DISCUSSION PAPER
No.3

Augmented Designs for International Yield Trials

by

Roger G. Petersen

The International Center For Agricultural Research In The Dry Areas
(ICARDA)

July 1980

PREFACE

This Discussion Paper was written by Roger G. Petersen, a statistician and biometrician working at ICARDA on sabbatical leave from Oregon State University, U.S.A.

The paper is written for scientists involved in International Yield Trials at ICARDA, for collaborating scientists throughout the Near East and North Africa and for other institutions involved in similar trials.

CONTENTS

		Page
1.	Introduction	1
2.	Design plan	1
3.	Analysis	3
4.	Example	7

1. Introduction

The international yield trial program at ICARDA involves screening a large number of new varieties at a large number of locations around the world. In the past, these trials consisted of single rows of the new varieties along with rows of a check, or standard, variety placed systematically throughout the trial. The new varieties were evaluated, subjectively, by comparing their yield to that of a nearby check. Since the new varieties were not replicated no valid means of statistical analysis was available.

In an effort to put yield evaluation on a sounder statistical basis the Food Legume Improvement Program and the Cereals Improvement Program have adopted "augmented designs" for some of their yield screening trials. These designs were developed by W.T. Federer ('Augmented designs'., Hawaiin Planters' Record 55, 191-208, 1956) for the purpose of the evaluation, including statistical analysis, of a large number of varieties.

2. Design plan

The basic design plan is to divide the experimental area into a number of blocks. With augmented designs, three or more check varieties are included within each block, while the remaining plots in each block are assigned to the new variety under test. The new varieties are not replicated but are assigned at random throughout the blocks. Their yields are adjusted for block differences, which are measured by the yields of the check varieties which occur in every block.

Blocks need not all be of the same size, but if they are the trial is more efficient. Block size is determined by the number of blocks, b, the number of check varieties, c, the number of new varieties, v. In general the following definitions and relations hold:

c = number of check varieties

v = number of new varieties

b = number of blocks

$n = v/b$ = number of new varieties per block

$p = c + n$ = number of plots per block

$N = bc + v = b\,(c+n)$ = total number of plots.

The total number of blocks is determined by the need to have at least 10 degrees of freedom for error in the analysis of the yield data. This in turn is determined by the number of check varieties (c) used in the trial, there being c-1 degrees of freedom for error contributed by each block. As a result the minumum number of blocks (b) must be such that the following relation holds:

$$b > 10/(c-1)$$

For example, with three check varieties then

$$b > 10/(3-1) = b > 5$$

The minimum number of blocks would be five.

In constructing the design the checks are randomly assigned to plots within each block. Little is lost, however, if one check variety is systematically assigned to, say, the first plot in each block. The other c-1 checks are then assigned at random to c-1 of the remaining plots in the block. The v new varieties are then assigned at random to the bn remaining plots in the experiment.

For example, suppose we have three checks and 20 new varieties. Assume we want to use five blocks. Then

c = 3 : A, B, C
v = 20 : 1, 2, ... 20
b = 5
n = v/b = 20/5 = 4
p = c + n = 3 + 4 = 7
N = bc + v = 15 + 20 = 35

The field plan might appear as follows:

I	II	III	IV	V
A	A	A	A	A
3	9	B	6	15
5	C	18	7	C
B	4	1	C	B
20	12	C	16	19
17	10	13	B	8
C	B	2	14	11

3. Analysis

The first step in the analysis is to construct a two-way table of check yields, totals and means:

Check Variety	Block 1	2	3	...	b	Total	Mean
1	x_{11}	x_{12}	x_{13}	...	x_{1b}	C_1	$\bar{x}_1$
2	x_{21}	x_{22}	x_{23}	...	x_{2b}	C_2	$\bar{x}_2$
.	.	.	.		.	.	.
.	.	.	.		.	.	.
.	.	.	.		.	.	.
c	x_{c1}	x_{c2}	x_{c3}	...	x_{c6}	C_c	$\bar{x}_c$
TOTAL	B_1	B_2	B_3	...	B_b	G	M

In which

x_{ij} = yield of i^{th} check in j^{th} block

$B_j = \sum_i x_{ij}$ = sum of all checks in j^{th} block

$C_i = \sum_j x_{ij}$ = sum of all yields of 1^{th} check

$G = \sum_j B_j = \sum_i C_i$ = Grand total of all checks

$\bar{x}_i = C_i/b$ = Mean of i^{th} check

$M = \sum_i \bar{x}_i$ = G/b = sum of check means

The next step is to compute a block effect, r_j, for each block where

$$r_j = (1/c)\ (B_j - M)$$

Note that as a check on computation, $\sum_j r_j = 0$

A table of adjusted and unadjusted yields for the new varieties can now be constructed.

Variety	Block	Yield	
		Unadj.	Adj.
1		y_{1j}	$\hat{y}_1$
2		y_{2j}	$\hat{y}_2$
3		y_{3j}	$\hat{y}_3$
.		.	.
.		.	.
.		.	.
V		y_{vj}	$\hat{y}_v$

Where

y_{ij} = Yield of the i^{th} new variety (in the j^{th} Block)

$y_i = y_{iv} - r_j$ = Adjusted yield of the i^{th} variety, adjusted for Block differences.

To obtain an estimate of error for computing L.S.D.'s or other ways of comparing means the following ANOVA is used:

A N O V A

Source	df	SS	MS
Total	bc - 1	SSTOT	
Blocks	b - 1	SSB	
Checks	c - 1	SSC	
Error	(b-1)(c-1)	SSE	MSE

The computations for this ANOVA table are:

$$SSTOT = \sum_i \sum_j x_{ij}^2 - G^2/bc$$

$$SSB = (1/c) \sum_j B_j^2 - G^2/bc$$

$$SSC = (1/b) \sum_i C_i^2 - G^2/bc$$

$$SSE = SSTOT - SSB - SSC$$

$$MSE = SSE/\ (b-1)(c-1)$$

Note: This is simply a randomised block ANOVA on the check yields.

$MSE = S^2$ is an estimate of error.

Variances:

1. Difference between two check means: 2 SE/b
2. Difference between adjusted yields of two varieties in the same block: 2 MSE
3. Difference between adjusted yields of two varieties in different blocks-: 2 MSE (1 + 1/c)
4. Difference between an adjusted variety yield and a check mean -: MSE (b + 1)(c + 1)/bc

Least significant difference (L.S.D.'s) :

1. Check Means LSD = $t_{\alpha} \sqrt{2\ MSE/b}$
2. Adjusted varieties in same block

$$LSD = t_{\alpha} \sqrt{2\ MSE}$$

3. Adjusted varieties in different blocks

$$LSD = t_{\alpha} \sqrt{2\ MSE\ (c + 1)/c}$$

4. Adjusted variety against check mean

$$LSD = t_{\alpha} \sqrt{MSE\ (b + 1)(c + 1)/bc}$$

For all L.S.D.'s t_{α} has (b-1)(c-1) d.f.

(A computer program has been written for the analysis of data from an augmented design using the HP9825 computer. This program is available on request).

4. Example

3 check varieties	(c = 3)
12 new varieties	(v = 12)
3 blocks	(b = 3)
7 plots/block	(p = 7)
21 total plots	(N = 21)

Field lay-out and yields

A	83	A	79	A	92
(10)	89	(4)	96	(2)	89
(7)	75	(8)	74	C	87
B	77	B	81	(9)	98
(5)	78	C	81	B	89
C	78	(3)	70	(6)	82
(11)	82	(12)	92	(1)	79

Table of check yields

	Block				
Check	1	2	3	Total	Mean
A	83	79	92	254	84.67
B	77	81	89	247	82.33
C	78	81	87	246	82.00
Total:	238	241	268	747	249.00

Block adjustments, $r_j = (1/c)(Bj-M)$

$r_1 = (1/3)(238-249) = -3.67$

$r_2 = (1/3)(241-249) = -2.67$

$r_3 = (1/3)(268-249) = \underline{\ 6.33}$

SUM -0.01

Adjusted and unadjusted variety yields:

Variety	Block	Unadj.	Adj.
1	3	79	72.67
2	3	89	82.67
3	2	70	72.67
4	2	96	98.67
5	1	78	81.67
6	3	82	75.67
7	1	75	78.67
8	2	74	76.67
9	3	98	91.67
10	1	89	92.67
11	1	82	85.67
12	2	92	94.67

A N O V A

Source	d f	SS	MS
TOTAL	8	218.00	
Blocks	2	182.00	
Checks	2	12.67	
Error	4	23.33	5.83

$$\% \text{ CV} = (c \sqrt{MSE/m})\ 100$$
$$= (3 \sqrt{5.83/249})\ 100 = 2.9\%$$

L.S.D.'s (5%)

1. Check means

$$LSD = t_{\alpha}\sqrt{2\ MSE/b}$$
$$= 2.776 \sqrt{(2)(5.83)/3}$$
$$= 5.48$$

2. Adjusted Varieties in same Block:

$$LSD = t_{\alpha}\sqrt{2MSE}$$
$$= 2.776 \sqrt{(2)\ (5.83)}$$
$$= 9.49$$

3. Adjusted Varieties in different Blocks:

$$LSD = t_{\alpha}\sqrt{2MSE\ (c+1)/c}$$
$$= 2.776 \sqrt{(2 \times 5.83 \times 3+1)/3}$$
$$= 10.96$$

4. Adjusted Variety vs. Check Mean:

$$LSD = t_{\alpha}\sqrt{MSE\ (b+1)(c+1)/bc}$$
$$= 2.776 \sqrt{5.83\ (3+1)(3+1)/3.3}$$
$$= 8.95$$