Using ARM to Plan Experiments Based on Required Precision

Steven R. Gylling, Ph.D.
Gylling Data Management, Inc.

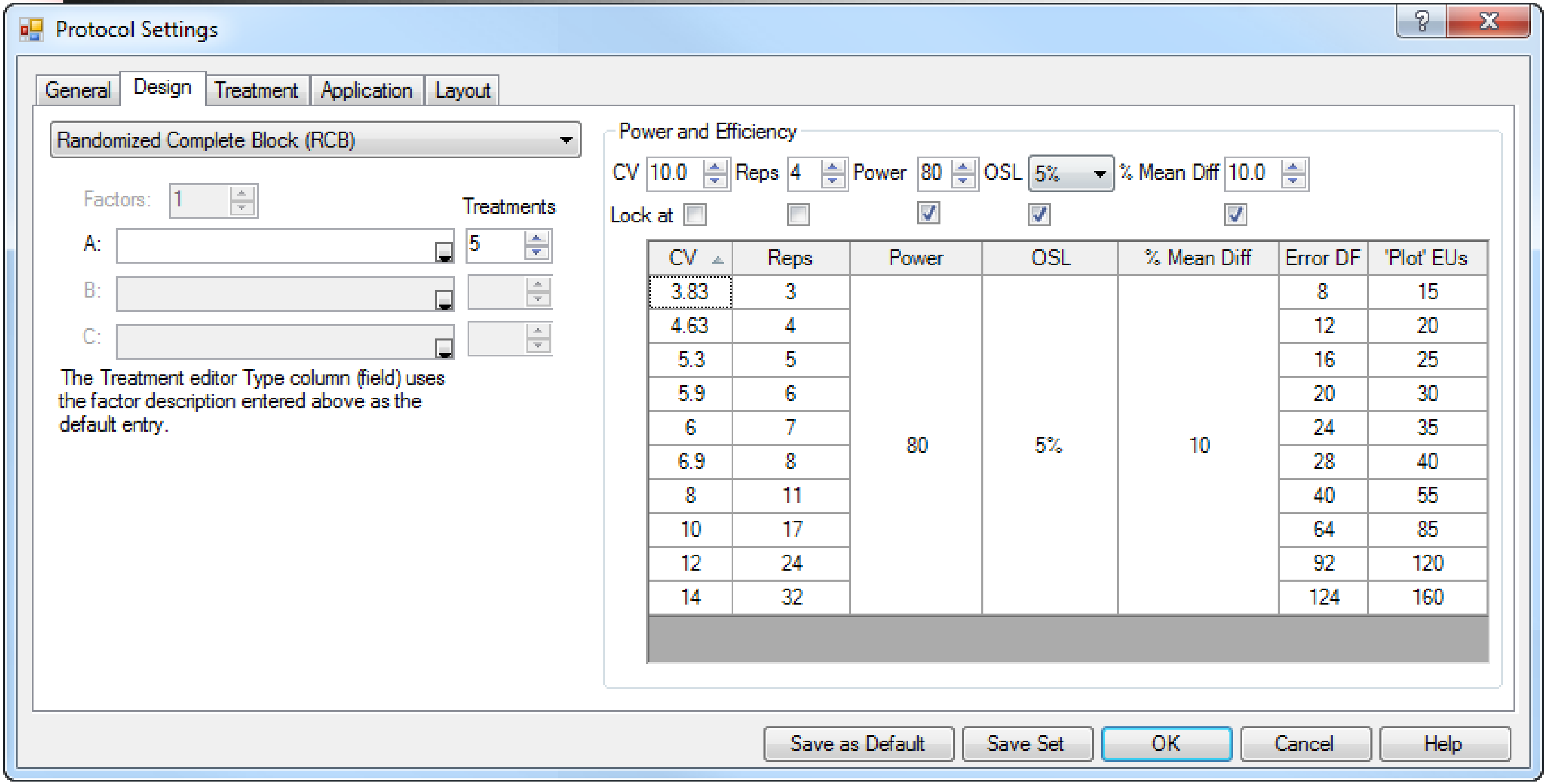
Plan Experiments to Have:

- A reasonable chance of distinguishing anticipated treatment differences
- The optimum number of replicates required to meet objectives
- An efficient experimental design and randomization for desired precision
- Cost-effective utilization of the available experimental area

Why is Planning Critical?

- Can reduce costs by selecting optimum number of replicates and samples
- Expected treatment differences are typically < 10%, and frequently < 5%, so small precision gains can help to:
  - Distinguish an actual treatment difference (reject null hypothesis H_0)
  - Strengthen evidence of no treatment diff.) (do not reject null hypothesis H_0)

ARM 10.2015
Power and Efficiency Planner



Randomized Complete Block (RCB)

Factors: 1

Treatments

A: 5

B:

C:

The Treatment editor Type column (field) uses the factor description entered above as the default entry.

Power and Efficiency

CV 10.0 Reps 4 Power 80 OSL 5% % Mean Diff 10.0

Lock at ☐ ☐ ☑ ☑ ☑

CV	Reps	Power	OSL	% Mean Diff	Error DF	'Plot' EUs
3.83	3	80	5%	10	8	15
4.63	4				12	20
5.3	5				16	25
5.9	6				20	30
6	7				24	35
6.9	8				28	40
8	11				40	55
10	17				64	85
12	24				92	120
14	32				124	160

ARM 10.2015
Power and Efficiency Planner

- Calculates "power" based on:
    - Estimated CV of key assessment (e.g. yield)
    - Number of replicates
    - Power = Level of certainty to detect “real” treatment effects (80% or 90%)
    - Observed Significance Level (e.g. 5%, 10%)
    - % Mean Diff = estimated treatment effect, expressed as percentage of overall (grand) mean across treatments of key assessment

Power and Efficiency Planner

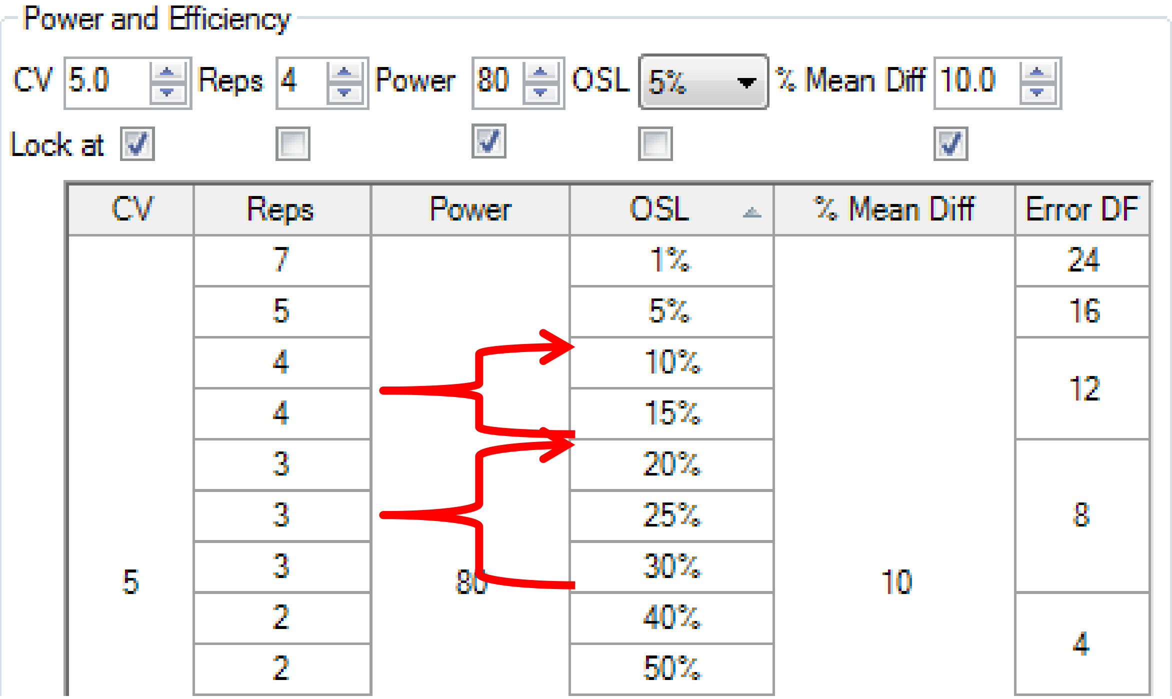
Power and Efficiency

	CV	Reps	Power	OSL	% Mean Diff
	10.0	4	80	5%	10.0
Lock at	☐	☐	☑	☑	☑

- "Lock at" to keep 3-4 columns constant
- Calculates table of possible values for "unlocked" columns (e.g. Rep or CV)
- Values entered by protocol writer are carried into trials created from protocol, conveying protocol expectations

Power and Efficiency Planner

Plan replicates to achieve required precision
5 treatments with CV=5, 10% mean diff.



Power and Efficiency

CV 5.0 Reps 4 Power 80 OSL 5% % Mean Diff 10.0

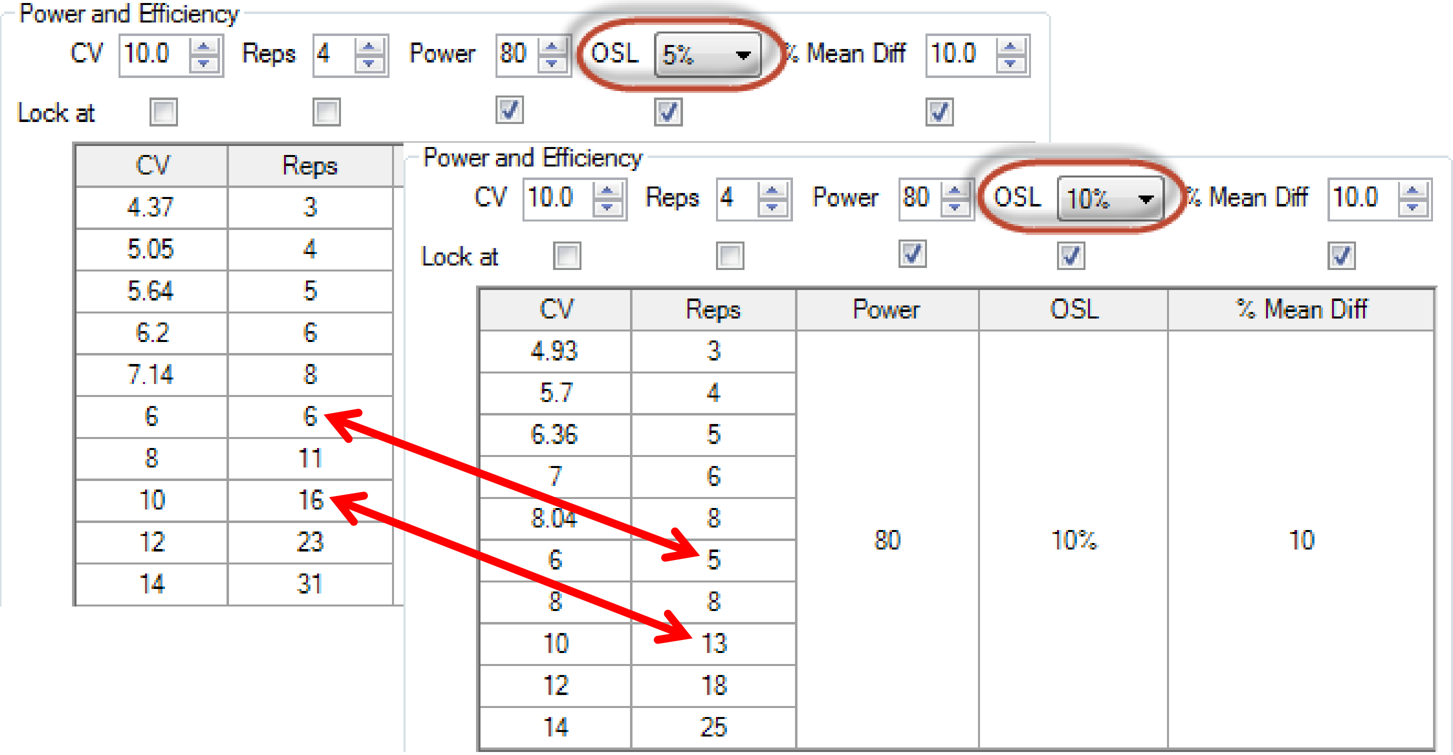
Lock at ☑ ☐ ☑ ☐ ☑

CV	Reps	Power	OSL	% Mean Diff	Error DF
5	7	80	1%	10	24
	5		5%		16
	4		10%		12
	4		15%		
	3		20%		8
	3		25%		
	3		30%		
	2		40%		4
	2		50%		

Summary		
Reps	OSL=Significance	
7	1%	0.01
5	5%	0.05
4	10-15%	0.1-0.15
3	20-30%	0.2-0.3
2	40-50%	0.4-0.5

Power and Efficiency Planner

Compare effect of significance level on minimum replicates for CV=6% vs. 10%



Power and Efficiency

CV 10.0 Reps 4 Power 80 OSL 5% % Mean Diff 10.0

Lock at ☐ ☐ ☑ ☑ ☑

CV	Reps
4.37	3
5.05	4
5.64	5
6.2	6
7.14	8
6	6
8	11
10	16
12	23
14	31

Power and Efficiency

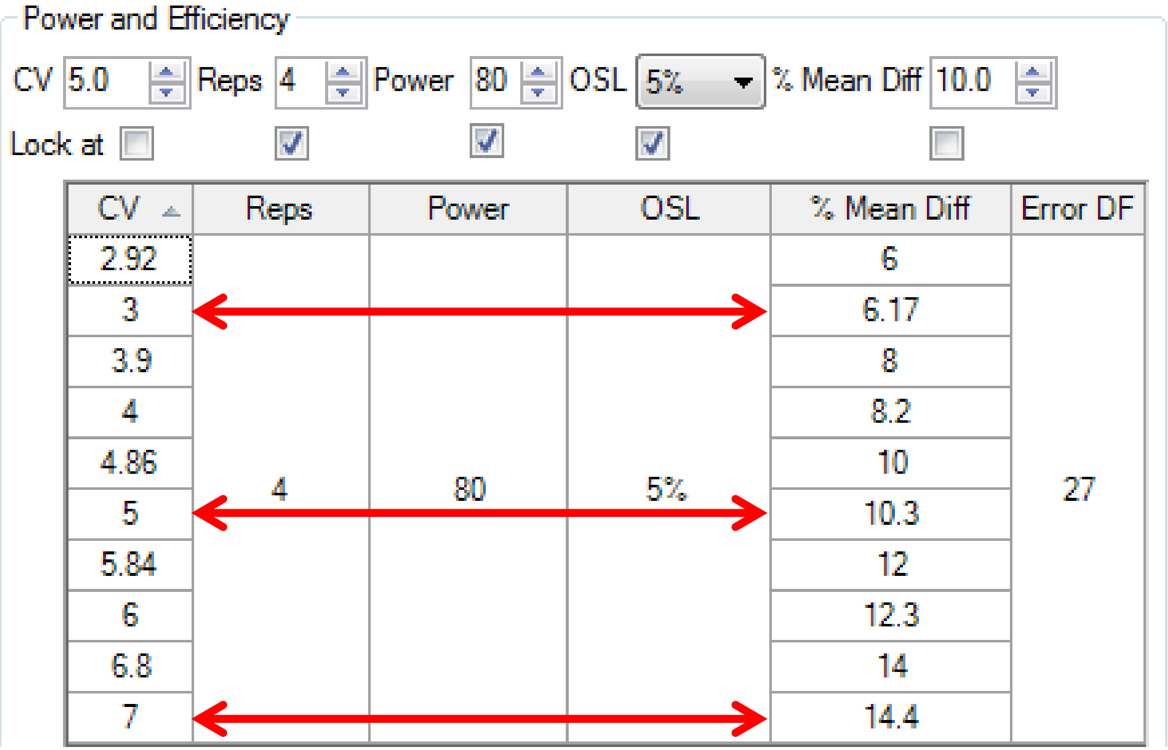
CV 10.0 Reps 4 Power 80 OSL 10% % Mean Diff 10.0

Lock at ☐ ☐ ☑ ☑ ☑

CV	Reps	Power	OSL	% Mean Diff
4.93	3	80	10%	10
5.7	4			
6.36	5			
7	6			
8.04	8			
6	5			
8	8			
10	13			
12	18			
14	25			

Power and Efficiency Planner

CV effect on min. detectable % mean difference at 5% OSL for 10 trt., 4 reps



Power and Efficiency

CV 5.0 Reps 4 Power 80 OSL 5% % Mean Diff 10.0

Lock at ☐ ☑ ☑ ☑ ☐

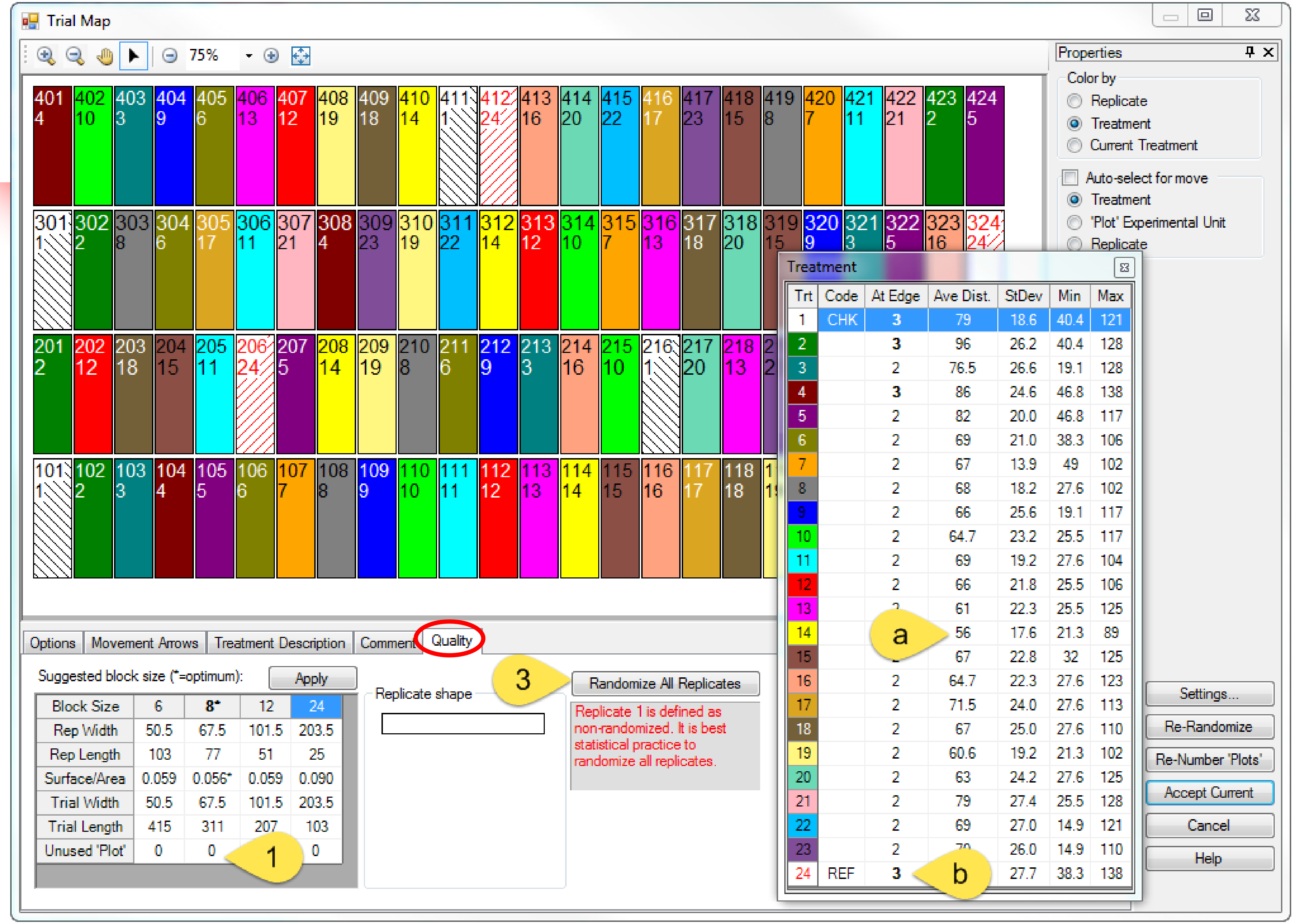
CV	Reps	Power	OSL	% Mean Diff	Error DF
2.92	4	80	5%	6	27
3				6.17	
3.9				8	
4				8.2	
4.86				10	
5				10.3	
5.84				12	
6				12.3	
6.8				14	
7				14.4	

Detectable Difference between Trt. Means	
CV	% Mean Diff.
3	6.17% difference
4	8.2% difference
5	10.3% difference
6	12.3% difference
7	14.4% difference

ARM 10.2015 Randomization Quality Review

Goal is to improve experiment precision:

1. Arrange replicates as squares, not strips
2. Equalize treatment distribution
   a. Balance average distance from all other treatments
   b. Balance "Edge effect" across treatments
3. Randomize all replicates



401 4	402 10	403 3	404 9	405 6	406 13	407 12	408 19	409 18	410 14	411 1	412 24	413 16	414 20	415 22	416 17	417 23	418 15	419 8	420 7	421 11	422 21	423 2	424 5
301 1	302 2	303 8	304 6	305 17	306 11	307 21	308 4	309 23	310 19	311 22	312 14	313 12	314 10	315 7	316 13	317 18	318 20	319 15	320 9	321 3	322 5	323 16	324 24
201 2	202 12	203 18	204 15	205 11	206 24	207 5	208 14	209 19	210 8	211 6	212 9	213 3	214 16	215 10	216 1	217 20	218 13						
101 1	102 2	103 3	104 4	105 5	106 6	107 7	108 8	109 9	110 10	111 11	112 12	113 13	114 14	115 15	116 16	117 17	118 18						

Color by
○ Replicate
● Treatment
○ Current Treatment

☐ Auto-select for move
● Treatment
○ 'Plot' Experimental Unit
○ Replicate

Trt	Code	At Edge	Ave Dist.	StDev	Min	Max
1	CHK	3	79	18.6	40.4	121
2		3	96	26.2	40.4	128
3		2	76.5	26.6	19.1	128
4		3	86	24.6	46.8	138
5		2	82	20.0	46.8	117
6		2	69	21.0	38.3	106
7		2	67	13.9	49	102
8		2	68	18.2	27.6	102
9		2	66	25.6	19.1	117
10		2	64.7	23.2	25.5	117
11		2	69	19.2	27.6	104
12		2	66	21.8	25.5	106
13		2	61	22.3	25.5	125
14			56	17.6	21.3	89
15		2	67	22.8	32	125
16		2	64.7	22.3	27.6	123
17		2	71.5	24.0	27.6	113
18		2	67	25.0	27.6	110
19		2	60.6	19.2	21.3	102
20		2	63	24.2	27.6	125
21		2	79	27.4	25.5	128
22		2	69	27.0	14.9	121
23		2	70	26.0	14.9	110
24	REF	3		27.7	38.3	138

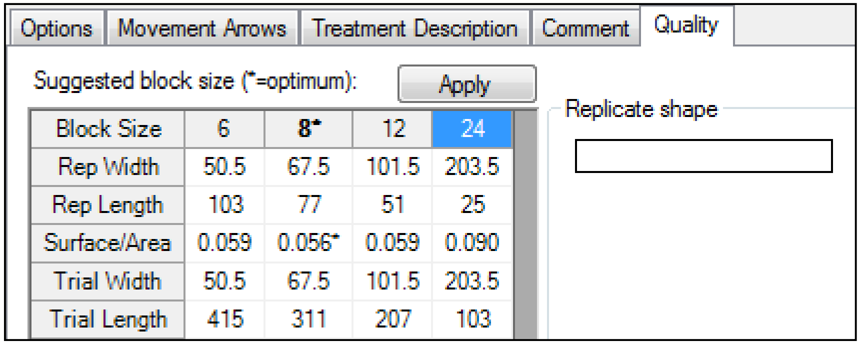
Suggested block size (*=optimum):

Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090
Trial Width	50.5	67.5	101.5	203.5
Trial Length	415	311	207	103
Unused 'Plot'	0	0		0

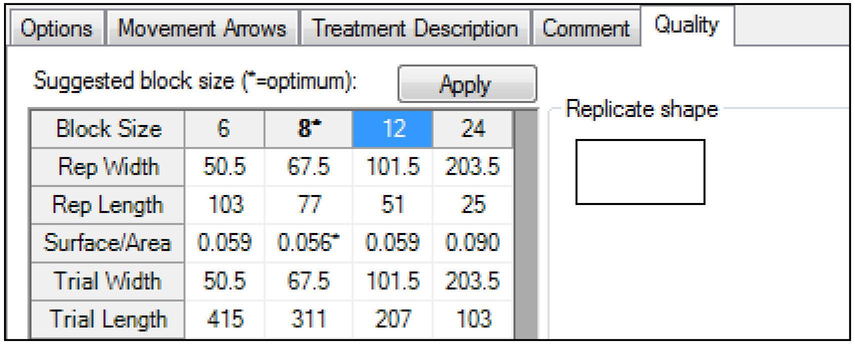
Replicate 1 is defined as non-randomized. It is best statistical practice to randomize all replicates.

Arrange Replicates as Squares not Strips

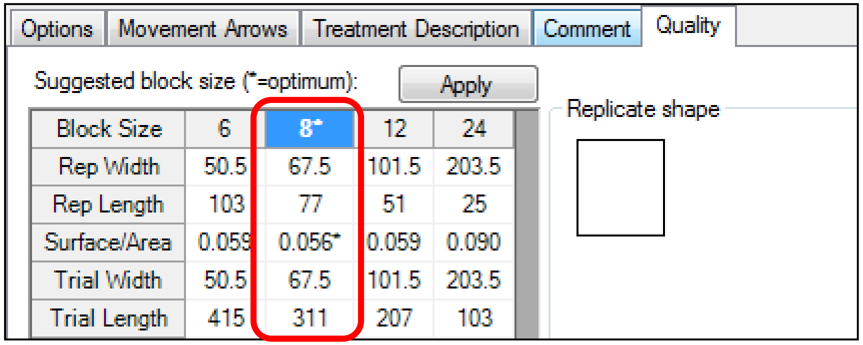
“Optimum” is smallest surface-to-area ratio



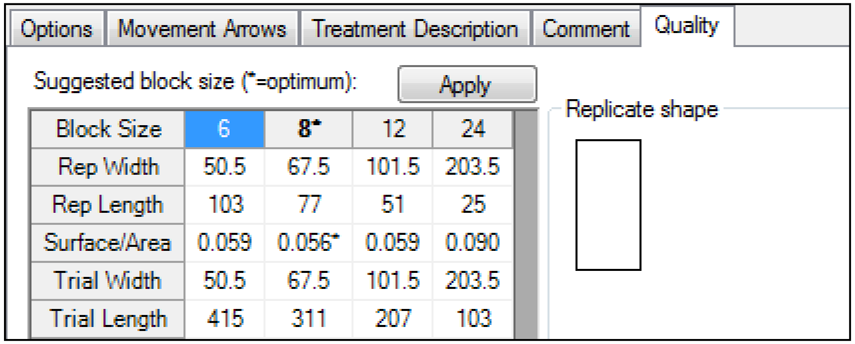
Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090
Trial Width	50.5	67.5	101.5	203.5
Trial Length	415	311	207	103



Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090
Trial Width	50.5	67.5	101.5	203.5
Trial Length	415	311	207	103



Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090
Trial Width	50.5	67.5	101.5	203.5
Trial Length	415	311	207	103

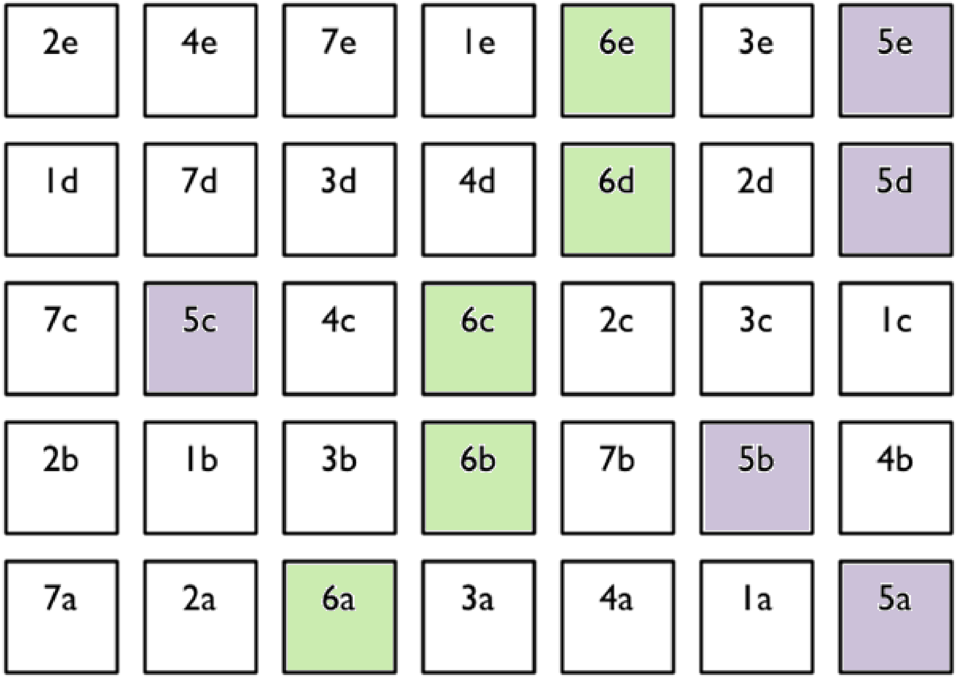


Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090
Trial Width	50.5	67.5	101.5	203.5
Trial Length	415	311	207	103

Equalize Treatment Distribution

“Undesirable” layout of 7 treatments and 5 replicates in Randomized Complete Block:

- Trt. 6 in middle 3 columns of all reps
- Trt. 5 in right 2 cols for all but one plot



2e	4e	7e	1e	6e	3e	5e
1d	7d	3d	4d	6d	2d	5d
7c	5c	4c	6c	2c	3c	1c
2b	1b	3b	6b	7b	5b	4b
7a	2a	6a	3a	4a	1a	5a

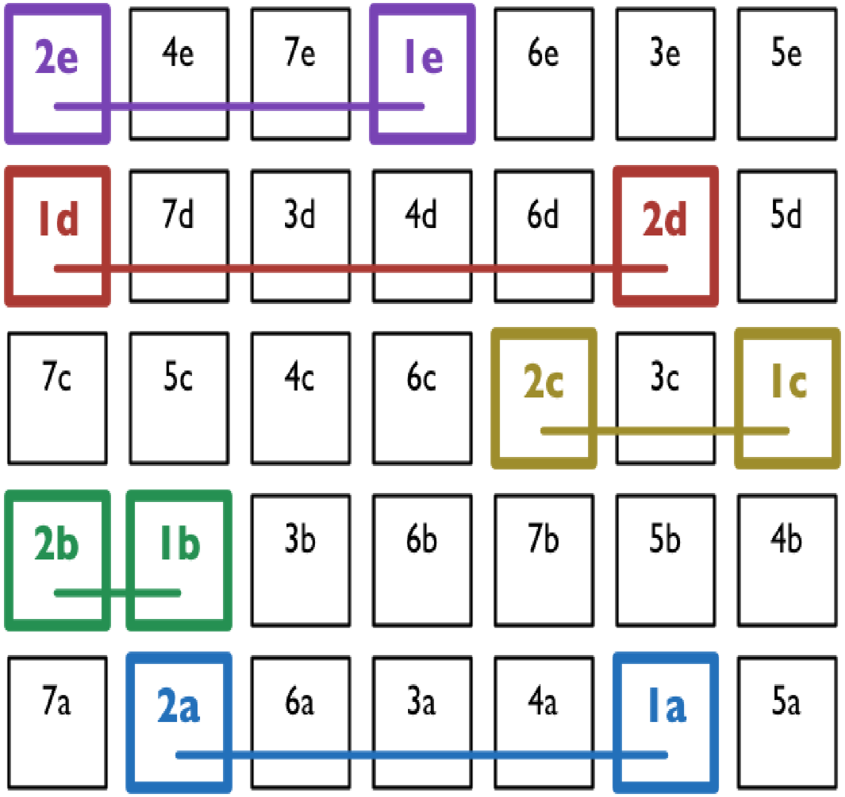
Example from Federer, “Experimental Design” 1955

Uses “Average Distance of Treatment” Comparison (ATDC)

- van Es and van Es, “Spatial Nature of Randomization and Its Effect on the Outcome of Field Experiments”, Agron J, 85:420-428 (1993).
- Comparison between treatments 1 and 2 is taken from 5 plots for each treatment.
- Measure the plot-to-plot distance for each plot containing treatment 1 to the paired plot within replicate containing treatment 2, for a total of 5 distances.
- ADTC for the treatment pair 1-2 is the average of the 5 distances.

Distances, Treatments 1-2

- Average distance = 3 plots = 24 feet for 8 foot wide plots

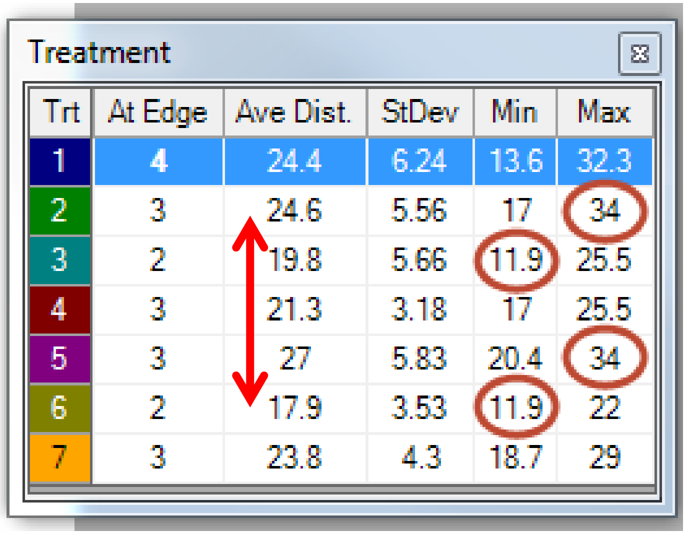


2e	4e	7e	**1e**	6e	3e	5e
1d	7d	3d	4d	6d	**2d**	5d
7c	5c	4c	6c	**2c**	3c	**1c**
2b	**1b**	3b	6b	7b	5b	4b
7a	**2a**	6a	3a	4a	**1a**	5a

Unequal Treatment Distribution

- Average distance from 17.9 to 24.6
- Ranges from 11.9(T3,T6) to 34(T2,T5)
- Error variances for treatments may not be homogeneous

501 7	502 2	503 6	504 3	505 4	506 1	507 5
401 2	402 1	403 3	404 6	405 7	406 5	407 4
301 7	302 5	303 4	304 6	305 2	306 3	307 1
201 1	202 7	203 3	204 4	205 6	206 2	207 5
101 2	102 4	103 7	104 1	105 6	106 3	107 5

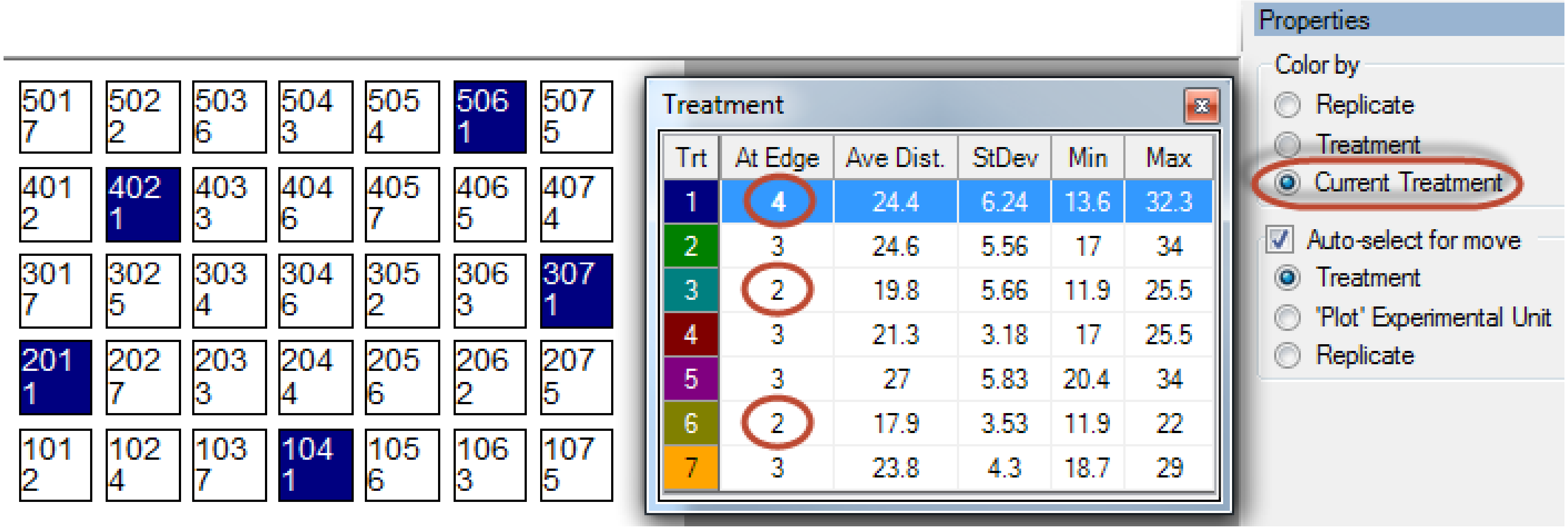


Treatment

Trt	At Edge	Ave Dist.	StDev	Min	Max
1	4	24.4	6.24	13.6	32.3
2	3	24.6	5.56	17	34
3	2	19.8	5.66	11.9	25.5
4	3	21.3	3.18	17	25.5
5	3	27	5.83	20.4	34
6	2	17.9	3.53	11.9	22
7	3	23.8	4.3	18.7	29

Unbalanced "Edge effect"

- Treatment 1 occurs at edge 4 times, T2 and T3 at edge only 2 times



501 7	502 2	503 6	504 3	505 4	506 1	507 5
401 2	402 1	403 3	404 6	405 7	406 5	407 4
301 7	302 5	303 4	304 6	305 2	306 3	307 1
201 1	202 7	203 3	204 4	205 6	206 2	207 5
101 2	102 4	103 7	104 1	105 6	106 3	107 5

Treatment

Trt	At Edge	Ave Dist.	StDev	Min	Max
1	4	24.4	6.24	13.6	32.3
2	3	24.6	5.56	17	34
3	2	19.8	5.66	11.9	25.5
4	3	21.3	3.18	17	25.5
5	3	27	5.83	20.4	34
6	2	17.9	3.53	11.9	22
7	3	23.8	4.3	18.7	29

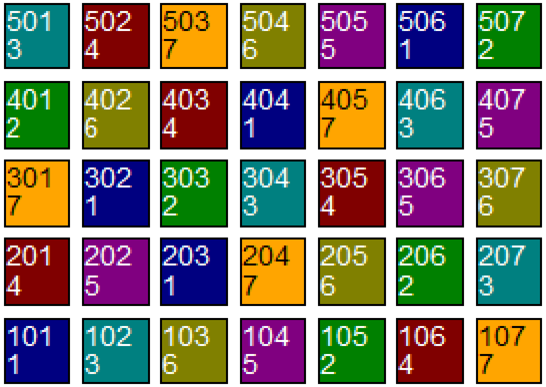
Properties

Color by
○ Replicate
○ Treatment
● Current Treatment

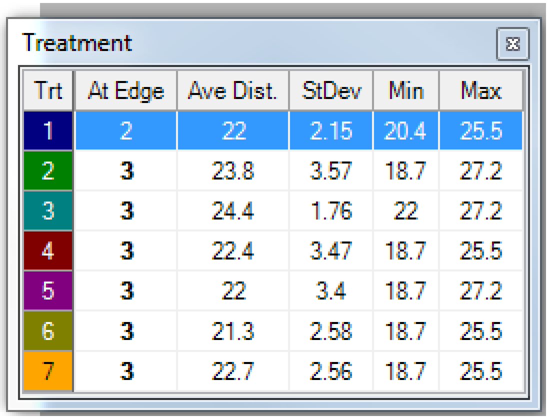
☑ Auto-select for move
● Treatment
○ 'Plot' Experimental Unit
○ Replicate

Balanced Treatment Distribution and Edge Effect

- Average distance from 21.3 to 24.4
- Distances range from 18.7 to 27.2
- “Edge effect” is balanced



501 3	502 4	503 7	504 6	505 5	506 1	507 2
401 2	402 6	403 4	404 1	405 7	406 3	407 5
301 7	302 1	303 2	304 3	305 4	306 5	307 6
201 4	202 5	203 1	204 7	205 6	206 2	207 3
101 1	102 3	103 6	104 5	105 2	106 4	107 7

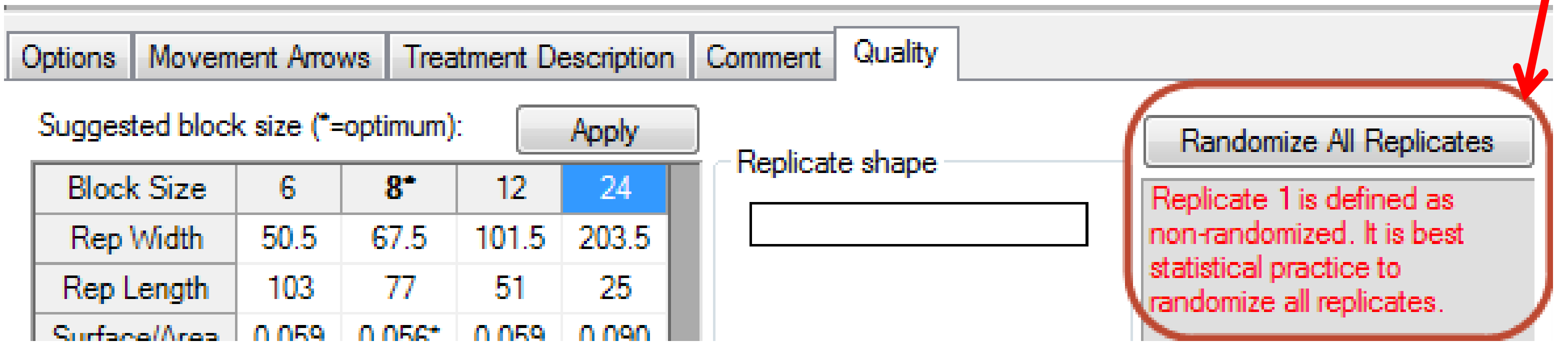


Treatment

Trt	At Edge	Ave Dist.	StDev	Min	Max
1	2	22	2.15	20.4	25.5
2	3	23.8	3.57	18.7	27.2
3	3	24.4	1.76	22	27.2
4	3	22.4	3.47	18.7	25.5
5	3	22	3.4	18.7	27.2
6	3	21.3	2.58	18.7	25.5
7	3	22.7	2.56	18.7	25.5

Randomize All Replicates

- This frame displays when a non-randomized replicate is defined in Settings
- Select “Randomize All Replicates” to follow recommended statistical practice



Suggested block size (*=optimum):

Block Size	6	8*	12	24
Rep Width	50.5	67.5	101.5	203.5
Rep Length	103	77	51	25
Surface/Area	0.059	0.056*	0.059	0.090

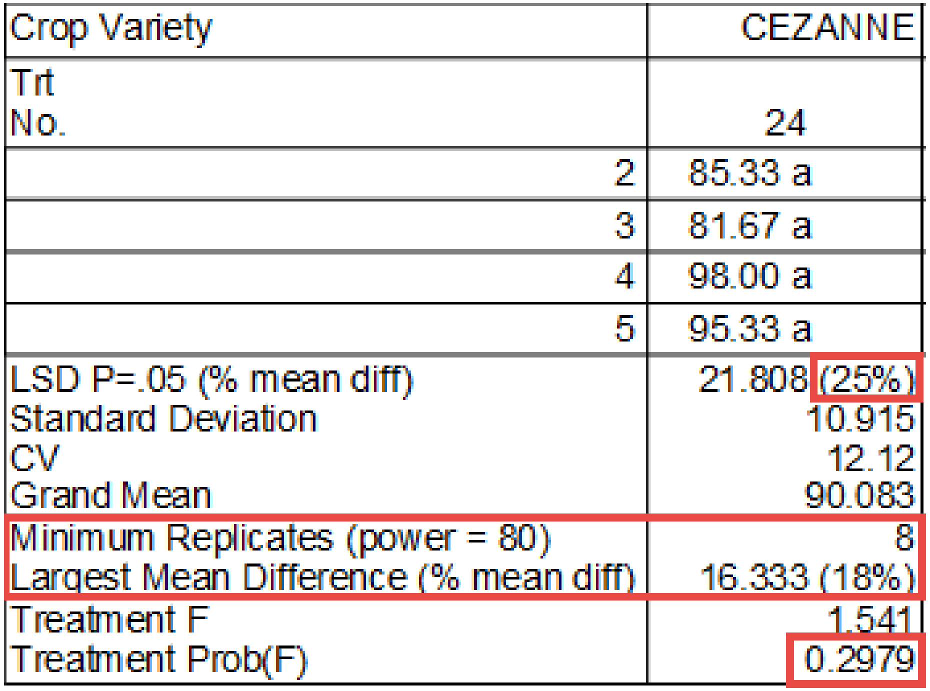
Replicate 1 is defined as non-randomized. It is best statistical practice to randomize all replicates.

ARM 10.2015
Post-hoc Power Analysis

- Optional descriptive statistic printed on AOV Means Table report
- Lists, for each assessment column, the minimum number of replicates required to statistically separate treatment means based on Treatment P(F) and current significance level
- Use for planning future trials

Post-hoc Power Analysis

- In example, LSD can distinguish 25% mean difference (largest existing difference is 18%)
- Current AOV Trt P(F) is 0.2970, so use 0.30+ significance level to separate treatment means
- Need 8+ replicates to reject null hypothesis at 0.05 significance



Crop Variety	CEZANNE
Trt No.	24
2	85.33 a
3	81.67 a
4	98.00 a
5	95.33 a
LSD P=.05 (% mean diff)	21.808 (25%)
Standard Deviation	10.915
CV	12.12
Grand Mean	90.083
Minimum Replicates (power = 80)	8
Largest Mean Difference (% mean diff)	16.333 (18%)
Treatment F	1.541
Treatment Prob(F)	0.2979

Summary

New ARM 10.2015 tools can help improve trial quality and efficiency:

- Plan appropriate number of replicates
- Improve quality of randomizations
- Analyze results to improve planning of follow-up experiments

ARM 10.2015 is available 4Q 2014