

Data Set 7: Cowpea Varietal Trial

Statistical Setting

This handout is an example of a randomized-block single-factor ANOVA with one observation per cell.

Background and Data

Twelve lines (varieties) of cowpea were obtained from the International Institute of Tropical Agriculture in Nigeria, and tested in a field trial in Nepal; the objective was to determine which lines were most productive under the Nepalese growing conditions.

The study was done in one large field, which was divided into four blocks. Each block was divided into twelve 4m x 2m plots. The twelve lines were randomly assigned to plots within each block; 80 plants of a given line were grown in each plot. Once fruits were ripe five haphazardly selected pods were collected from each plot, and the mean number of seeds per pod was determined (for each set of five pods).

[There obviously were some problems with this study design. First, more blocks of smaller plots (few plants) would have been preferable. Second, some proper form of random selection should have been used to select pods to be collected. Finally, neither pod length or seeds per pod seem likely the most useful measures of production.]

Data

line:	1	2	3	4	5	6	7	8	9	10	11	12
blk 1:	15.2	8.8	12.3	7.6	9.1	11.2	9.7	9.9	12.5	15.5	10.8	10.8
blk 2:	15.4	11.0	12.1	11.8	10.3	12.0	9.6	11.2	13.1	12.9	8.9	10.6
blk 3:	15.8	9.5	12.5	10.8	10.8	9.3	11.0	9.6	10.6	14.9	11.4	8.6
blk 4:	17.3	7.0	12.2	10.3	9.9	11.1	9.0	11.0	13.0	14.2	9.6	8.8

Preliminary Data Exploration

Descriptive Statistics

line	N	Mean	Median	TrMean	StDev
1	4	15.925	15.600	15.925	0.950
2	4	9.075	9.150	9.075	1.660
3	4	12.275	12.250	12.275	0.171
4	4	10.125	10.550	10.125	1.795
5	4	10.025	10.100	10.025	0.718
6	4	10.900	11.150	10.900	1.140
7	4	9.825	9.650	9.825	0.842
8	4	10.425	10.450	10.425	0.793
9	4	12.300	12.750	12.300	1.163
10	4	14.375	14.550	14.375	1.118
11	4	10.175	10.200	10.175	1.132
12	4	9.700	9.700	9.700	1.160

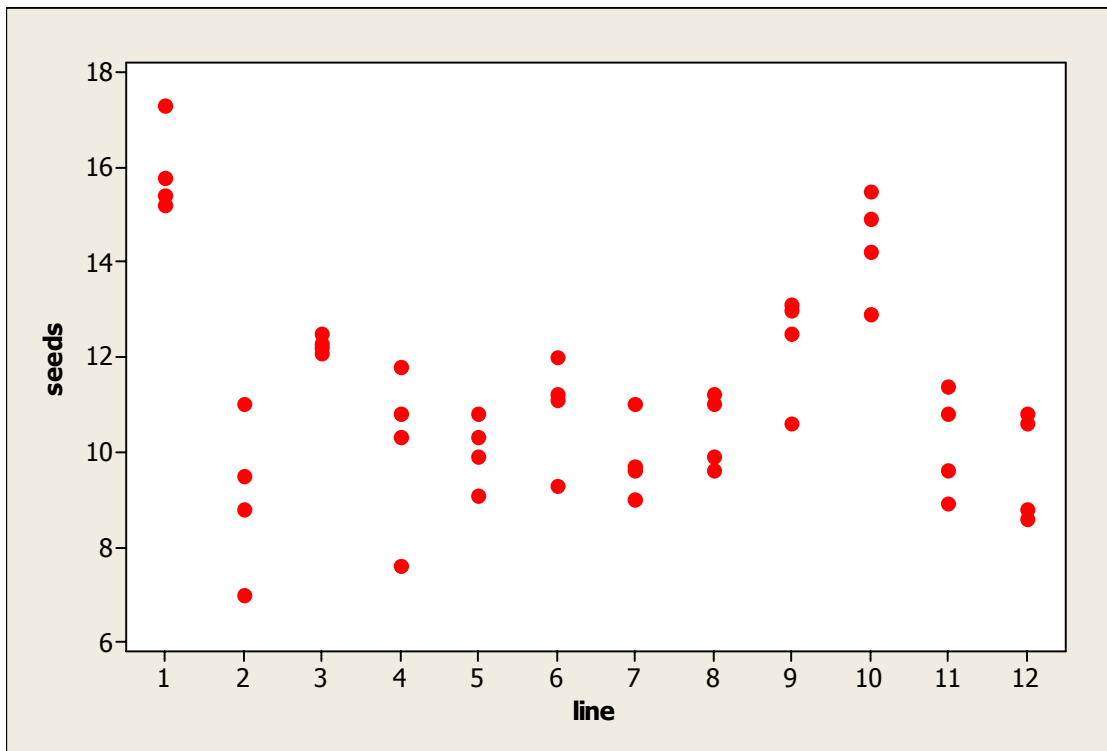
Most lines averaged about 10 seeds/pod, with lines 1 and 10 having considerably larger means. Medians and means were similar, indicating symmetric distributions. Most standard deviations were about 1 (which is quite small relative to the means), with line 3 having much less variation and line 2 having somewhat greater variation.

Block	N	Mean	Median	TrMean	StDev
1	12	11.117	10.800	11.030	2.425
2	12	11.575	11.500	11.460	1.740
3	12	11.233	10.800	11.040	2.197
4	12	11.117	10.650	10.910	2.759

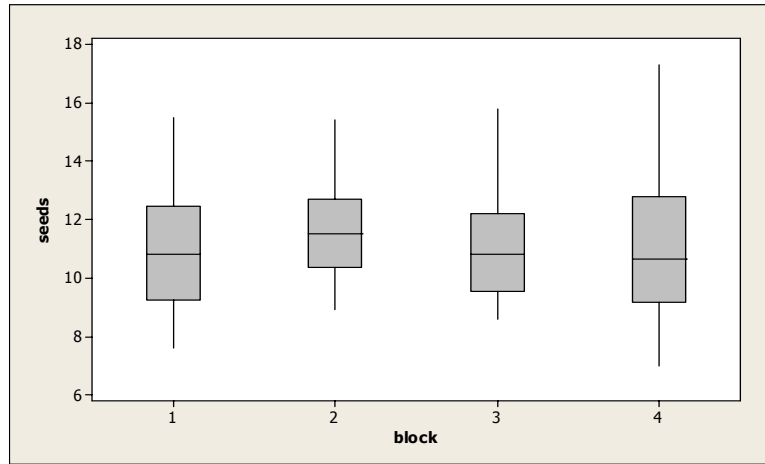
There were no substantial differences among blocks.

Plots

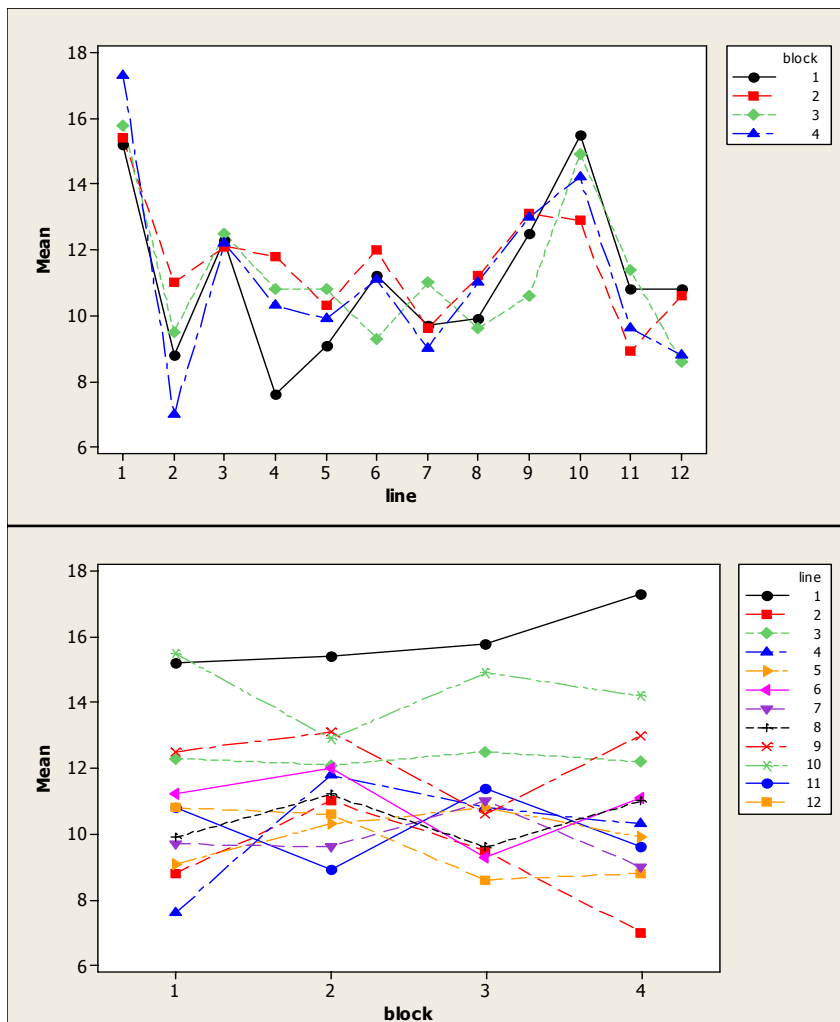
Since there are only four observations per line, dot plots are more appropriate than box plots (and can be implemented simply as a scatter plot, since the “group” variable is coded numerically). This plot shows the same features as the descriptive statistics: higher values for line 10 and especially line 1, with fairly similar amounts of spread except for the tight cluster for line 3.



Blocks can be compared by boxplots, which show the overall similarity among blocks, and also somewhat greater spread in block 4.



It also is useful to look at interaction plots, to assess visually whether the differences among lines are consistent across the blocks. This appears to be the case, particularly for the lines with the most seeds per pod: there is some crossing of lines, but not a great deal.



ANOVA

This randomized-block design without replication is analyzed using the additive two-factor ANOVA model. This can be interpreted either as a fixed-effects model with the assumption of no interaction, or as a mixed model (random block effects) with the “error” term actually representing the **line x block** interaction.

The “line” effect is highly significant, while the block effect is not significant.

Source	df	SS	MS	F	P
Model	14	192.340	13.739	10.26	0.0001
Error	33	44.195	1.339		
Corrected Total	47	236.535			
Line	11	190.647	17.332	12.94	0.0001
Block	3	1.692	0.564	0.42	0.7390

Analysis of Effects

Given the preceding results, and the absence of any *a priori* hypotheses concerning particular lines, the appropriate follow-up analysis is Tukey pairwise comparisons among means for the lines (see next page). At an overall α of 0.05, these comparisons indicate that:

- lines 1 and 10 had significantly more seeds/pod than any other line, but were not significantly different from each other;
- line 2 had significantly fewer seeds/pod than lines 1, 3, 9 and 10; and
- there were no other significant differences.

These results are shown graphically on the last page (Conclusions).

Aptness of ANOVA Model

From the design of the experiment, it can be assumed that observations are independent unless the plots were near enough to each other for the plants in one to affect those in another plot. There is no way to assess this possible problem from the available data.

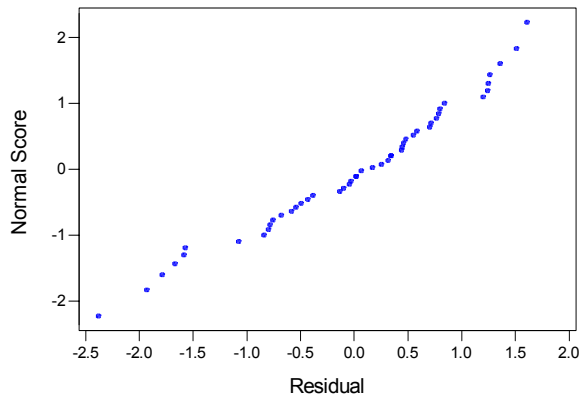
The very small standard deviation for line 3 is troublesome. Bearing in mind, however, that each standard deviation was calculated from only four observations, and that there are 12 of them being compared, this degree of difference could be due to chance. Supporting this is that Levene’s test for homogeneity of variances was strongly nonsignificant for comparisons across lines and across blocks. The equal sample sizes also make the analysis fairly robust to unequal variances. I therefore chose to assume that the population variances are equal.

The residuals appear reasonably close to normally distributed (see NQQ plot at bottom of next page).

I therefore feel the ANOVA model and analysis are valid for these data.

	Difference of Means	T	Adjusted P-Value
line = 1 subtracted from:			
2	-6.850	-8.371	0.0000
3	-3.650	-4.460	0.0044
4	-5.800	-7.088	0.0000
5	-5.900	-7.210	0.0000
6	-5.025	-6.141	0.0001
7	-6.100	-7.454	0.0000
8	-5.500	-6.721	0.0000
9	-3.625	-4.430	0.0048
10	-1.550	-1.894	0.7544
11	-5.750	-7.027	0.0000
12	-6.225	-7.607	0.0000
line = 2 subtracted from:			
3	3.2000	3.9105	0.0187
4	1.0500	1.2831	0.9757
5	0.9500	1.1609	0.9886
6	1.8250	2.2302	0.5412
7	0.7500	0.9165	0.9984
8	1.3500	1.6498	0.8774
9	3.2250	3.9411	0.0173
10	5.3000	6.4768	0.0000
11	1.1000	1.3442	0.9662
12	0.6250	0.7638	0.9997
line = 3 subtracted from:			
4	-2.150	-2.627	0.3055
5	-2.250	-2.750	0.2475
6	-1.375	-1.680	0.8644
7	-2.450	-2.994	0.1556
8	-1.850	-2.261	0.5213
9	0.025	0.031	1.0000
10	2.100	2.566	0.3375
11	-2.100	-2.566	0.3375
12	-2.575	-3.147	0.1135
line = 4 subtracted from:			
5	-0.1000	-0.1222	1.0000
6	0.7750	0.9471	0.9979
7	-0.3000	-0.3666	1.0000
8	0.3000	0.3666	1.0000
9	2.1750	2.6579	0.2903
10	4.2500	5.1937	0.0006
11	0.0500	0.0611	1.0000
12	-0.4250	-0.5194	1.0000

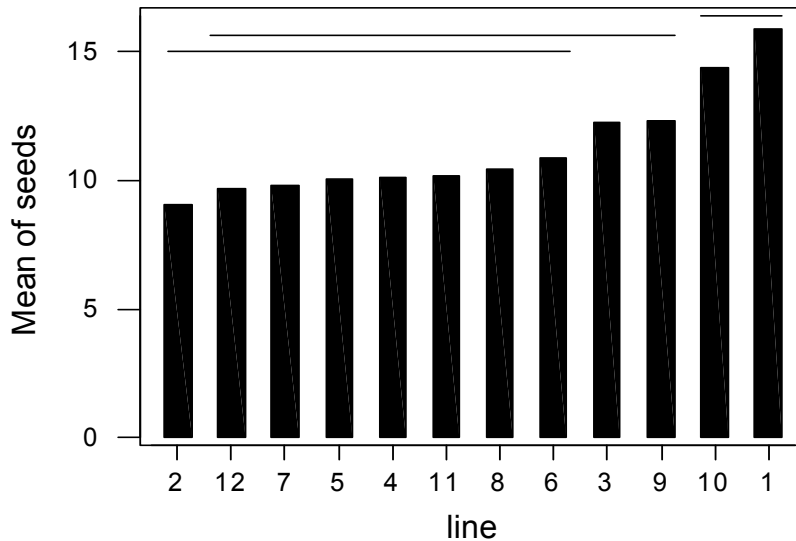
Level line	Difference of Means	T	Adjusted P-Value
line = 5 subtracted from:			
6	0.8750	1.0693	0.9941
7	-0.2000	-0.2444	1.0000
8	0.4000	0.4888	1.0000
9	2.2750	2.7801	0.2342
10	4.3500	5.3159	0.0004
11	0.1500	0.1833	1.0000
12	-0.3250	-0.3972	1.0000
line = 6 subtracted from:			
7	-1.075	-1.314	0.9713
8	-0.475	-0.580	1.0000
9	1.400	1.711	0.8507
10	3.475	4.247	0.0078
11	-0.725	-0.886	0.9988
12	-1.200	-1.466	0.9395
line = 7 subtracted from:			
8	0.6000	0.7332	0.9998
9	2.4750	3.0245	0.1463
10	4.5500	5.5603	0.0002
11	0.3500	0.4277	1.0000
12	-0.1250	-0.1528	1.0000
line = 8 subtracted from:			
9	1.8750	2.2913	0.5016
10	3.9500	4.8270	0.0016
11	-0.2500	-0.3055	1.0000
12	-0.7250	-0.8860	0.9988
line = 9 subtracted from:			
10	2.075	2.536	0.3542
11	-2.125	-2.597	0.3213
12	-2.600	-3.177	0.1063
line = 10 subtracted from:			
11	-4.200	-5.133	0.0007
12	-4.675	-5.713	0.0002
line = 11 subtracted from:			
12	-0.4750	-0.5805	1.0000



Conclusion

The conclusion is obvious: there is very strong evidence that the lines differ in the mean number of peas per pod. That is, there are differences which are quite consistent across the blocks. Lines 1 and 10 stand out as having substantially more seeds per pod than the other lines.

The following chart summarizes these results. Varieties (“lines”) which are connected by one of the bars across the top of the chart are not significantly different from each other.



The blocks appear not to differ much. More precisely, there are no block effects which are consistent for all the different lines.

These conclusions could be considered to apply to any other plots similar to those in this study (*i.e.* to whatever “population” of conditions the researchers felt their blocks could be regarded as a representative sample of).