ICARDA – JICA Training Program

Training Course:

Improving Agricultural Water Productivity (*with emphasis on rainfed production systems*)
24 April – 12 May 2016, ICARDA, Amman, Jordan

Topic:

Design and Analysis of Water Resources Experiments

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Schedule:
11:00 -13:30 h on 9 May 2016 (Monday)

Design and Analysis of Water Resources Experiments

1. Basic principles of experimental designs

2. Design and analysis of experiments in RCB

3. Design and analysis of two-factor factorial experiments in RCB

4. Design and analysis of split-plot experiments in RCB

5. Design and analysis of strip-plot experiments in RCB

1. Basic principles of experimental designs

- An experiment
- Basic elements of experimental design
- Requirements of a Good Experiment
- Fisher’s 3Rs: Basic principles
- Illustration through an RCBD
- Experimental Process

2. Design and analysis of experiments in RCB

- Analysis of Data from Designed Experiments
- Assumptions
- An example
- Genstat demonstration
  - Randomized plan
  - Analysis of data

BASIC PRINCIPLES OF EXPERIMENTAL DESIGNS

Resources:

Cochran, W.G. and Cox, G.M. (1957). *Experimental Designs*, (New York: John Wiley and Sons Inc)

Cox, D. R. (1958). *Planning of Experiments* . (New York: John Wiley and Sons Inc)

Kempthorne, O., 1983. *The Design and Analysis of Experiments*. R.E. Krieger Publishing Co., Malabar, Florida.

Gomez, K.A. & Gomez, A.A. 1984. *Statistical procedures for agricultural research*. (New York: John Wiley and Sons Inc)

Hinkelmann, K.H., Kempthorne, O., 2005. *Design and Analysis of Experiments*. Volume 2: Advanced Experimental Design. John Wiley & Sons, New York.

An Example

- In agricultural field trials, an **objective** may be
    - to assess or compare a number of varieties of wheat, or a number of fertilizer treatments, or a number of systems of land and water management, or a number of disease control methods etc.
- The area allotted for the trial is generally divided into plots and the treatments (e.g. varieties) are allotted to these plots -- one treatment to one plot basis.
- The crop response (in terms of yield, days to fifty percent flowering, etc) is measured.
- These observations, particularly their variability, form the basis of comparisons of the varieties or treatments.

Treatments:

The different factors or procedures intended to create variation in a response (responses) in an experiment, e.g. varieties, fertilizers, etc.

Experimental Unit:

Smallest division of experimental area (material) such that any two units may receive different treatments. For example, plots (but not samples in a plot).

Experimental Material:

Collection of all experimental units, the experimental area.

Variability in the response

- Even if we grow the same variety of a crop over all experimental units, the variation in the response may exist.

  Following may be the reasons.

  (i) There may be the systematic fertility trends or local periodic variation present in the field,

  (ii) Responses in neighbor plots are more similar in comparison to the distant plots,

  (iii) If the experiment is repeated over time and location, the variation in the mean response occurs.

- Experimental procedures are needed for separating precisely the variety effects (differences) from uncontrolled variation.

Requirements of a Good Experiment

Comparison of treatments should be free from systematic errors, estimates should have high precision, conclusion to be widely valid, uncertainties in the conclusion assessable, and the experimental arrangement simple and operationally convenient.

(a) Systematic Error

- Experimental units should differ in no systematic way.
- Units under one treatments should show only random differences from the units under any other treatments and
- should respond independently of one another.
- In the absence of this,
    i. possible variables be measured
    ii. and/or plot history be used to reflect the systematic difference.
- Randomization minimizes the influence of systematic errors.

(b) Precision:

- In the absence of systematic errors, the bias in treatment differences (contrasts) is from the random error.
- The magnitude of such error is measured by standard errors giving an idea of the precision of experiment. This depends on :

  (i) inherent variability, or the experimental variability and accuracy of the experimental work.

  (ii) number of experimental units.

  (iii) the design of experiments.

The standard error (SE or se) of mean is

$$\text{SE(mean)} = \frac{\sigma}{\sqrt{r}}$$

where σ = per plot error standard deviation,

r = the number of replications the mean is based on.

(c) Range of Validity:

Conclusions drawn from one or few experiments should be generalized or applied to some new conditions. Given the population of conditions/environments the proper sampling of conditions may be done for validation of the conclusions, or the experiment be conducted in wide range of conditions.

(d) Uncertainty:

The experiments should provide a valid (statistical) estimate of error (or standard error of the differences), to compute limits (confidence limits) for true differences of treatment effects and to perform the test of significance.

(e) Operational Convenience:

Easy operation for field preparation, preparing field books, seed packets preparation, and sorting packets for machine sowing, and measurements, etc.

Fisher's Principles of Experimentation

These are

- randomization,
- replication, and
- local control

also called Fisher's 3Rs for experimentation.

Randomization:

- random allotment of the treatments to the experimental unit

Treatments {1, 2, 3, 4, 5, 6, 7}

random assignment

Plot101	Plot102	Plot103	Plot104	Plot105	Plot106	Plot107
5	1	7	3	4	2	6

- Representative responses
- Validity of estimates of effects and errors
- Minimizes bias (effect of systematic errors) in presence of replications
- Test of significance (enhances random order in uncontrolled errors of any patterns)

NO

Treatments {1, 2, 3, 4, 5, 6, 7}

(Non random) Systematic assignment

Plot101	Plot102	Plot103	Plot104	Plot105	Plot106	Plot107
1	2	3	4	5	6	7

Replications

- The application of a treatment to more than one unit

T1	T2	T3

T1	T2	T3	T1	T2
T3	T2	T1	T3	T1
T1	T3	T2	T1	T3

Homogeneous experimental material

Experimental errors:

- <u>Variation in responses on the experimental units under the same treatment</u>

- We observe variation in the response even if the same treatment is applied on different experimental units.
- This variation, arising from chances causes/random error, is called happening due to experimental error (not any ‘mistake’ on experimenter’s part)
- To measure experimental error, we thus need more than one exp. unit receiving the same treatments

Such a variation would be required

- to measure precision of an estimate of a given treatment,

$$\text{SE(mean)} = \frac{\sigma}{\sqrt{r}}$$

- to compare two or more treatments

Such a variation could be used to determine number of replications for a set standard in terms of precision of treatment effect.

Formula:

$$r = \frac{\theta^2 t^2}{\varepsilon^2}$$

where

θ = coefficient of variation ($\frac{\sigma}{\mu}$)

t = critical value of t- distribution (r- 1 df) and approximated at 2 for 5% level of significance,

ε = maximum error set , $\left|\frac{\bar{x}-\mu}{\mu}\right|$, where $\bar{x}$ is sample mean expected from r- replications, μ is the population mean (unknown)

Local Control or Reduction of Error:

An accounting of systematic variation in the experimental material at

- design stage
- measurement /analysis stage

Consider a situation:

Experimental material is not fully homogeneous/heterogeneous

- possible to group in the experimental units in homogeneous groups called **blocks**
- the allocation of treatments to the units within groups is made through randomization.

- Account for variation due to groups/blocks

- This helps reduce the experimental error.

Randomized Complete Block Design (RCBD, RCB)

Fertility gradient

High	Medium	Low

Block 1	Block-2	Block-3
Plot101:	Plot201:	Plot301:
Plot102:	Plot202:	Plot302:
Plot103:	Plot203:	Plot303:
Plot104:	Plot204:	Plot304:
Plot105:	Plot205:	Plot305:
Plot106:	Plot206:	Plot306:
Plot107:	Plot207:	Plot307:

Field-plot preparation

- Field
- Prepare/mark the blocks (Complete blocks are also called replicates)
- Prepare/mark the plots within each block

Randomization

- Randomly assign treatments to the plots within each blocks
- Carry out independent randomization for plots of each block

{1,2,3,4,5,6,7}

Randomize Randomize Randomize

Block 1		Block-2		Block-3	
Plot101:	3	Plot201:	7	Plot301:	3
Plot102:	7	Plot202:	6	Plot302: :	4
Plot103:	1	Plot203:	3	Plot303:	2
Plot104:	4	Plot204:	2	Plot304:	7
Plot105:	6	Plot205:	4	Plot305:	1
Plot106:	2	Plot206:	1	Plot306:	5
Plot107:	5	Plot207:	5	Plot307:	6

Experiment Process

Design of experiments

Experiment management
- Planting
- Crop husbandry
- Etc

Data collection

Data Entry

Data Management
    Transformation to units for analysis

Statistical Analysis

Presentation of results

Publication

Analysis of Data from Designed Experiments

Consider a certain response (y) being obtained on experimental units under the treatments applied according to a block design.

- Variability in the response generally form, the basis of analysis of treatment differences and the estimation of experimental error variation.

- A response model is needed

Response (data) = general mean
+ effect of blocking factor(s)
+ effect of treatment applied
+ experimental error

- ANOVA (Analysis of variance, AOV)
  A method which partitions the total variation in the response into the components (sources of variation) in the above model is called the analysis of variance (ANOVA).

- ANOVA assumptions:

  (i) additivity of factors effects

  (ii) constancy of error variance

  (iii) normality of experimental errors

  (iv) independence of experimental errors

An Example:

Data from a chickpea yield trial conducted at Helhadya, Aleppo, Syria, spring sown, 1995/96.

PLOT	REP	ENTRY	GYLD (kg/ha)
101	1	14	1147
102	1	15	1180
103	1	12	1153
104	1	10	1563
105	1	2	904
106	1	19	1208
107	1	4	1616
108	1	5	1535
109	1	18	1635
110	1	11	1420
111	1	13	1288
112	1	1	1482
113	1	21	1586
114	1	9	1922
115	1	7	1894
116	1	17	1633
117	1	6	1639
118	1	3	1357
119	1	20	1392
120	1	23	1651
121	1	24	2312
122	1	22	1949
123	1	8	1584
124	1	16	1420
201	2	12	1447
202	2	11	1365
203	2	13	1457

204	2	3	1345
205	2	23	1643
206	2	17	1667
207	2	6	1543
208	2	19	1290
209	2	21	1661
210	2	2	1104
211	2	5	1629
212	2	16	1416
213	2	9	1765
214	2	7	1682
215	2	24	1963
216	2	4	1880
217	2	15	1594
218	2	8	1796
219	2	20	1404
220	2	22	1776
221	2	1	1539
222	2	10	1759
223	2	18	1565
224	2	14	1329
301	3	5	1488
302	3	13	1310
303	3	22	1741
304	3	23	1790
305	3	6	1647
306	3	19	1343
307	3	10	1957
308	3	1	1406
309	3	7	1751
310	3	14	1298
311	3	16	1431
312	3	21	1553

313	3	17	1724
314	3	12	1335
315	3	4	1651
316	3	8	1531
317	3	15	1416
318	3	24	2043
319	3	2	1006
320	3	11	1290
321	3	9	1541
322	3	3	1263
323	3	18	1386
324	3	20	1224

ANALYSIS OF DATA

- **MENU driven**
- **Codes**

```
"One-way ANOVA (in Randomized Blocks)."

 BLOCK Rep
```

TREATMENTS Genotype

```
 COVARIATE "No Covariate"

ANOVA\
[PRINT=aovtable,information,means,%cv;\
FPROB=yes; PSE=lsd,means;\
LSDLEVEL=5]  YieldKgHa
```

1) Analysis of variance

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

Variate: YieldKgHa

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

Rep stratum                2      50990.      25495.    1.93

Rep.*Units* stratum
Genotype                  23    3942156.     171398.   12.97  <.001
Residual                  46     607884.      13215.

Total                     71    4601030.


* MESSAGE: the following units have large residuals.

Rep 1     *units* 21          217.   s.e. 92.
Rep 3     *units* 7           223.   s.e. 92.
```

2) ***** Tables of means *****

Variate: YieldKgHa

Grand mean 1531.

Genotype	1	2	3	4	5	6	7
	1476.	1005.	1322.	1716.	1551.	1610.	1776.

Genotype	8	9	10	11	12	13	14
	1637.	1743.	1760.	1358.	1312.	1352.	1258.

Genotype	15	16	17	18	19	20	21
	1397.	1422.	1675.	1529.	1280.	1340.	1600.

Genotype	22	23	24
	1822.	1695.	2106.

***** Standard errors of means *****

Table	Genotype
rep.	3
d.f.	46
e.s.e.	66.4

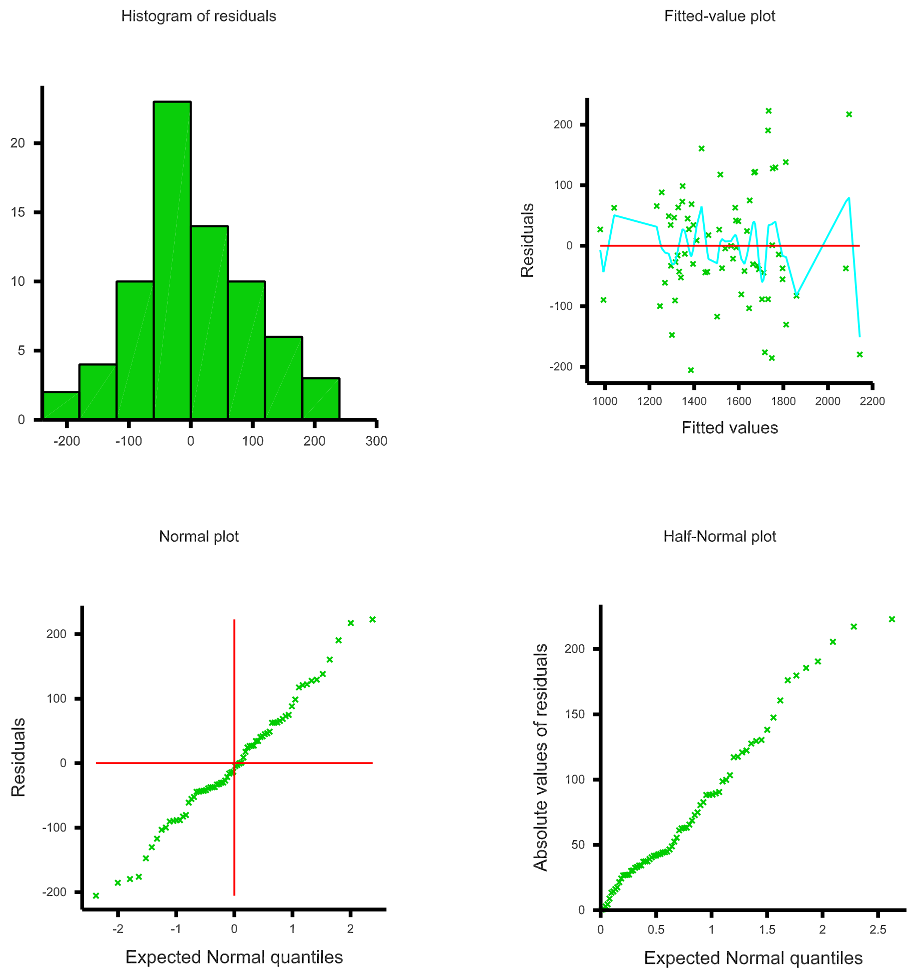
*** Least significant differences of means (5% level) ***

Table	Genotype
rep.	3
d.f.	46
l.s.d.	188.9

***** Stratum standard errors and coefficients of variation *****

Variate: YieldKgHa

Stratum	d.f.	s.e.	cv%
Rep	2	32.6	2.1
Rep.*Units*	46	115.0	7.5


Histogram of residuals
Fitted-value plot
Residuals
Fitted values
Normal plot
Residuals
Expected Normal quantiles
Half-Normal plot
Absolute values of residuals
Expected Normal quantiles

3. Presentation

Table 1. Mean yields of chickpea genotypes evaluated in spring sown International Yield Trial at Tel Hadya, Aleppo, Syria, 1995/96.

Genotype	Yield(kg/ha)
1	1476
2	1005
3	1322
4	1716
5	1551
6	1610
7	1776
8	1637
9	1743
10	1760
11	1358
12	1312
13	1352
14	1258
15	1397
16	1422
17	1675
18	1529
19	1280
20	1340
21	1600
22	1822
23	1695
24	2106
SE	±66
Grand mean	1531
CV%	7.5

Table 1. Mean yields of chickpea genotypes evaluated in spring sown International Yield Trial at Tel Hadya, Aleppo, Syria, 1995/96.

Genotype	Yield(t/ha)
1	1.48
2	1.00
3	1.32
4	1.72
5	1.55
6	1.61
7	1.78
8	1.64
9	1.74
10	1.76
11	1.36
12	1.31
13	1.35
14	1.26
15	1.40
16	1.42
17	1.67
18	1.53
19	1.28
20	1.34
21	1.60
22	1.82
23	1.69
24	2.11
SE	±0.66
Grand mean	1.53
CV%	7.5

3. Design and analysis of two-factor factorial experiments in randomized complete blocks

- Factors of Crop Productivity
- Approaches of evaluation of multi-factors
- An example
- Interaction
- Design: Randomization schema
- An experiment: Data
- Analysis
- Presentation

Factors/components of Crop Productivity

Crop (Germplasm)
- Variety/genotype (stable, high yielding)

Resource management
- Land preparation methods
- Seed treatments
- Date of planting
- Sowing/planting methods
- Spacing (plot geometry)
- Fertilizer rates
- Irrigation methods
- Others

Crop protection methods
- Disease control
- Insect control
- Weed control
- others

Approaches of evaluation of multi-factors

- Vary the level of one factor at a time, while keeping other factors fixed
    - No assessment of interactions

- Vary all the factors together, take all possible combinations
    - Too many combinations
    - Heterogeneous blocks/incomplete blocks
    - Confounding of effects

- Vary all the factors together, take a **fraction** of all possible combinations
    - Heterogeneous blocks/incomplete blocks
    - Confounding of effects

An example:

Two factors:

1) Variety (qualitative factor)

Labels	V_1	V_2	V_3
Levels	1	2	3
ordinal levels	1	2	3

2) Nitrogen (quantitative factor)

Labels	N_1	N_2	N_3	N_4
Levels(kg/ha)	0	30	60	90
Ordinal levels	1	2	3	4

Controls

1) Variety: V_1 = local variety
2) Nitrogen: N_1 = 0 kg/ha : no nitrogen

Combinations of Variety and Nitrogen: 3 x 4 =12

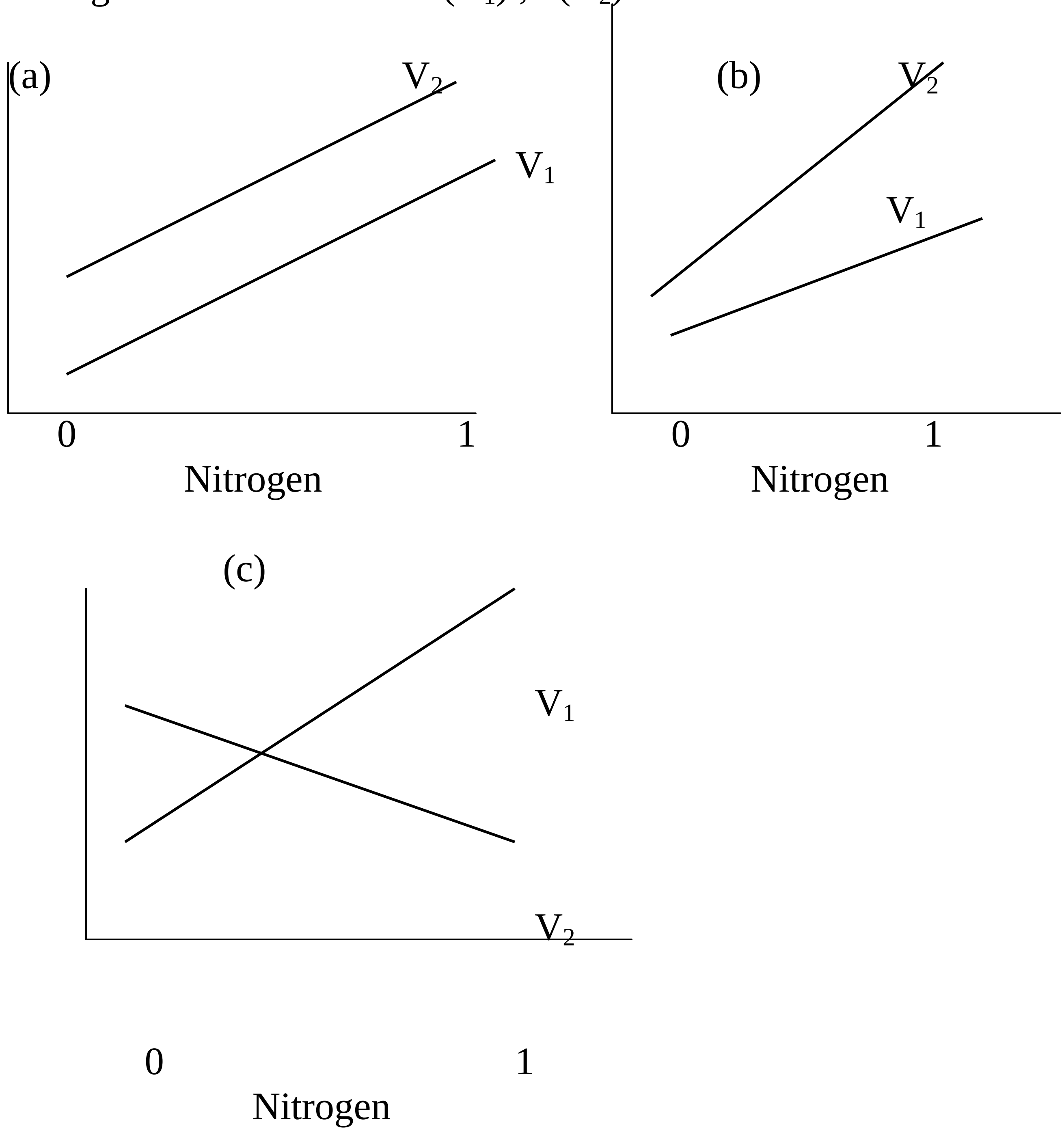
V_1N_1 V_1N_2 V_1N_3 V_1N_4

V_2N_1 V_2N_2 V_2N_3 V_2N_4

V_3N_1 V_3N_2 V_3N_3 V_3N_4

Interaction between two factors: A schema

Variety: labels: V_1 , V_2
Nitrogen: Levels/Labels: 0 (N_1) , 1(N_2)



(a): No interaction. (b, c): interactions

Treatments design (nature of the treatment factors)
Environmental/field design

Example:

Two factors: 1) Nitrogen (N): Labels: N_1, N_2, N_3, N_4
2) Wheat variety (V): V_1 , V_2 , V_3

Combinations of Nitrogen and Variety: 3 x 4 =12

V_1N_1	V_1N_2	V_1N_3	V_1N_4
V_2N_1	V_2N_2	V_2N_3	V_2N_4
V_3N_1	V_3N_2	V_3N_3	V_3N_4

Main effects	V
Main effects	N
Interaction	V x N

Experimental designs:

Treatment design:

All combinations of Nitrogen and the Variety

Field design: RCBD for the combinations of N and V

Schema:

Rep 1

N_3 V_2	N_1 V_3	N_2 V_2	N_1 V_1	N_4 V_2	N_3 V_1	N_2 V_3	N_1 V_2	N_4 V_3	N_2 V_1	N_3 V_3	N_4 V_1

Rep 2

Example 1: (details unknown)

Design: Two factors factorial in randomized complete blocks.

Factors: SeedRate: Seed rate (2 levels), SowDepth: sowing depth (4 levels), Rep: replications (3).

Variables: KGY: Grain yield (kg/ha), KST: Straw yield (kg/ha), KBio: Biomass (kg/ha)

Data

Rep	SowDepth	SeedRate	Kbio	KGY	KSt
1	1	1	11810	4735	7075
2	1	1	11850	4550	7300
3	1	1	8800	4010	4790
1	1	2	12790	4550	8240
2	1	2	12130	5100	7030
3	1	2	13440	4750	8690
1	2	1	13260	5540	7720
2	2	1	11405	4605	6800
3	2	1	10495	4200	6295
1	2	2	14390	5510	8880
2	2	2	11860	4640	7220
3	2	2	10640	4365	6275
1	3	1	10205	4505	5700
2	3	1	9680	5045	4635
3	3	1	10140	3795	6345
1	3	2	11285	4780	6505
2	3	2	10685	4560	6125
3	3	2	9450	4160	5290
1	4	1	8535	3925	4610
2	4	1	7790	3070	4720
3	4	1	6975	3710	3265
1	4	2	10010	4965	5045
2	4	2	9330	3630	5700
3	4	2	10610	4250	6360

Analysis of data on grain yield

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

Variate: KGY

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1773775.	886888.	4.78	
Rep.*Units* stratum					
SeedRate	1	531038.	531038.	2.86	0.113
SowDepth	3	2598921.	866307.	4.67	0.018
SeedRate.SowDepth	3	444554.	148185.	0.80	0.515
Residual	14	2596075.	185434.		
Total	23	7944362.			

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

Variate: KGY

Grand mean 4456.

SeedRate	1	2
	4308.	4605.

SowDepth	1	2	3	4
	4616.	4810.	4474.	3925.

SeedRate	SowDepth	1	2	3	4
1		4432.	4782.	4448.	3568.
2		4800.	4838.	4500.	4282.

*** Standard errors of means ***

Table	SeedRate	SowDepth	SeedRate SowDepth
rep.	12	6	3
d.f.	14	14	14
e.s.e.	124.3	175.8	248.6

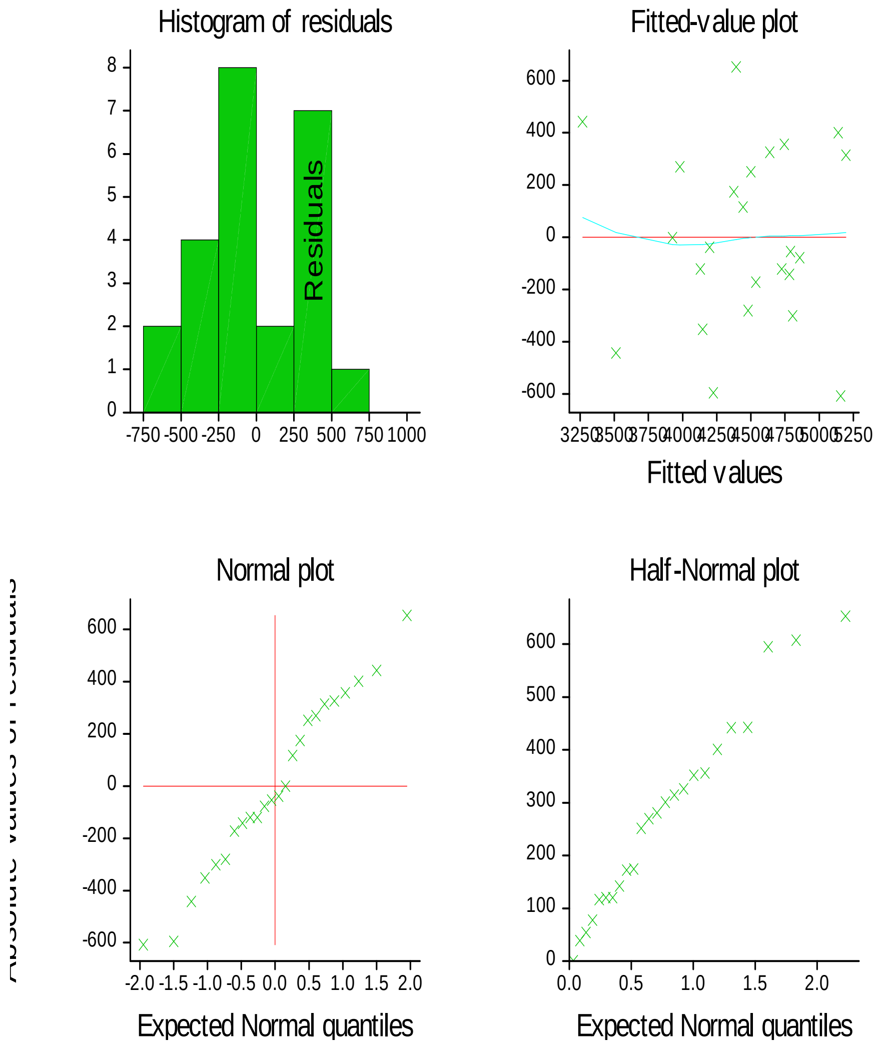
*** Least significant differences of means (5% level) ***

Table	SeedRate	SowDepth	SeedRate SowDepth
rep.	12	6	3
d.f.	14	14	14
l.s.d.	377.1	533.2	754.1

***** Stratum standard errors and coefficients of variation *****

Variate: KGY

Stratum	d.f.	s.e.	cv%
Rep	2	333.0	7.5
Rep.*Units*	14	430.6	9.7


Histogram of residuals
8
7
6
5
4
3
2
1
0
-750 -500 -250 0 250 500 750 1000
Residuals
Fitted-value plot
600
400
200
0
-200
-400
-600
3250 3500 3750 4000 4250 4500 4750 5000 5250
Fitted values
Normal plot
600
400
200
0
-200
-400
-600
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0
Expected Normal quantiles
Half-Normal plot
600
500
400
300
200
100
0
0.0 0.5 1.0 1.5 2.0
Expected Normal quantiles

Example 2:
An experiment was conducted on durum wheat (Cham 1 cultivar) to evaluate the response of nitrogen and phosphorus fertilizers in 4 levels of N (0, 40, 80, 120 kg N /ha as ammonium nitrate) and 4 levels of P (0, 20, 40, and 80 Kg P_2O_5 /ha as triple super-phosphate). The 16 combinations of N and P were randomly applied to the plots of RCBD with two replications.
The data on grain yield was analyzed and presented as follows.

Table 1. Cham-1 (a durum wheat cultivar) grain yields (t/ha) from four rates of nitrogen and four rates of phosphorus, Khan Shekhoun, Hama, 1989.

Nitrogen N (kg/ha)	P_2O_5 (kg/ha) 0	20	40	80	Mean
0	1.57	1.51	1.14	1.97	1.55
40	1.79	1.60	1.93	2.03	1.84
80	1.72	1.81	2.09	1.80	1.86
120	1.81	1.76	1.42	2.09	1.72
SE			±0.14		±0.071
Mean	1.72	1.67	1.65	1.97	1.75
SE			±0.071		

4. Design and Analysis of Split-plot Experiments in Randomized Complete Blocks

- Factors of Crop Productivity
- Approaches of evaluation of multi-factors
- An example
- Interaction
- Design: Randomization schema
- An experiment: Data
- Analysis
- Presentation

- Treatments design (nature of the treatment factors)
- Environmental/field design

Example:

Two factors: 1) Irrigation (I): Labels: I_1, I_2, I_3, I_4
2) Wheat variety (V): V_1 , V_2 , V_3

Combinations of Irrigation and Variety: 3 x 4 =12

V_1I_1	V_1I_2	V_1I_3	V_1I_4
V_2I_1	V_2I_2	V_2I_3	V_2I_4
V_3I_1	V_3I_2	V_3I_3	V_3I_4

Main effects	V
Main effects	I
Interaction	V x I

Experimental designs:

Option 1:

Treatment design:

All combinations of Irrigation and the cultivars

Field design: RCBD for the combinations of I and V

Schema:

Rep 1

I_3 V_2	I_1 V_3	I_2 V_2	I_1 V_1	I_4 V_2	I_3 V_1	I_2 V_3	I_1 V_2	I_4 V_3	I_2 V_1	I_3 V_3	I_4 V_1

Rep 2

Option 2:

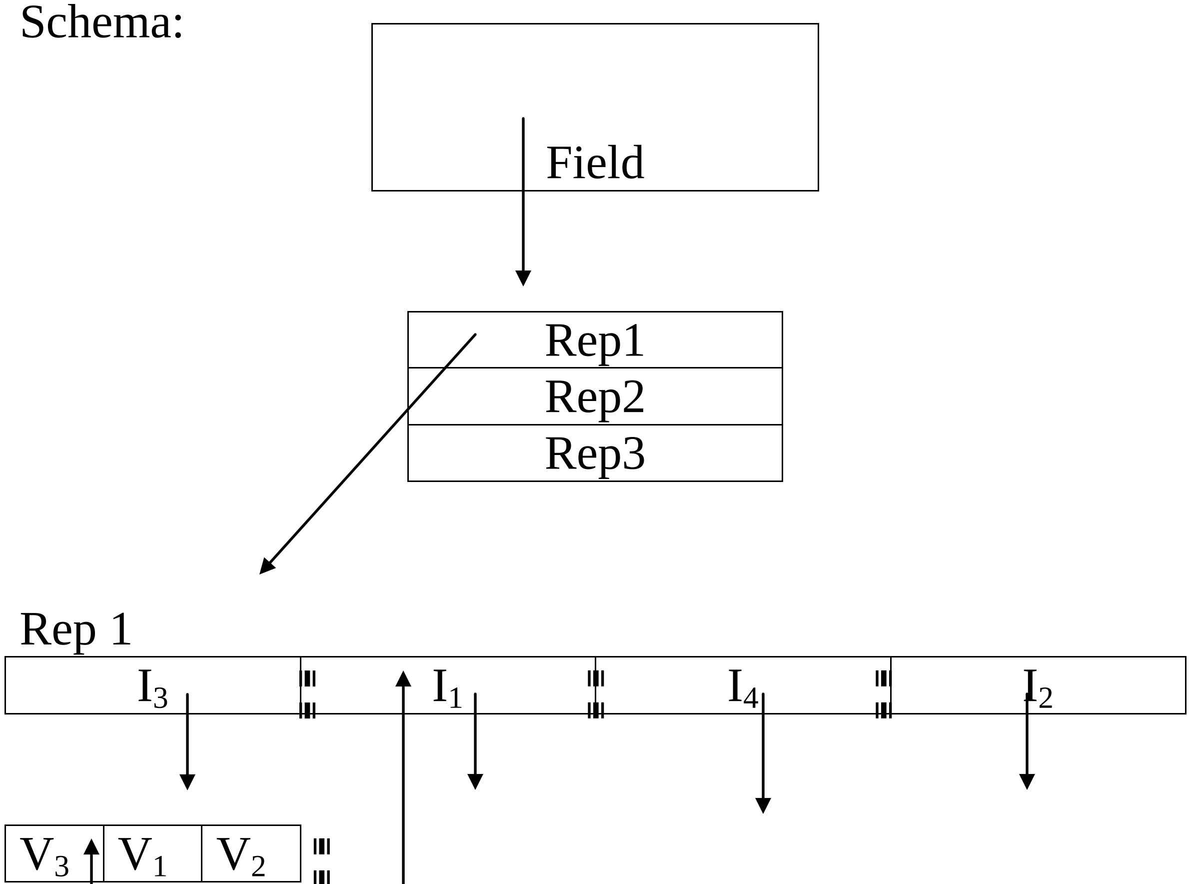
Treatment design:

All combinations of Irrigation and the cultivars

Field design: RCBD for I

Vs within each level of I.

Schema:



- Less number of buffers.
- Operational convenience

Main or whole plots

Sub plots

Split-plot experiments in a given field design/ RCBD

Generation of randomized plan for a split-plot experiment in RCBD

Identify – the factor to be assigned to main-plots
– the factor to be assigned to sub-plots
determine the field design for main-plot factor .

Randomization:

- Field
- Form replicates/blocks
- Randomly assign main-plot treatment factor to the main-plots; independently within each replicate/block
- Randomly assign sub-plot treatment factor to the sub-plots within each main-plot and within each replicate/block.

Use Genstat Menu

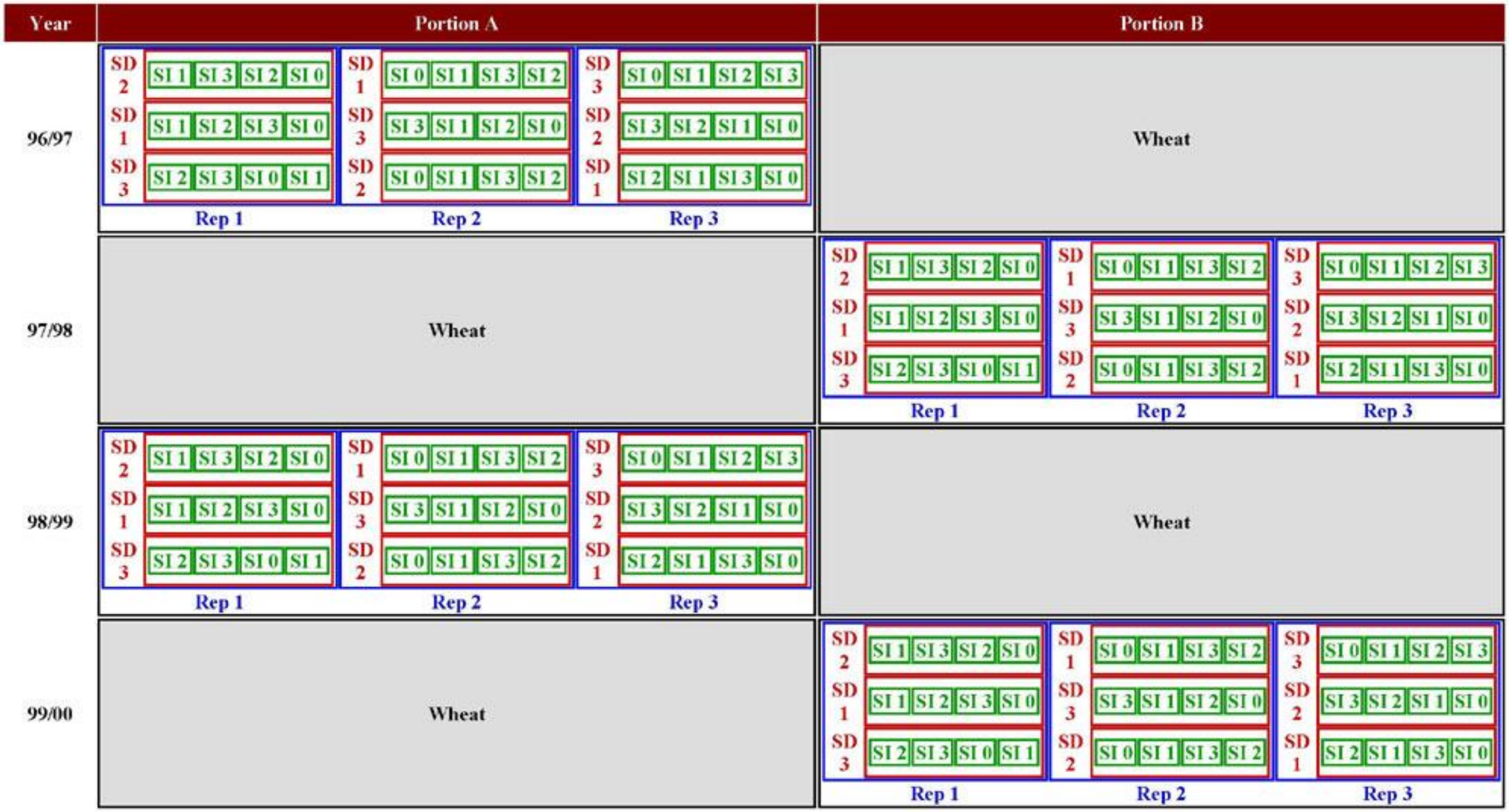

Year
Portion A
Portion B
96/97
SD 2 SI 1 SI 3 SI 2 SI 0
SD 1 SI 1 SI 2 SI 3 SI 0
SD 3 SI 2 SI 3 SI 0 SI 1
SD 1 SI 0 SI 1 SI 3 SI 2
SD 3 SI 3 SI 1 SI 2 SI 0
SD 2 SI 0 SI 1 SI 3 SI 2
SD 3 SI 0 SI 1 SI 2 SI 3
SD 2 SI 3 SI 2 SI 1 SI 0
SD 1 SI 2 SI 1 SI 3 SI 0
Rep 1
Rep 2
Rep 3
Wheat
97/98
Wheat
SD 2 SI 1 SI 3 SI 2 SI 0
SD 1 SI 1 SI 2 SI 3 SI 0
SD 3 SI 2 SI 3 SI 0 SI 1
SD 1 SI 0 SI 1 SI 3 SI 2
SD 3 SI 3 SI 1 SI 2 SI 0
SD 2 SI 0 SI 1 SI 3 SI 2
SD 3 SI 0 SI 1 SI 2 SI 3
SD 2 SI 3 SI 2 SI 1 SI 0
SD 1 SI 2 SI 1 SI 3 SI 0
Rep 1
Rep 2
Rep 3
98/99
SD 2 SI 1 SI 3 SI 2 SI 0
SD 1 SI 1 SI 2 SI 3 SI 0
SD 3 SI 2 SI 3 SI 0 SI 1
SD 1 SI 0 SI 1 SI 3 SI 2
SD 3 SI 3 SI 1 SI 2 SI 0
SD 2 SI 0 SI 1 SI 3 SI 2
SD 3 SI 0 SI 1 SI 2 SI 3
SD 2 SI 3 SI 2 SI 1 SI 0
SD 1 SI 2 SI 1 SI 3 SI 0
Rep 1
Rep 2
Rep 3
Wheat
99/00
Wheat
SD 2 SI 1 SI 3 SI 2 SI 0
SD 1 SI 1 SI 2 SI 3 SI 0
SD 3 SI 2 SI 3 SI 0 SI 1
SD 1 SI 0 SI 1 SI 3 SI 2
SD 3 SI 3 SI 1 SI 2 SI 0
SD 2 SI 0 SI 1 SI 3 SI 2
SD 3 SI 0 SI 1 SI 2 SI 3
SD 2 SI 3 SI 2 SI 1 SI 0
SD 1 SI 2 SI 1 SI 3 SI 0
Rep 1
Rep 2
Rep 3

Table1. Plot-wise yields of a lentil genotype under three dates of sowing in main-plots and four levels of supplemental irrigation in sub-plots at Tel Hadya, 1996/97 in a split-plot experiment in randomized complete blocks with three replications.

Rep	Plot No.	Sowing Date	Suppl. Irrigation	Grain Yield (kg/ha)	Biomass (kg/ha)
1	101	3	2	1464	4134
1	102	3	3	1852	5164
1	103	3	0	1076	3654
1	104	3	1	1146	3481
1	105	1	0	931	5319
1	106	1	3	1753	6899
1	107	1	2	2564	8667
1	108	1	1	1481	7465
1	109	2	1	1721	6596
1	110	2	3	1975	6801
1	111	2	2	1855	6787
1	112	2	0	864	5005
2	201	2	0	896	4684
2	202	2	1	1065	5101
2	203	2	3	1577	6289
2	204	2	2	1566	6557
2	205	3	0	1002	3139
2	206	3	2	1446	3922
2	207	3	1	1390	4247
2	208	3	3	1340	4018
2	209	1	0	1005	5919

2	210	1	1	829	6074
2	211	1	3	1785	7714
2	212	1	2	1672	7376
3	301	1	2	1157	6067
3	302	1	1	907	5975
3	303	1	3	1002	6444
3	304	1	0	395	5337
3	305	2	0	681	5252
3	306	2	1	907	5986
3	307	2	2	1189	5354
3	308	2	3	1884	6677
3	309	3	0	790	3037
3	310	3	1	1005	4067
3	311	3	2	1422	4854
3	312	3	3	1601	4741

Sowing dates:

1: Mid November

2: Late December

3: Mid February

Statistical Analysis:

- Partitioning of variability :ANOVA
- Estimation of error variability (ies)
- Estimation of means (main effects and interactions)
- Standard errors
- Coefficient of variation
- Presentation of results

Demonstration using Genstat Menu system

```
 "Split-Plot Design."
 BLOCK Rep/SD/Irr
 TREATMENTS SD*Irr
  COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means,%cv;
FACT=32; FPROB=yes; PSE=lsd,means; LSDLEVEL=5]
GY
```

- Partitioning of variability

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

Variate: GY

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

Rep stratum                       2    1376920.     688460.    6.19

Rep.SD stratum
SD                                2      25242.      12621.    0.11  0.896
Residual                          4     445217.     111304.    1.96

Rep.SD.Irr stratum
Irr                               3    3818509.    1272836.   22.44  <.001
SD.Irr                            6     411849.      68641.    1.21  0.346
Residual                         18    1020779.      56710.

Total                            35    7098517.
```

Tables of means

Variate: GY

Grand mean 1311.

SD	1	2	3
	1290.	1348.	1294.

Irr	0.00	1.00	2.00	3.00
	849.	1161.	1593.	1641.

SD	Irr	0.00	1.00	2.00	3.00
1		777.	1072.	1798.	1513.
2		814.	1231.	1537.	1812.
3		956.	1180.	1444.	1598.

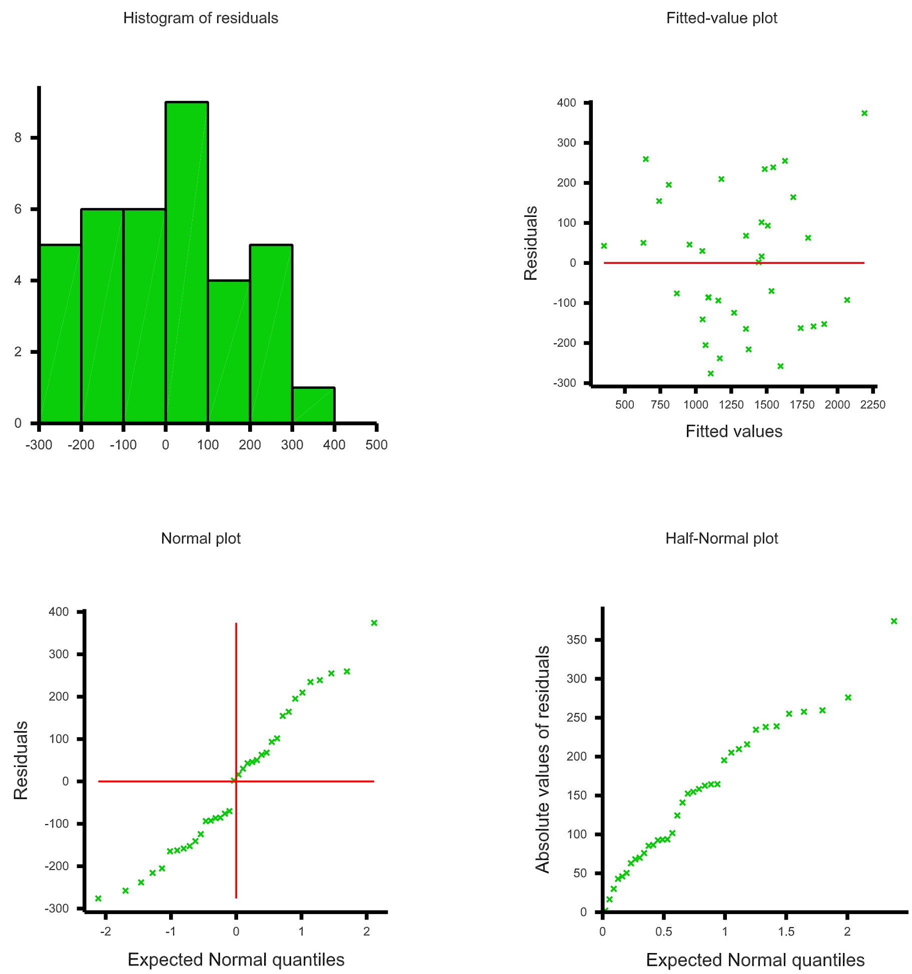
```
 *** Standard errors of means ***
Table                       SD          Irr          SD
                                                    Irr
rep.                        12            9           3
e.s.e.                    96.3         79.4       153.1
d.f.                         4           18       16.83
Except when comparing means with the same level(s) of
 SD                                               137.5
 d.f.                                                18


*** Least significant differences of means (5% level) ***
Table                       SD          Irr          SD
                                                    Irr
rep.                        12            9           3
l.s.d.                   378.1        235.8       457.3
d.f.                         4           18       16.83
Except when comparing means with the same level(s) of
 SD                                               408.5
 d.f.                                                18
```

***** Stratum standard errors and coefficients of variation *****

Variate: GY

Stratum	d.f.	s.e.	cv%
Rep	2	239.5	18.3
Rep.SD	4	166.8	12.7
Rep.SD.Irr	18	238.1	18.2



Histogram of residuals
Fitted-value plot
Residuals
Fitted values
Normal plot
Residuals
Expected Normal quantiles
Half-Normal plot
Absolute values of residuals
Expected Normal quantiles

- Presentation of results

Table 1. Mean grain yield (kg/ha) of a lentil genotype under three dates of sowing and four levels of supplemental irrigation at Tel Hadya, 1996/97.

Supplemental Irrigation	Sowing dates			Mean
	Mid November	Late December	Mid February	
0(rainfed)	777	814	956	849
1(33% of requirement)	1072	1231	1180	1161
2(66% of requirement)	1798	1537	1444	1593
3(full irrigation)	1513	1812	1598	1641
SE	±153 (±138[$])			±79
Mean	1290	1348	1294	1311
SE		±96		

[$]: for comparing irrigation levels at same sowing dates.

Experimental design was a split-plot experiment, with sowing dates in main-plots and supplemental irrigation in sub-plots, conducted in a randomized complete blocks with three replications.

Table 1. Mean grain yield (t/ha) of a lentil genotype under three dates of sowing and four levels of supplemental irrigation at Tel Hadya, 1996/97.

Supplemental Irrigation	Sowing dates			Mean
	Mid November	Late December	Mid February	
0(rainfed)	**0.78**	**0.81**	**0.96**	**0.85**
1(33% of requirement)	**1.07**	**1.23**	**1.18**	**1.16**
2(66% of requirement)	**1.80**	**1.54**	**1.44**	**1.59**
3(full irrigation)	**1.51**	**1.81**	**1.60**	**1.64**
SE	**±0.15(±0.14[$])**			**±0.79**
Mean	**1.29**	**1.35**	**1.29**	**1.31**
SE		**±0.96**		

[$]: for comparing irrigation levels at same sowing dates.
Experimental design was a split-plot experiment, with sowing dates in main-plots and supplemental irrigation in sub-plots, conducted in a randomized complete blocks with three replications.

5. Design and analysis of strip-plot experiments in RCB

- **Nature of the factors**
- **Review of the nature of factors in**
  - **factorial combinations in randomized complete blocks (RCB)**
  - **split-plots in RCB**

- **Consider two factors e. g. Irrigation methods, and tillage methods. Both of these two factor require large areas for their operation.**

- **How to design such an experiment? and analyze the data?**

- **Let Irrigation be at 5 levels (I1,I2,I3,I4,I5)**

- **Let Soil tillage be at 4 levels (S1, S2, S3, S4)**

- **RCB designs for these factors would look like:**

Irrigation:

			Randomized
Rep I	I1	Rep I	I5
	I2		I2
	I3		I4
	I4		I1
	I5		I3
Rep II	I1	Rep II	I2
	I2		I5
	I3		I3
	I4		I1
	I5		I4
Rep III	I1	Rep III	I1
	I2		I5
	I3		I2
	I4		I3
	I5		I4

- **Soil tillage methods**

			Randomized
	S1		**S3**
	S2		**S1**
Rep I	**S3**	**Rep I**	**S4**
	S4		**S2**
	S1		**S2**
	S2		**S1**
Rep II	**S3**	**Rep II**	**S3**
	S4		**S4**
	S1		**S1**
	S2		**S2**
Rep III	**S3**	**Rep III**	**S4**
	S4		**S3**

- **Placing two together is possible if they could be laid out in orthogonal/ perpendicular directions**

-

		Randomized			
	Randomized	S3	S1	S4	S3
	I5				
	I2				
Rep I	I4				
	I1				
	I3				

		Randomized			
	Randomized	S2	S1	S3	S4
	I2				
	I5				
Rep II	I3				
	I1				
	I4				

		Randomized			
	Randomized	S1	S2	S4	S3
	I1				
	I5				
Rep III	I2				
	I3				
	I4				

-

An example:

An agronomist wanted to measure the effect of two Autumn or Fall tillage treatments and three Spring tillage treatments on the yield of wheat. Because of the size of machinery involved, the Spring treatments were applied to strips of plots at right angels to the Autumn treatments. He used the following treatments:

Factor A = Autumn (fall) tillage : F_1 = Chisel, F_2 = Subsoil

Factor B = Spring tillage S_1 =Plow, S_2 = Sweep, S_3 = Offset disk.

The experiment was run in three blocks. The field lay-out and yield (Kg/Hectare) were

I	Plow S_1	Disk S_3	Sweep S_2
Chisel F_1	312	315	278
Subsoil F_2	318	222	267

II	Disk S_3	Plow S_1	Sweep S_2
Subsoil F_2	334	374	296
Chisel F_1	314	350	286

III	Disk S_3	Sweep S_2	Plow S_1
Subsoil F_2	298	228	384
Chisel F_1	312	309	361

- **Spread-sheet**

Rep	AutumnTill	SpringTill	YieldKgHa
1	Chisel	Plow	312
1	Chisel	Disk	315
1	Chisel	Sweep	278
1	SubSoil	Plow	318
1	SubSoil	Disk	222
1	SubSoil	Sweep	267
2	SubSoil	Disk	334
2	SubSoil	Plow	374
2	SubSoil	Sweep	296
2	Chisel	Disk	314
2	Chisel	Plow	350
2	Chisel	Sweep	286
3	SubSoil	Disk	298
3	SubSoil	Sweep	228
3	SubSoil	Plow	384
3	Chisel	Disk	312
3	Chisel	Sweep	309
3	Chisel	Plow	361

-

Analysis of variance

Variate: YieldKgHa

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5267.1	2633.6		
Rep.AutumnTill stratum					
AutumnTill	1	747.6	747.6	0.68	0.497
Residual	2	2203.1	1101.6	1.25	
Rep.SpringTill stratum					
SpringTill	2	16600.1	8300.1	14.81	0.014
Residual	4	2241.9	560.5	0.63	
Rep.AutumnTill.SpringTill stratum					
AutumnTill.SpringTill	2	2102.8	1051.4	1.19	0.393
Residual	4	3530.6	882.6		
Total	17	32693.1			

Tables of means

Variate: YieldKgHa

Grand mean 308.8

AutumnTill	Chisel	SubSoil
	315.2	302.3

SpringTill	Disk	Plow	Sweep
	299.2	349.8	277.3

AutumnTill	SpringTill	Disk	Plow	Sweep
Chisel		313.7	341.0	291.0
SubSoil		284.7	358.7	263.7

Standard errors of means

Table	AutumnTill	SpringTill	AutumnTill SpringTill
rep.	9	6	3
e.s.e.	11.06	9.66	16.27
d.f.	2	4	6.83
Except when comparing means with the same level(s) of			
AutumnTill			15.51
d.f.			7.62
SpringTill			17.85
d.f.			5.93

Least significant differences of means (5% level)

Table	AutumnTill	SpringTill	AutumnTill SpringTill
rep.	9	6	3
l.s.d.	67.32	37.95	54.70
d.f.	2	4	6.83
Except when comparing means with the same level(s) of			
AutumnTill			51.02
d.f.			7.62
SpringTill			61.94
d.f.			5.93

Stratum standard errors and coefficients of variation

Variate: YieldKgHa

Stratum	d.f.	s.e.	cv%
Rep	2	20.95	6.8
Rep.AutumnTill	2	19.16	6.2
Rep.SpringTill	4	16.74	5.4
Rep.AutumnTill.SpringTill	4	29.71	9.6

- **(source: George Ghannoun's experiments)**

Example from Line source experiment.

```
31..............................................................

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

Variate: SDWTPPLN

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

Rep stratum                2     30.2821     15.1411

Rep.Trt stratum
Trt                        5    236.9607     47.3921   26.00  <.001
Residual                  10     18.2255      1.8225    2.48

Rep.Variety stratum
Variety                   14     63.3211      4.5229    2.48  0.020
Residual                  28     51.1278      1.8260    2.49

Rep.Trt.Variety stratum
Trt.Variety               70     58.3190      0.8331    1.14  0.261
Residual                 140    102.7254      0.7338

Total                    269    560.9616
```

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

Variate: SDWTPPLN

Grand mean 4.072

Trt	L1	L2	L3	L4	L5	L6
	4.941	5.221	4.562	3.893	3.233	2.584

Variety	72.00	452.00	1929.00	2293.00	2799.00	3193.00	3279.00
	3.780	4.311	4.528	3.779	3.106	4.223	3.893

Variety	3764.00	4162.00	4236.00	4446.00	4463.00	4958.00	8759.00
	4.801	4.643	4.635	4.061	4.315	3.858	3.175

Variety	8785.00
	3.974

Trt	Variety	72.00	452.00	1929.00	2293.00	2799.00	3193.00
L1		4.923	6.143	4.690	4.387	3.450	4.833
L2		5.857	5.540	6.153	4.873	3.463	5.143
L3		4.437	4.067	5.410	3.843	3.717	5.000
L4		3.860	3.730	4.370	2.927	2.740	4.663
L5		2.230	3.127	3.200	3.680	2.763	3.173
L6		1.373	3.260	3.347	2.967	2.500	2.527

Trt	Variety	3279.00	3764.00	4162.00	4236.00	4446.00	4463.00
L1		4.913	6.293	5.767	5.427	5.090	5.230
L2		6.053	6.517	5.850	5.527	4.640	5.777
L3		4.757	5.767	5.570	5.007	4.927	4.437
L4		3.457	3.690	4.527	4.797	3.960	4.227

L5		2.637	3.777	3.353	3.583	3.400	3.383
L6		1.543	2.760	2.790	3.470	2.350	2.837

Trt	Variety	4958.00	8759.00	8785.00
L1		4.313	3.930	4.723
L2		4.660	3.833	4.430
L3		3.840	3.620	4.027
L4		3.930	3.207	4.310
L5		4.097	2.680	3.407
L6		2.307	1.780	2.950

```
*** Standard errors of means ***

Table                    Trt     Variety         Trt
                                             Variety
rep.                      45          18           3
e.s.e.                0.2012      0.3185      0.5740
d.f.                      10          28      138.67
Except when comparing means with the same level(s) of
 Trt                                            0.5525
 d.f.                                         140.28
 Variety                                      0.5184
 d.f.                                         134.72



*** Standard errors of differences of means ***

Table                    Trt     Variety         Trt
                                             Variety
rep.                      45          18           3
s.e.d.                0.2846      0.4504      0.8117
d.f.                      10          28         138.67
Except when comparing means with the same level(s) of
 Trt                                             0.7814
 d.f.                                         140.28
 Variety                                      0.7332
 d.f.                                         134.72
```

*** Least significant differences of means ***

Table	Trt	Variety	Trt Variety
rep.	45	18	3
l.s.d.	0.6341	0.9227	1.6050
d.f.	10	28	138.67
Except when comparing means with the same level(s) of			
Trt			1.5448
d.f.			140.28
Variety			1.4500
d.f.			134.72

***** Stratum standard errors and coefficients of variation *****