Experimental Designs for Alley Cropping to Estimate Shrub × Grass Interaction$

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This Presentation

- Introduction/Alley Cropping- what is it?
- Experimental designs
- Model(s) for analysis
- An illustration (simulated data)

Alley Cropping- what is it?

- Rational
- Alley cropping, an agroforestry practice, is a low input system for forage and food production and serves as a mechanism for sustainable agriculture.

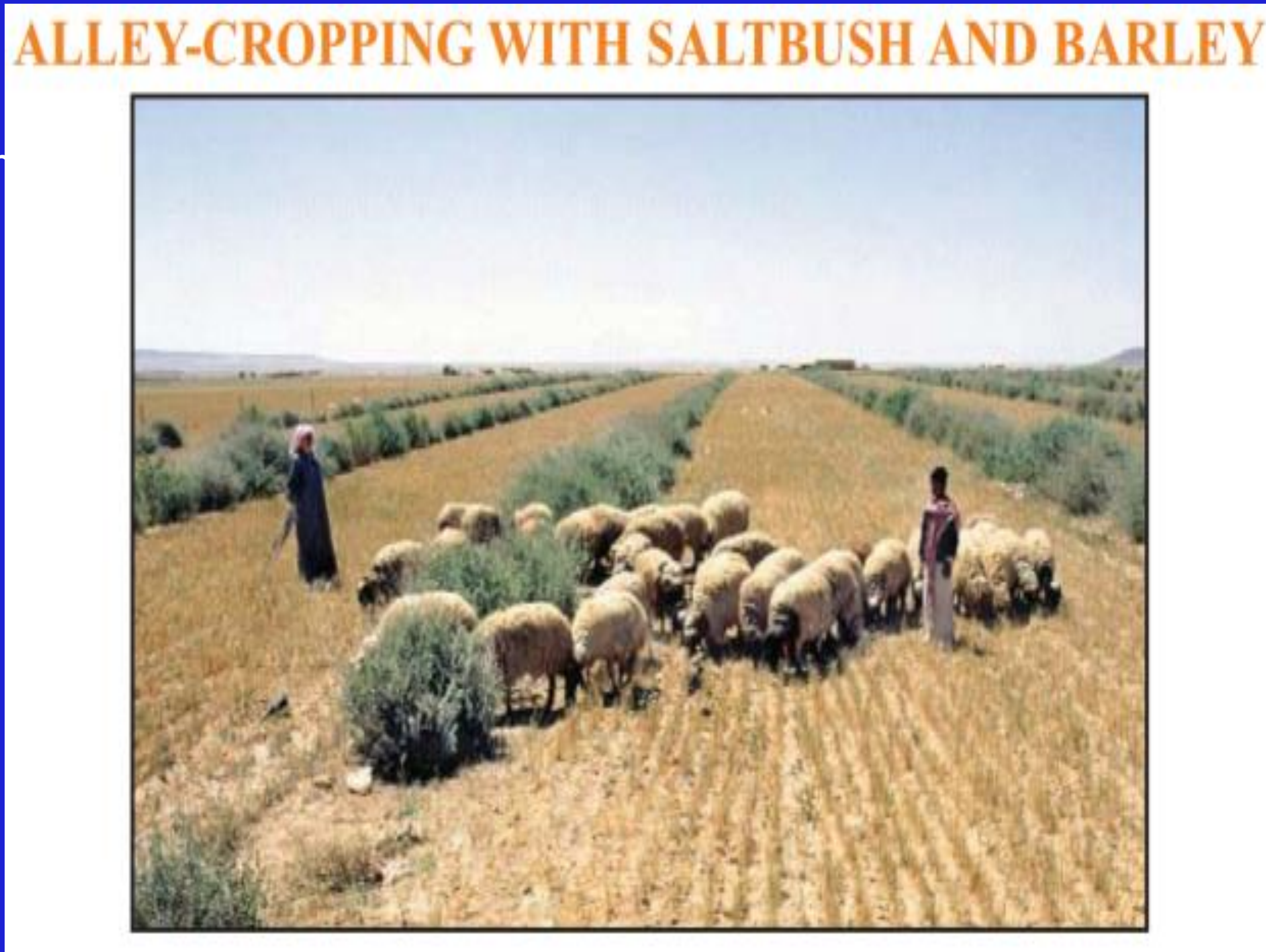
- With suitable choice of crop, shrub or tree species in the system it supports diverse needs of human and other domestic animals, and arrest the land degradation and soil erosion, and plays a major role in mitigating climate change.

- Alley cropping manages the soil nutrients more effectively between the species, e.g., perennial trees/shrubs and annual crops, and different layers of soil depth.
- References include Solaimalai et al., 2005; AFNTA 1992a, b.

Alley Cropping- what is it?...2

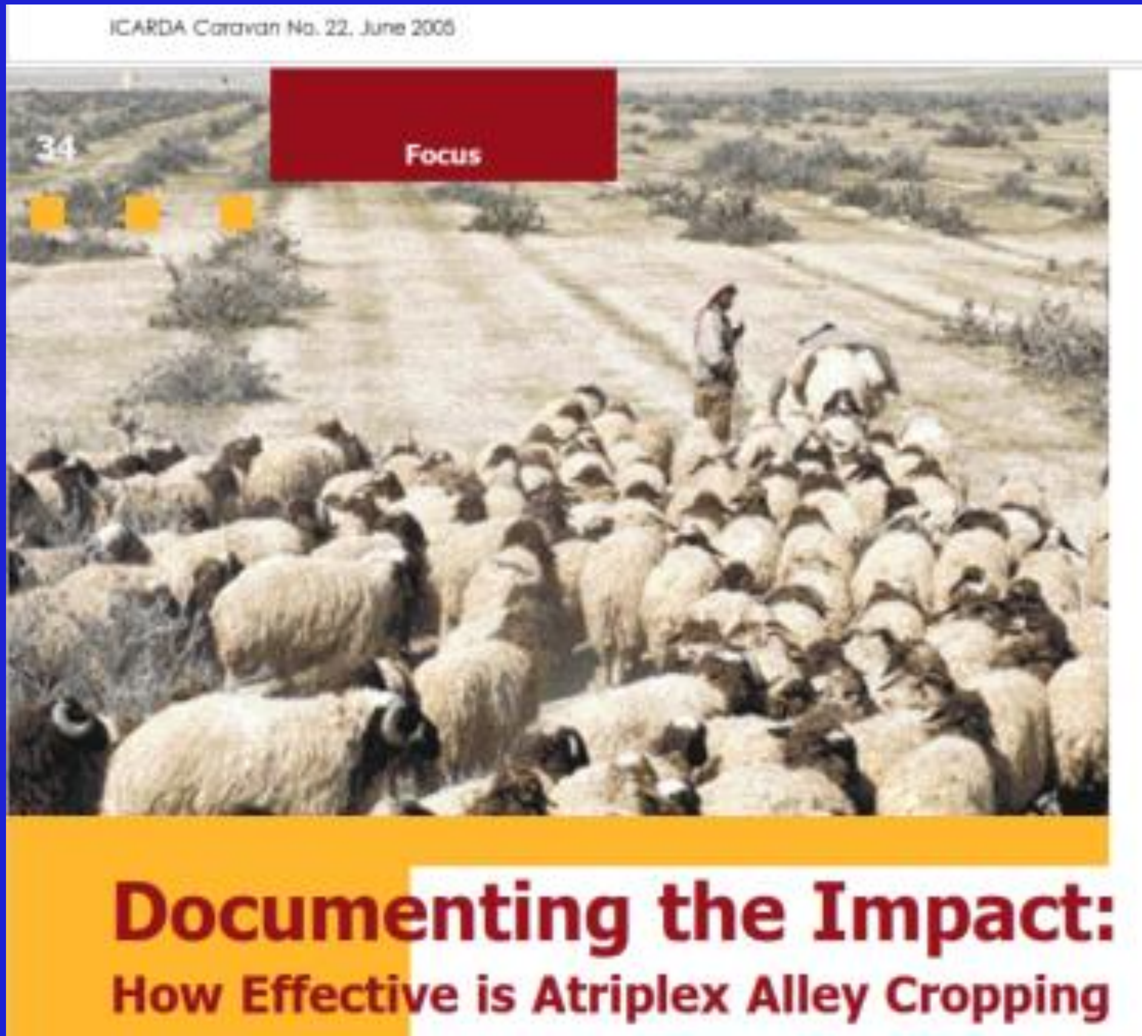
- Alley cropping is practiced in rangeland research where shrubs are established as borders to the alleys which grow grasses or crops.

- Alley cropping systems look like these pictures.



Source:
Page 30 of ICARDA (2005). Sustainable Agricultural Development For Marginal Dry Areas: Khanasser Valley Integrated Research Site. 51pp

Alley Cropping- what is it?...3



Source:
Page 34, ICARDA (2005). ICARDA Caravan: Review of agriculture in the dry areas. Issue No. 22, 43pp.

Alley Cropping- what is it?...4

Source:

Rehabilitating degraded steppe lowlands with damage cause by continuous grazing, notably a large increase in invasive species. http://www.icarda.org/features/rehabilitating-degraded-steppe-lowlands#sthash.SrVLk5i0.dpuf

Alley Cropping- what is it?...4

- The following links also exhibit alley crops and hedgerow intercrops in the fields.
- Link: http://www.cof.orst.edu/pubs/cof/plntdfor/tnxch/ch12.htm
- http://www.igfri.res.in/pdf/AR-15-16/AR-15-16-eng.pdf
- http://www.igfri.res.in/pdf/AR-15-16/AR-15-16-eng.pdf

http://www.icarda.org/features/rehabilitating-degraded-steppe-lowlands#sthash.SrVLk5i0.dpuf

Experimental Designs for Alley Cropping

Consider a set of shrubs denoted by $S_1,\ldots, S_s$ for planting as the borders and a number of grasses/crops $G_1,\ldots, G_g$ for the alleys.

The following frames of experimental units, or, shrub –grass plots will be considered. Experimental units receive

- combinations of shrubs and grasses
- shrubs with long borders and all grasses in smaller alleys within these borders

http://www.icarda.org/features/rehabilitating-degraded-steppe-lowlands#sthash.SrVLk5i0.dpuf

Experimental Designs for Alley Cropping

The following two treatment designs:

- Self-borders and grasses combination, and
- Diallel-borders and grasses combination

can be implemented with any one of the above two frames of the experimental units.

The resulting designs may or may not share borders between the two alleys.

In case they do, search for appropriate covariance structures for grass plot errors would be needed..

http://www.icarda.org/features/rehabilitating-degraded-steppe-lowlands#sthash.SrVLk5i0.dpuf

Experimental Designs and Models for Statistical Analysis

Examples of such designs are given in the following schemas along with models for data analysis

Non-shared borders between the alleys

i.e. same shrub does not affect the grasses on its opposite sides of alleys.

Self- borders:

using the same shrubs on both sides of the borders.

http://www.icarda.org/features/rehabilitating-degraded-steppe-lowlands#sthash.SrVLk5i0.dpuf

Experimental Designs & Models ...2

Design 1. Self-borders and grasses combinations in RCBD.

Schema 1: A randomized plan for 4 shrubs (S1...S4), 3 grasses (G1...G3), self-borders, factorial in RCBD, one replicate shown.

Replicate	1											
Left-border	S1	S1	S2	S2	S1	S3	S4	S4	S3	S2	S4	S3
Alley	G2	G3	G2	G3	G1	G3	G2	G1	G2	G1	G3	G1
Right-border	S1	S1	S2	S2	S1	S3	S4	S4	S3	S2	S4	S3
Plots	101	102	103	104	105	106	107	108	109	110	111	112

Experimental Designs & Models ...2

$y_{i,jj,l}$	response from the alley under grass G_i or i, self-borders (left, right): (S_j, S_j) or jj, block/replicate l ($i = 1,\ldots,g;\ j = 1,\ldots,s;$ and $l = 1,\ldots,r$)
μ	general mean
β_l	effect of block l
γ_i ψ_j	effect of grass i effect of borders, jj, under shrub j from both sides
δ_{ij}	interaction between grass i and shrub borders jj

Experimental Designs & Models ...2

Design 1:

Response = general mean + block effect + grass effect + shrub-effect + shrub × grass interaction + Error

$$y_{i,jj,l} = \mu + \beta_l + \gamma_i + \psi_j + \delta_{ij} + \varepsilon_{i,jj,l}$$

where independently distributed errors

$$\varepsilon_{i,jj,l} \sim N(0, \sigma^2)$$

Design 2. Self-borders in main plots in RCBD and grasses in sub-plots.

Schema 2. A randomized plan for 4 shrubs (S1...S4), 3 grasses (G1...G3), self-borders, split-plot (Shrub-borders main plot) in RCBD, one replicate

Replicate	1											
Left-border	S2	S2	S2	S3	S3	S3	S1	S1	S1	S4	S4	S4
Alley	G1	G3	G2	G2	G3	G1	G1	G2	G3	G1	G2	G3
Right-border	S2	S2	S2	S3	S3	S3	S1	S1	S1	S4	S4	S4
Plots	101	102	103	104	105	106	107	108	109	110	111	112

Response = general mean + block effect + shrub-effect
+ Error (a)[Block × Shrub interaction]
+ grass effect + Shrub × grass interaction
+ Error(b)

$$y_{i,jj,l} = \mu + \beta_l + \psi_j + (\beta\psi)_{jl} [= \mathrm{E}rror(a)]$$

$$+ \gamma_i + \delta_{ij} + \varepsilon_{i,jj,l} [= Error(b)]$$

Diallel- borders: Different shrubs on the borders

Design 3. Diallel-borders and grasses combinations in RCBD

Schema 3. A randomized plan for 4 shrubs, 3 grasses, diallel-borders, factorial in RCBD, one replicate.

Replicate	1											
Left-border	S1	S4	S2	S2	S1	S3	S4	S1	S3	S2	S3	S4
Alley	G2	G1	G1	G3	G3	G3	G2	G1	G1	G2	G2	G3
Right-border	S3	S2	S1	S1	S3	S4	S2	S3	S4	S1	S4	S2
Plots	101	102	103	104	105	106	107	108	109	110	111	112

Partial Diallel Crosses references: many -- Curnow and Kempthorne (1961), Curnow (1963), Arya (1983), Singh and Hinkelmann (1990) , a review in Singh et al. (2012)

A statistical model for the response is:

$$y_{i,jk,l} = \mu + \beta_l + \gamma_i$$

$$+ \psi_j + \psi_k + \psi_{jk}$$

$$+ \delta_{ij} + \delta_{ik} + \delta_{ijk} + \varepsilon_{i,jk,l}$$

Where

$y_{i,jk,l}$ = response from the alley under grass G_i , diallel-borders (left, right): (S_j, S_k) and block/replicate l

ψ_j = gesg (general effect of shrub S_j on the grasses (irrespective of border direction)

: gca equivalent in case of partial dial crosses

ψ_{jk} = sesg (specific effect of shrub borders (S_j, S_k) on the grasses

: sca equivalent in case of partial dial crosses

A statistical model for the response (continued)

δ_{ij} = interaction between shrub S_j and grass G_i

= gs-gseg (grass-specific general effect of shrub S_j)

δ_{ijk} = gs-sesg (grass-specific specific effects of shrub borders (S_j, S_k) on the grass)

$\varepsilon_{i,jk,l} \sim N(0, \sigma^2)$

<u>A special case</u>

Assumptions: sesg ψ_{jk} and gs-sesg δ_{ijk} may be absent or negligible

The model reduces to:

$$y_{i,jk,l} = \mu + \beta_l + \gamma_i + \psi_j + \psi_k + \delta_{ij} + \delta_{ik} + \varepsilon_{i,jk,l}$$

Design 4. Diallel-borders in main plots in RCBD and grasses in sub-plots

Schema 4. A randomized plan for 4 shrubs, 3 grasses, diallel-borders, split-plot (Shrub-borders main plot) in RCBD

Replicate	**1**											
Left-border	S2	S2	S2	S4	S4	S4	S1	S1	S1	S3	S3	S3
Alley	**G2**	**G3**	**G1**	**G3**	**G1**	**G2**	**G3**	**G2**	**G1**	**G2**	**G3**	**G1**
Right-border	S4	S4	S4	S1	S1	S1	S3	S3	S3	S2	S2	S2
Plots	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**	**112**

Design 4:

Model:

$$y_{i,jk,l} = \mu + \beta_l + \psi_j + \psi_k + \psi_{jk} + (\beta\psi)_{jk,l} [= \mathrm{E}rror(a)]$$

$$+ \gamma_i + \delta_{ij} + \delta_{ik} + \delta_{ijk} + \varepsilon_{i,jk,l} [= Error(b)]$$

A Case:

Assumption: sesg ψ_{jk} and gs-sesg δ_{ijk} absent or negligible

$$y_{i,jk,l} = \mu + \beta_l + \psi_j + \psi_k + (\beta\psi)_{jk,l} [= \mathrm{E}rror(a)]$$

$$+ \gamma_i + \delta_{ij} + \delta_{ik} + \varepsilon_{i,jk,l} [= Error(b)]$$

Estimation of the effects and interactions

A practical approach would be to estimate the response of the combinations of shrub-borders and gasses with adjustment for block differences, covariates for slope and fertility trend in the alleys, spatial error structures.

Let the adjusted mean for the treatment combination: grass G_i and diallel-border (left, right) (j,k) be denoted by $\bar{y}_{i,jk}$. In vector notation, we can use

$$\bar{y} = (\bar{y}_{1,12}, \bar{y}_{1,13}, \bar{y}_{1,1s}, \dots, \bar{y}_{g,s-1s})'$$

Let the estimated variance covariance of vector $\bar{y}$ be expressed as

$$\hat{\Sigma} = (\hat{\sigma}^2 / r)I = (\mathrm{Re}\, sMS / r)I$$

Let the grass effects, shrub effects and their interaction be represented in vector form, respectively, as

$$\gamma = (\gamma_1, \ldots, \gamma_g)'$$

$$\psi = (\psi_1, \ldots, \psi_s)'$$

and
$$\delta = (\delta_{11}, \delta_{12} \ldots, \delta_{1s}, \ldots, \delta_{g1}, \delta_{g2}, \ldots, \delta_{gs})'$$

Let the interaction between grass and border combinations (not the individual shrubs) be denoted by

$$\phi = (\phi_{11}, \phi_{12} \ldots, \phi_{1p}, \ldots, \phi_{g1}, \phi_{g2}, \ldots, \phi_{gp})'$$

$$\phi_{im} = \delta_{ij} + \delta_{ik} \qquad (m = 1, \ldots, p)$$

A model for estimation of γ , ϕ and ψ

$$\bar{y} = \mu J + X_1 \gamma + X_2 \psi + X_3 \phi + \bar{\varepsilon}$$

$$\bar{\varepsilon} \sim \mathrm{MVN}(0, \hat{\Sigma}).$$

Conditions on the vectors of effects are:

$$\gamma' J = 0$$

$$\psi' J = 0$$

$$(I_p \otimes J_g')\phi = 0_{p,1}$$

and

$$(J_p' \otimes I_g)\phi = 0_{1,g}$$

Approach 1: One can estimate grasses and borders effects and interaction using ANOVA directives.

The border effects overall the grasses or for individual grasses data can be modelled by fitting columns of X_2 (no intercept) to estimate ψ s and δ respectively.

Approach 2: Another could be based on matrices but still using the ANOVA estimates of border effects with variance-covariance matrix or ignoring the covariances. This may be completed in the following two stages:

Stage 1: Estimate γ and ψ, we can fit a reduced model, ignoring ϕ

$$\bar{y} \sim MVN(X\beta, \hat{\Sigma})$$

where $X = [J : X_1 : X_2] \qquad (p, 1+g+s)$

$$\beta = (\mu, \gamma', \psi')'$$

Using Rao (1973)

$$\hat{\beta} = (\hat{\mu}, \hat{\gamma}', \hat{\psi}')' = S^{-1}Q$$

$$D(\hat{\beta}) = S^{-1}.$$

where

$$S = X'\hat{\Sigma}^{-1}X$$

$$Q = X'\hat{\Sigma}^{-1}\bar{y}$$

Interaction (border × grass) vector ϕ can be estimated as:

$$\hat{\phi} = \bar{y} - X\hat{\beta}$$

$$\mathrm{D}(\hat{\phi}) = \Sigma - XS^{-1}X' = \Sigma^{*}$$

Stage 2: Next step would be to partition $\hat{\phi}$ into δ

Obtain a matrix $Z_{p \times gs}$

with its column number $i_j = j + (i-1)s$

as element-wise (Schur) multiplication of $i-$th column of X_1 and $j-$th column of X_2

Solve for δ

$$\hat{\phi} = Z\delta, \text{ where}$$

$$D(\hat{\phi}) = \Sigma^{*}$$

to obtain

$$\hat{\delta} = (Z'\Sigma^{*+}Z)^{+} Z'\Sigma^{*+}\hat{\phi} \text{ , and}$$

$$D(\hat{\delta}) = (Z'\Sigma^{*+}Z)^{+}$$

where A^{+} =Moore-Penrose psuedoinverse of matrix A

Optimal design:

Optimality and efficiency of the design can be studied in terms of the respective covariance matrices for

$$\hat{\gamma},$$

$$\hat{\psi}$$

and $$\hat{\delta}.$$

Shared borders

Design 5. Sharing of borders between the alleys would lead to a resource saving design. However, data analysis may be based on a relatively more complex model due to the feature that the same shrub may affect grasses on its opposite sides of alleys. Self-borders or diallel-boders can be used. Due to sharing of the same border between the alleys the randomization of the shrubs as borders would become quite restricted.

Shared borders

Design 5

Left-border	**S1**	**S1**	**S1**
Alley	**G1**	**G3**	**G2**
Shared-border	**S3**	**S3**	**S3**
Alley	**G2**	**G3**	**G1**
Shared-border	**S2**	**S2**	**S2**
Alley	**G1**	**G2**	**G3**
Shared-border	**S4**	**S4**	**S4**
Alley	**G3**	**G1**	**G2**
Shared-border	**S3**	**S3**	**S3**
Alley	**G2**	**G3**	**G1**
Shared-border	**S1**	**S1**	**S1**
Alley	**G3**	**G2**	**G1**
Shared-border		.	
Alley		.	

Shared borders: Design 5

In this case correlated responses may be assumed and covariance modelling would a worthy exercise to induct in the analysis.

Model:

$$y_{i,jk,l} = \mu + \beta_l + \psi_j + \psi_k + (\beta\psi)_{jk,l} [= \mathrm{E}rror(a)]$$
$$+ \gamma_i + \delta_{ij} + \delta_{ik} + \varepsilon_{i,jk,l} [= Error(b)]$$

Correlated model structures:

$$\mathrm{Cov}((\beta\psi)_{jk,l}, (\beta\psi)_{km,l}) \quad \text{and} \quad Cov(\varepsilon_{i,jk,l}, \varepsilon_{i,km,l})$$

may need to be simplified using a criterion such as Akaike Information Criterion (AIC) (Akaike, 1974).

The selected covariance structure(s) can then be used for estimation of the effects and interaction.

An Illustration:

Table 1. Experimental design and randomly generated data for illustration

Rep	Border	Grass	Yield
1	S1S2	1	0.614
1	S1S2	3	4.801
1	S1S2	2	1.925
1	S2S3	2	3.622
1	S2S3	1	1.417
1	S2S3	3	4.35
1	S4S1	3	5.82
1	S4S1	2	4.185
1	S4S1	1	4.047
1	S3S5	1	2.984
1	S3S5	2	4.022
1	S3S5	3	6.098
1	S5S4	3	5.846
1	S5S4	1	4.581
1	S5S4	2	4.408

Rep	Border	Grass	Yield
2	S1S2	2	2.914
2	S1S2	1	2.278
2	S1S2	3	5.779
2	S5S4	1	3.999
2	S5S4	2	5.288
2	S5S4	3	6.432
2	S2S3	2	3.565
2	S2S3	3	5.656
2	S2S3	1	1.581
2	S3S5	1	4.672
2	S3S5	3	5.523
2	S3S5	2	5.169
2	S4S1	1	1.777
2	S4S1	2	3.446
2	S4S1	3	5.319

Rep	Border	Grass	Yield
3	S4S1	1	3.94
3	S4S1	2	3.397
3	S4S1	3	7.101
3	S3S5	2	6.133
3	S3S5	3	8.36
3	S3S5	1	5.21
3	S1S2	3	7.002
3	S1S2	1	3.23
3	S1S2	2	4.652
3	S2S3	3	8.165
3	S2S3	1	4.414
3	S2S3	2	8.435
3	S5S4	3	9.083
3	S5S4	2	5.587
3	S5S4	1	5.214

An Illustration:

Dataset: A dataset was generated for experimental design situation, Design 4 is given in Table 1. The following set of values of effects taken for random generation of data.

General mean: $\mu = 5$

Block effects: β_l (l=1…3)= -1.0, -0.5, 0.0

Grasses effects: γ_i (i=1…3) = -2,-1, 3

Shrubs effects: ψ_j (j) = -1.,-.5, 1., 0.5, 0.0

Interactions δ_{ij}:

	Shrubs				
Grasses	S1	S2	S3	S4	S5
G1	0.2	-0.4	-0.2	0.0	0.4
G2	-0.3	0.2	0.4	0.1	-0.4
G3	0.1	0.2	-0.2	-0.1	0.0

Table 4. Mean of 100 simulations of estimates of shrub effects and interaction with grasses

A. Shrub Effects			
	Shrub S j	True value (ψ_j)	Average of 100 simulations
	S1	-1.0	-0.997
	S2	-0.5	-0.518
	S3	1.0	1.068
	S4	0.5	0.478
	S5	0.0	-0.031
SE			±0.325

SE= Estimated standard error

Table 4. Mean of 100 simulations of estimates of shrub effects and interaction with grasses (continued)

A. Shrub x Grass interaction

Grass *i*	Shrub Sj	True value (δ_{ij})	Average of 100 simulations
1	S1	0.2	0.230
	S2	-0.4	-0.447
	S3	-0.2	-0.200
	S4	0	-0.018
	S5	0.4	0.435
2	S1	-0.3	-0.344
	S2	0.2	0.248
	S3	0.4	0.372
	S4	0.1	0.122
	S5	-0.4	-0.399
3	S1	0.1	0.114
	S2	0.2	0.199
	S3	-0.2	-0.172
	S4	-0.1	-0.104
	S5	0.0	-0.037
SE			±0.455

SE= Estimated standard error

Acknowledgements, Summary and Scope:

1. Thanks for discussions with Dr. Mounir Louhaichi and Ms Sawsan Hassan, Range Ecology and Management Research Team, SIRPS, ICARDA, Amman.
2. A few designs discussed for conducting alley cropping trials.
3. Steps for analysis presented and illustrated.

4. Intercrops:

   These designs and the approach of analysis can also be adapted for examining interactions or interference in intercropping experiments +
   further extension to analyze two or more correlated responses on the component crops.

5. The designs may be of interest to the researchers at Indian Grassland and Forage Research Institute (ICAR), Jhansi and CGIAR Centers such as ICARDA, IITA, CIFOR, among others.

Dhanyavadah!