    0.0590000004     8.1204     0.05147   18   157.78    <.0001
```

```
Differences ofLeast Squares Means                                       Standard
Effect        STRESS     SO2            _STRESS    _SO2           Estimate   Error     DF   t Value
STRESS        STRESSED                  WELL-WAT                  -0.1780    0.04202   18   -4.24
SO2                      0.0044999998              0.0170000009   0.02838    0.05147   18    0.55
SO2                      0.0044999998              0.0590000004   0.2169     0.05147   18    4.21
SO2                      0.0170000009              0.0590000004   0.1885     0.05147   18    3.66
STRESS*SO2    STRESSED   0.0044999998   STRESSED   0.0170000009   -0.04415   0.07279   18   -0.61
STRESS*SO2    STRESSED   0.0044999998   STRESSED   0.0590000004   0.1824     0.07279   18    2.51
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0044999998   -0.2493    0.07279   18   -3.43
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0170000009   -0.1484    0.07279   18   -2.04
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0590000004   0.002040   0.07279   18    0.03
STRESS*SO2    STRESSED   0.0170000009   STRESSED   0.0590000004   0.2266     0.07279   18    3.11
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0044999998   -0.2052    0.07279   18   -2.82
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0170000009   -0.1043    0.07279   18   -1.43
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0590000004   0.04619    0.07279   18    0.63
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0044999998   -0.4318    0.07279   18   -5.93
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0170000009   -0.3309    0.07279   18   -4.55
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0590000004   -0.1804    0.07279   18   -2.48
STRESS*SO2    WELL-WAT   0.0044999998   WELL-WAT   0.0170000009   0.1009     0.07279   18    1.39
STRESS*SO2    WELL-WAT   0.0044999998   WELL-WAT   0.0590000004   0.2514     0.07279   18    3.45
STRESS*SO2    WELL-WAT   0.0170000009   WELL-WAT   0.0590000004   0.1505     0.07279   18    2.07
```

```
Differences ofLeast Squares Means
Effect        STRESS     SO2            _STRESS    _SO2           Pr > |t|   Adjustment   Adj P
STRESS        STRESSED                  WELL-WAT                  0.0005     Tukey        0.0005
SO2                      0.0044999998              0.0170000009   0.5881     Tukey        0.8471
SO2                      0.0044999998              0.0590000004   0.0005     Tukey        0.0014
SO2                      0.0170000009              0.0590000004   0.0018     Tukey        0.0048
STRESS*SO2    STRESSED   0.0044999998   STRESSED   0.0170000009   0.5517     Tukey        0.9892
STRESS*SO2    STRESSED   0.0044999998   STRESSED   0.0590000004   0.0220     Tukey        0.1739
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0044999998   0.0030     Tukey        0.0304
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0170000009   0.0564     Tukey        0.3598
STRESS*SO2    STRESSED   0.0044999998   WELL-WAT   0.0590000004   0.9779     Tukey        1.0000
STRESS*SO2    STRESSED   0.0170000009   STRESSED   0.0590000004   0.0060     Tukey        0.0568
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0044999998   0.0114     Tukey        0.0996
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0170000009   0.1691     Tukey        0.7079
STRESS*SO2    STRESSED   0.0170000009   WELL-WAT   0.0590000004   0.5337     Tukey        0.9867
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0044999998   <.0001     Tukey        0.0002
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0170000009   0.0003     Tukey        0.0029
STRESS*SO2    STRESSED   0.0590000004   WELL-WAT   0.0590000004   0.0233     Tukey        0.1824
STRESS*SO2    WELL-WAT   0.0044999998   WELL-WAT   0.0170000009   0.1826     Tukey        0.7343
EXRESS*SO2    WELL-WAT   0.0044999998   WELL-WAT   0.0590000004   0.0028     Tukey        0.0287
STRESS*SO2    WELL-WAT   0.0170000009   WELL-WAT   0.0590000004   0.0534     Tukey        0.3460
```