Important Statistic Tools in ARM

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Overview: Research Questions

When we pose a research question, we want to know whether the outcome is from:

- the treatments (independent variables), or
- chance (meaning tested treatments are probably not effective)

based on experiment samples we collect.

Statistics

- Inferential statistics are used to make generalizations from a sample to a population
- The reason for calculating an inferential statistic is to get a *p* value (*p* = probability)
- For crop research, Analysis of Variance is commonly used for initial statistical analysis to obtain a *p* value

AOV Table for RCB Design

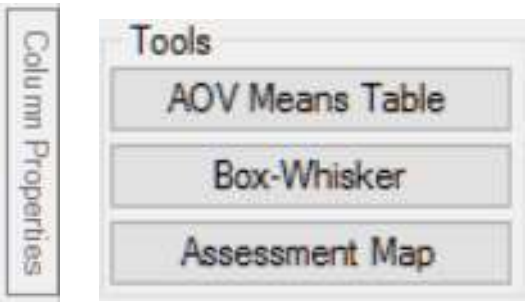
- Randomized Complete Block is a common design
- Consider key components of AOV table when planning and conducting trials:

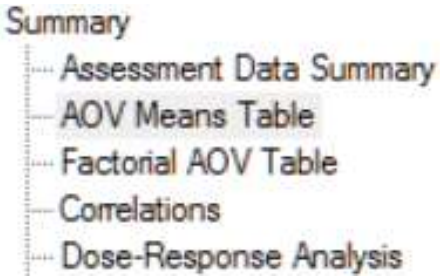
Randomized Complete Block (RCB) AOV

Source	DF	Sum of Squares	Mean Square	F	Prob(F)
Total	19	4519.800000			
Replicate	3	305.800000	101.933333	0.626	0.6121
Treatment	4	2258.800000	564.700000	3.466	0.0421
Error	12	1955.200000	162.933333		

ARM Tools Can Assist With Important Trial Activities

- **Planning**
- Trial Layout
- Data Review
- Statistical Analysis



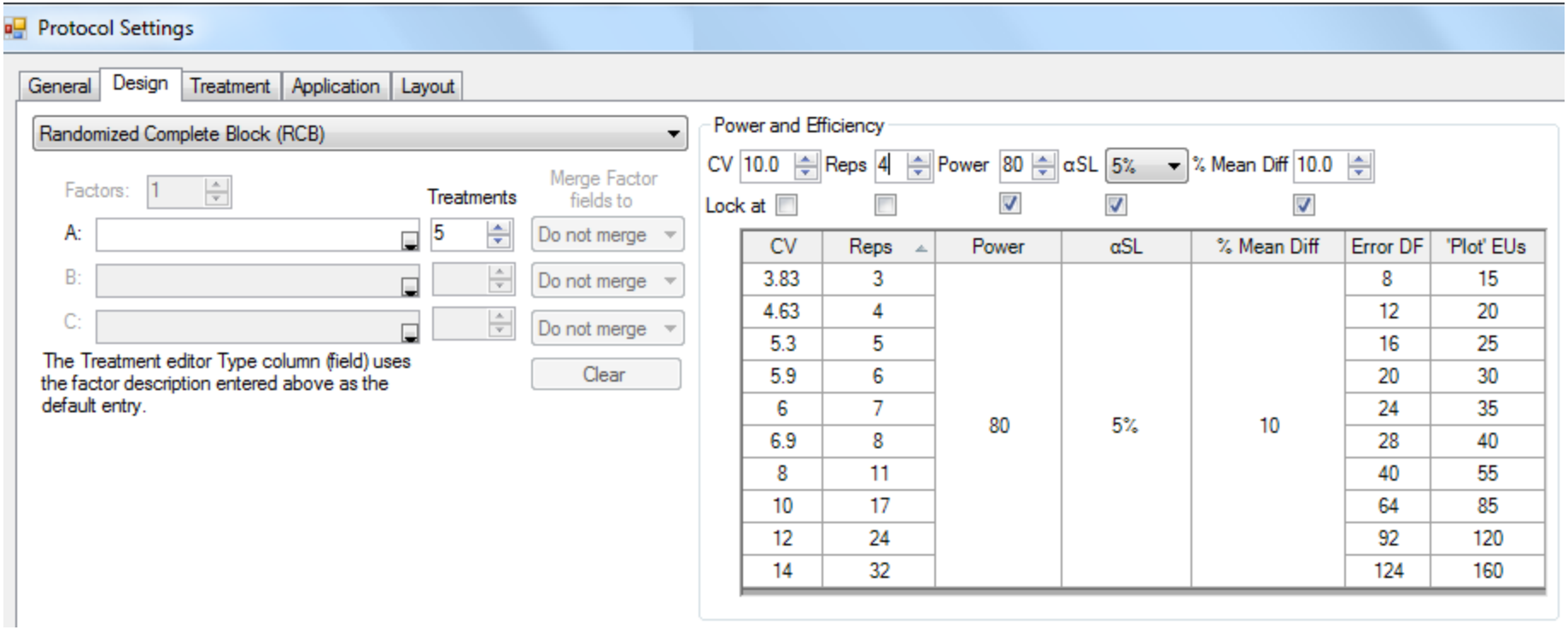


Planning - Key Considerations

- At least **12 error DF** (degrees of freedom) for RCB: Error DF=(Trts-1) x (Reps-1)
  - 2 T x 13 R
  - 3 T x 7 R
  - 4 T x 5 R
  - 5 T x 4 R
  - 7 T x 3 R
  - 13 T x 2 R
- Include **enough** replicates to statistically distinguish expected treatment differences
- Minimum **alpha** for statistical significance?

Power and Efficiency Planner

Define in ARM Protocol and Trial Settings



CV	Reps	Power	αSL	% 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

Power and Efficiency Planner

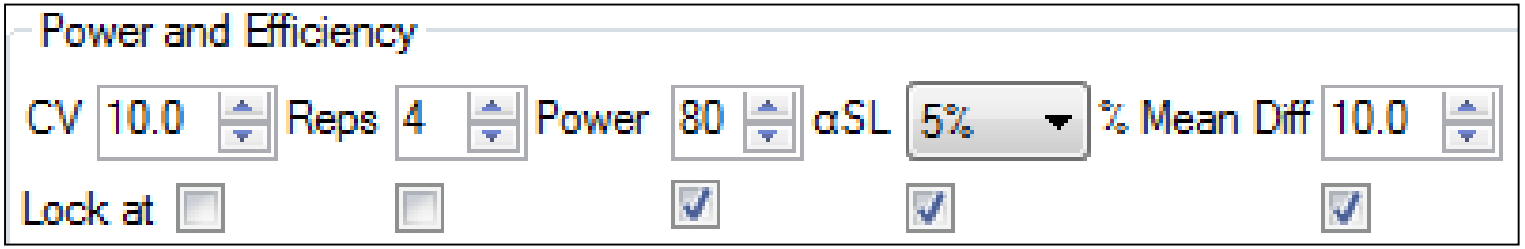
- Help plan experiments that successfully detect expected treatment differences
- Available in both protocols and trials so:
  - Protocol writers can more effectively plan experiments
  - Trialists can verify whether CV expectations are realistic based on local experience for specified crop(s)

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%)
- Alpha Significance Level (e.g. 5%, 10%)
- % Mean Diff = estimated treatment effect, expressed as percentage of overall (grand) mean across treatments of key assessment

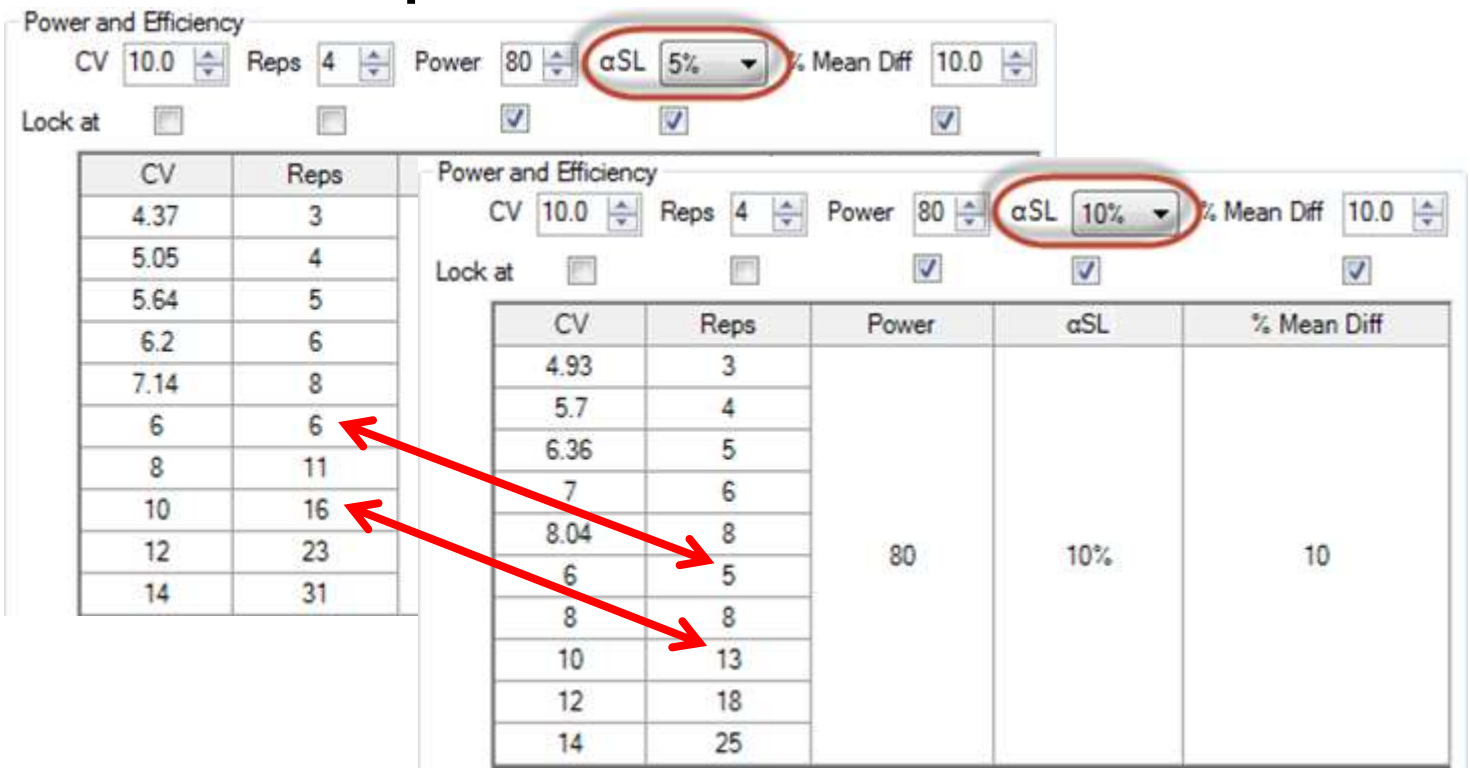
Power and Efficiency Planner



- "Lock at" to keep 3 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

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



Power and Efficiency Planner

Consider impact of Replicates on precision to detect treatment differences

Click on column heading to sort

Power and Efficiency

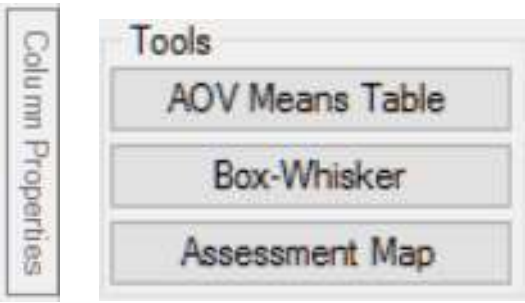
CV 5.0 Reps 4 Power 80 αSL 5% % Mean Diff 5.0

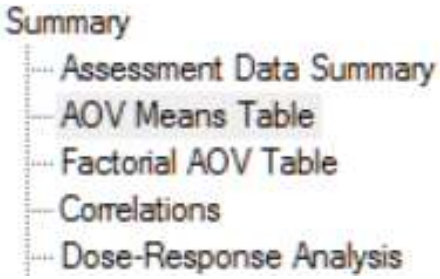
Lock at

CV	Reps	Power	αSL	% Mean Diff	Error DF	'Plot' EUs
5	3	80	5%	13	8	15
	4			10.8	12	20
	5			9.4	16	25
	6			8.5	20	30
	8			7.26	28	40
	9			7	32	45
	12			6	44	60
	17			5	64	85
	26			4	100	130
	45			3	176	225

ARM Tools Can Assist With Important Trial Activities

- Planning
- **Trial Layout**
- Data Review
- Statistical Analysis





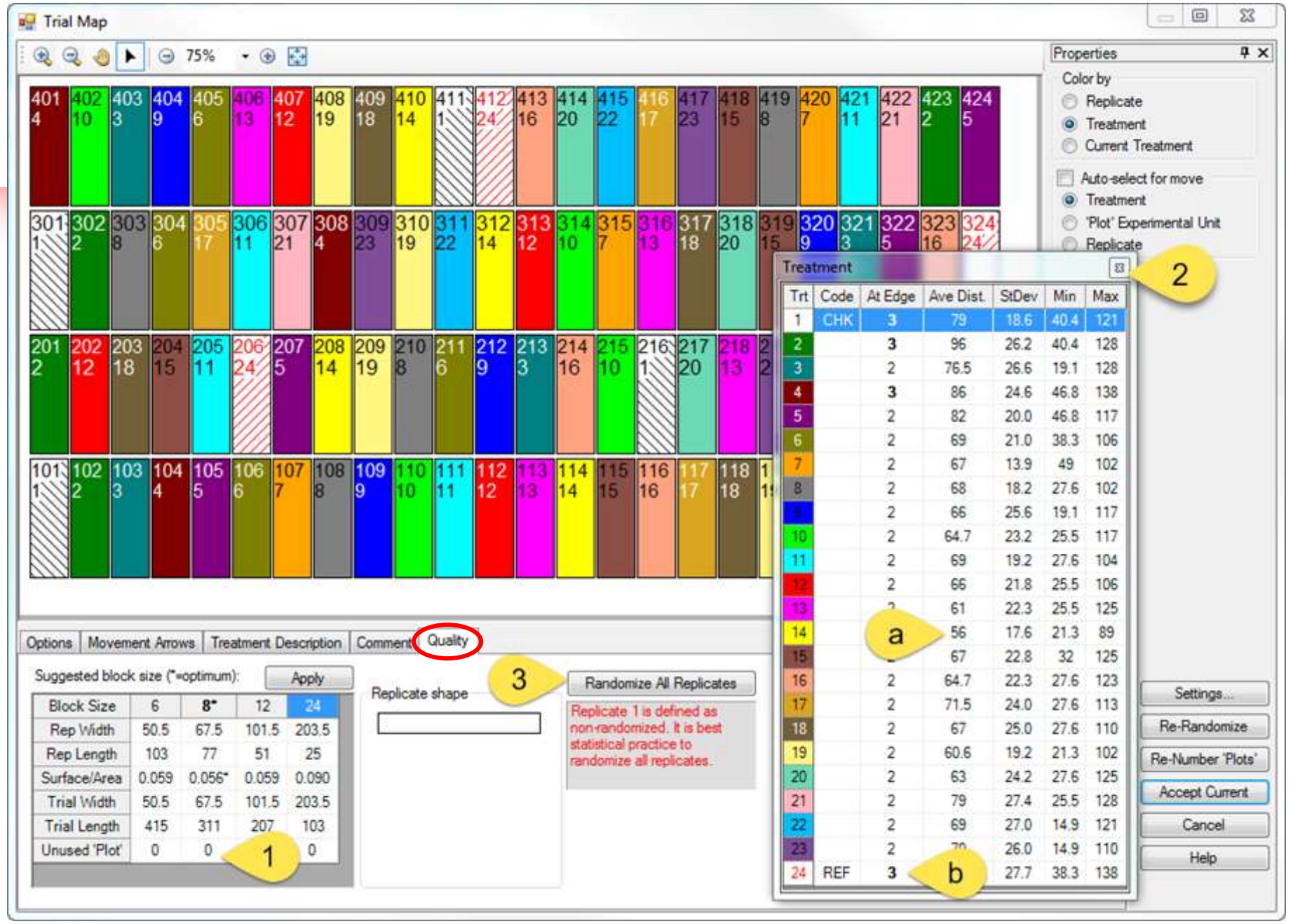
Trial Layout

- Experimental site
  - Is it uniform?
  - Is there a known gradient?
- Use an effective Block (replicate)
  1. Placement: within rep more uniform than trial
  2. Shape: reduce distance between plots
- Want to decrease Error Sum of Squares by increasing Replicate Sum of Squares

Trial Layout Should Include Randomization Quality Review

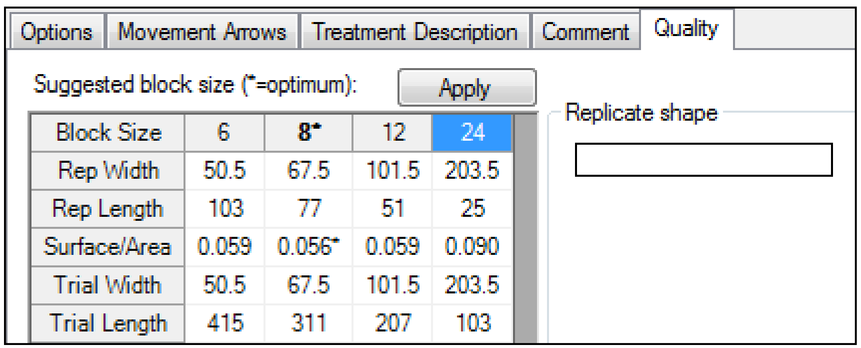
Goal is to improve experiment precision:

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

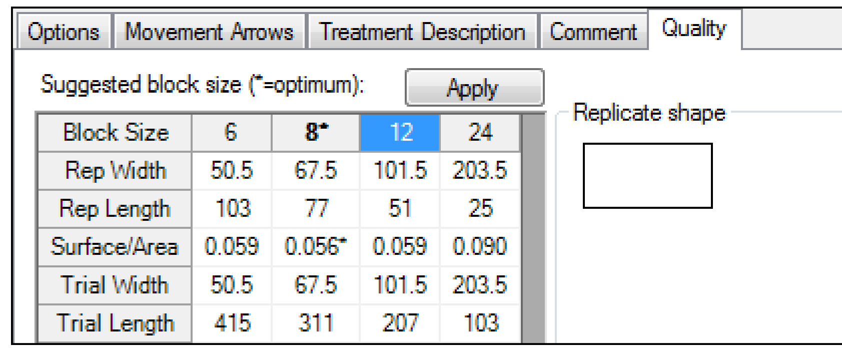

Trial Map
75%
Properties
Color by
Replicate
Treatment
Current Treatment
Auto-select for move
Treatment
'Plot' Experimental Unit
Replicate
Treatment
2
Trt Code At Edge Ave Dist. StDev Min Max
1 CHK 3 79 18.6 40.4 121
2 3 96 26.2 40.4 128
3 2 76.5 26.6 19.1 128
4 3 86 24.6 46.8 138
5 2 82 20.0 46.8 117
6 2 69 21.0 38.3 106
7 2 67 13.9 49 102
8 2 68 18.2 27.6 102
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
61 22.3 25.5 125
14 56 17.6 21.3 89
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 26.0 14.9 110
24 REF 3 27.7 38.3 138
a
b
Options
Movement Arrows
Treatment Description
Comment
Quality
Suggested block size (*=optimum):
Apply
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
1
Replicate shape
3
Randomize All Replicates
Replicate 1 is defined as non-randomized. It is best statistical practice to randomize all replicates.
Settings...
Re-Randomize
Re-Number 'Plots'
Accept Current
Cancel
Help

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



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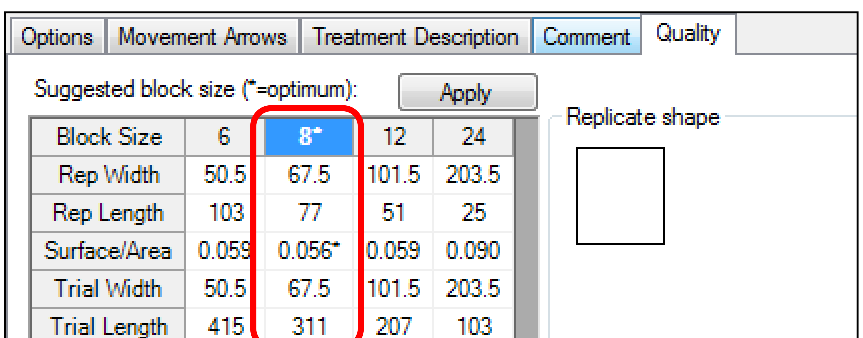

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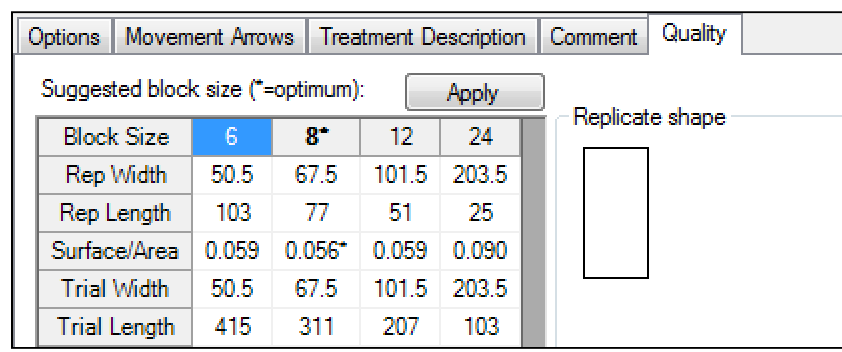

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Surface/Area	0.059	0.056*	0.059	0.090
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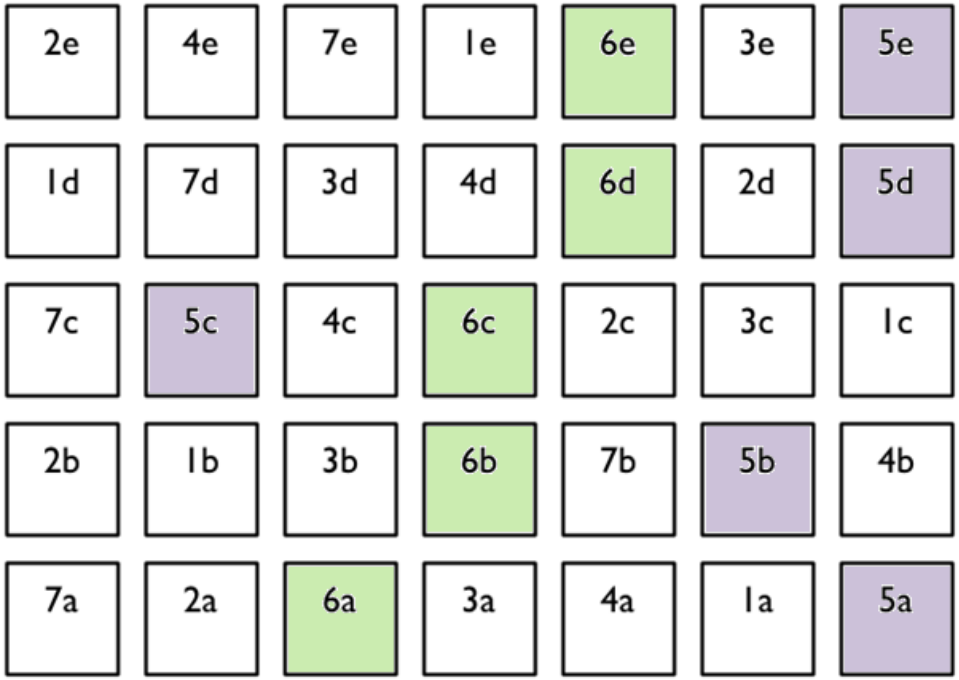
Equalize Treatment Distribution

"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

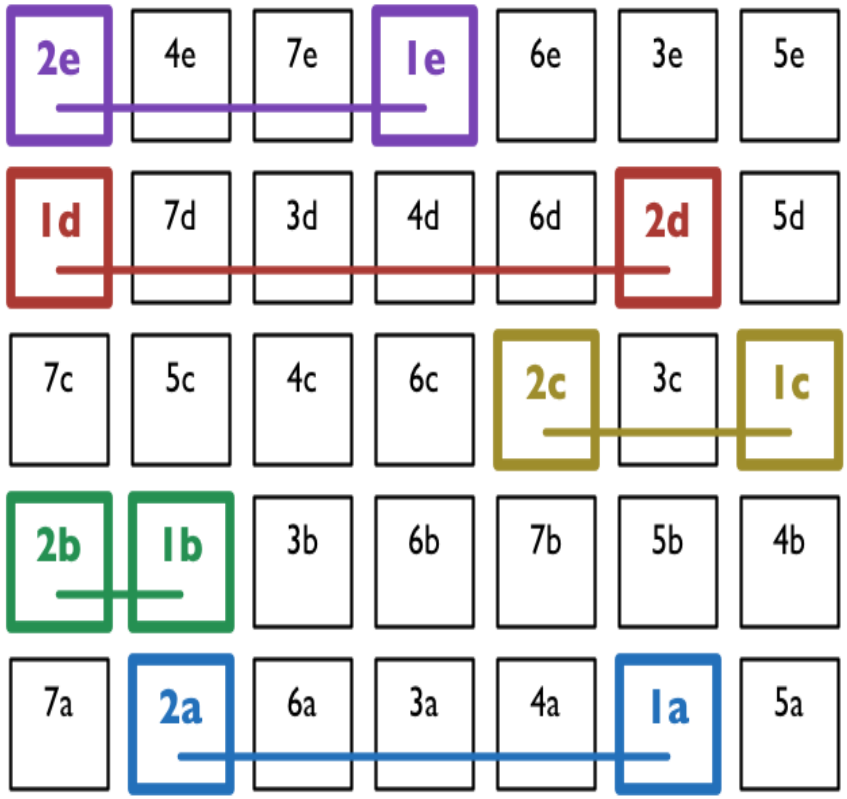


Uses "Average Distance of Treatment" Comparison (ADTC)

- van Es and van Es, "Spatial Nature of Randomization and Its Effect on the Outcome of Field Experiments", Agronomy Journal, 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



Unequal Treatment Distribution

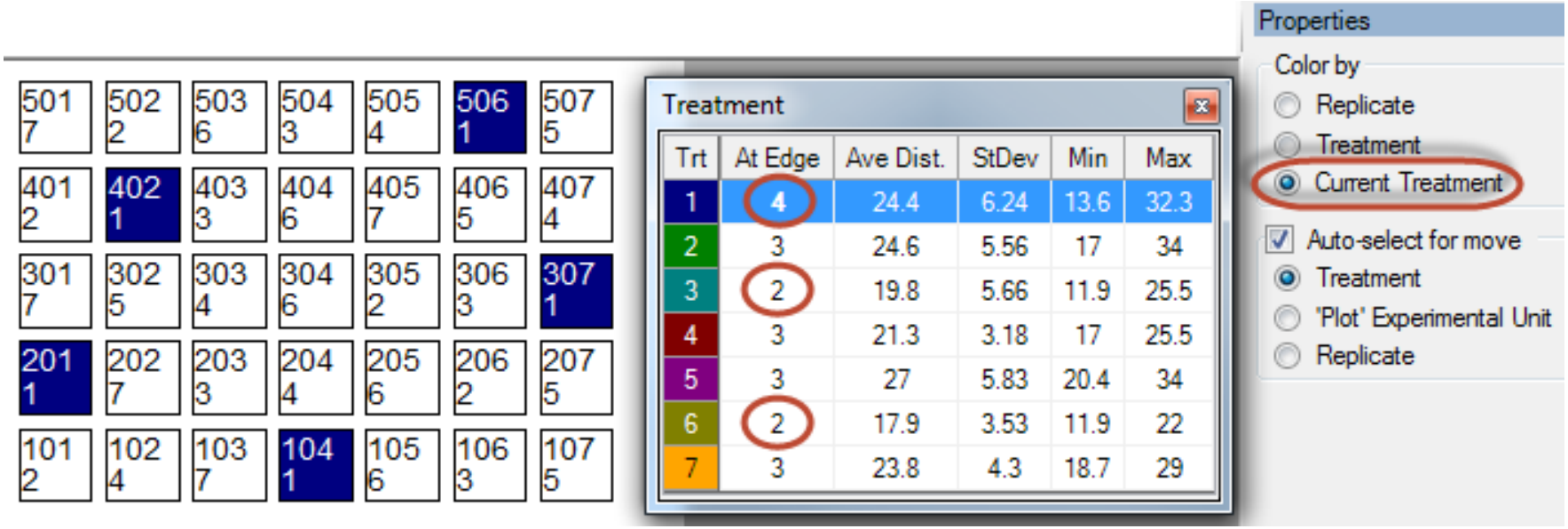
- Average distance from 17.9 to 24.6
- Ranges from 11.9(T3,T6) to 34(T2,T5)
- Error variances for treatments may not be homogeneous

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



Balanced Treatment Distribution and Edge Effect

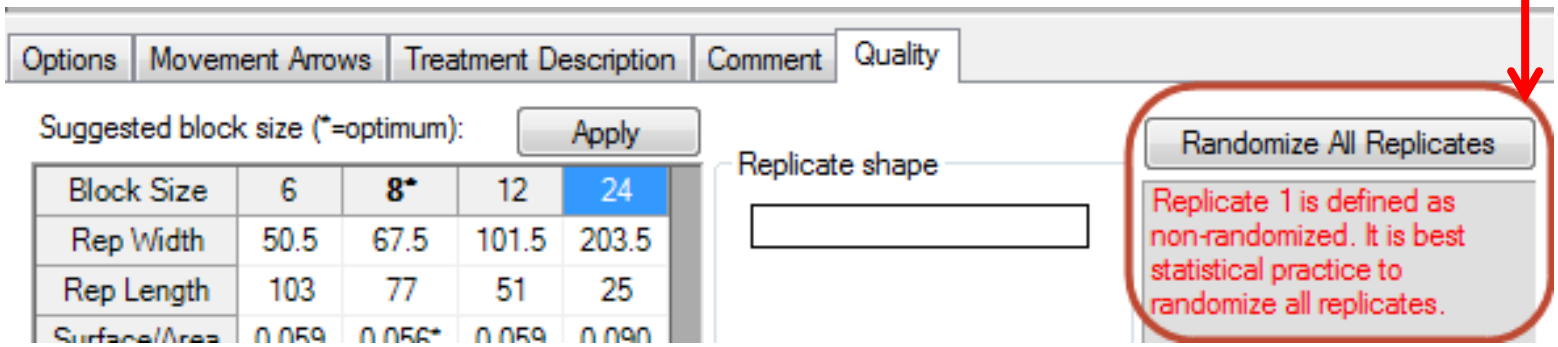
- Average distance from 21.3 to 24.4
- Distances range from 18.7 to 27.2
- "Edge effect" is balanced

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



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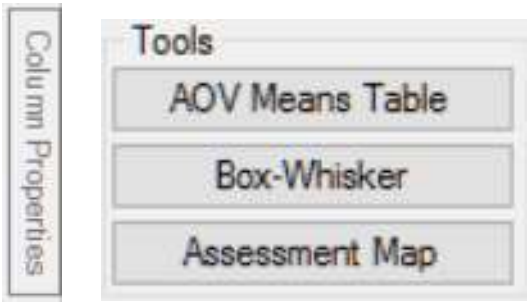
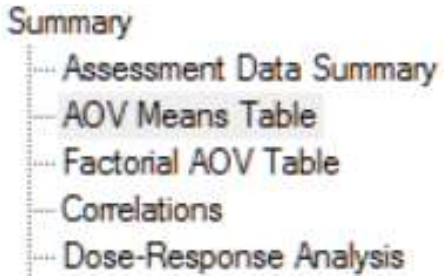
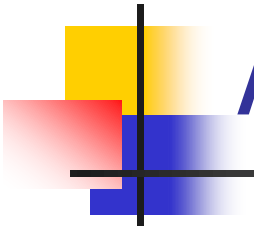
- **Data Review**
- Statistical Analysis







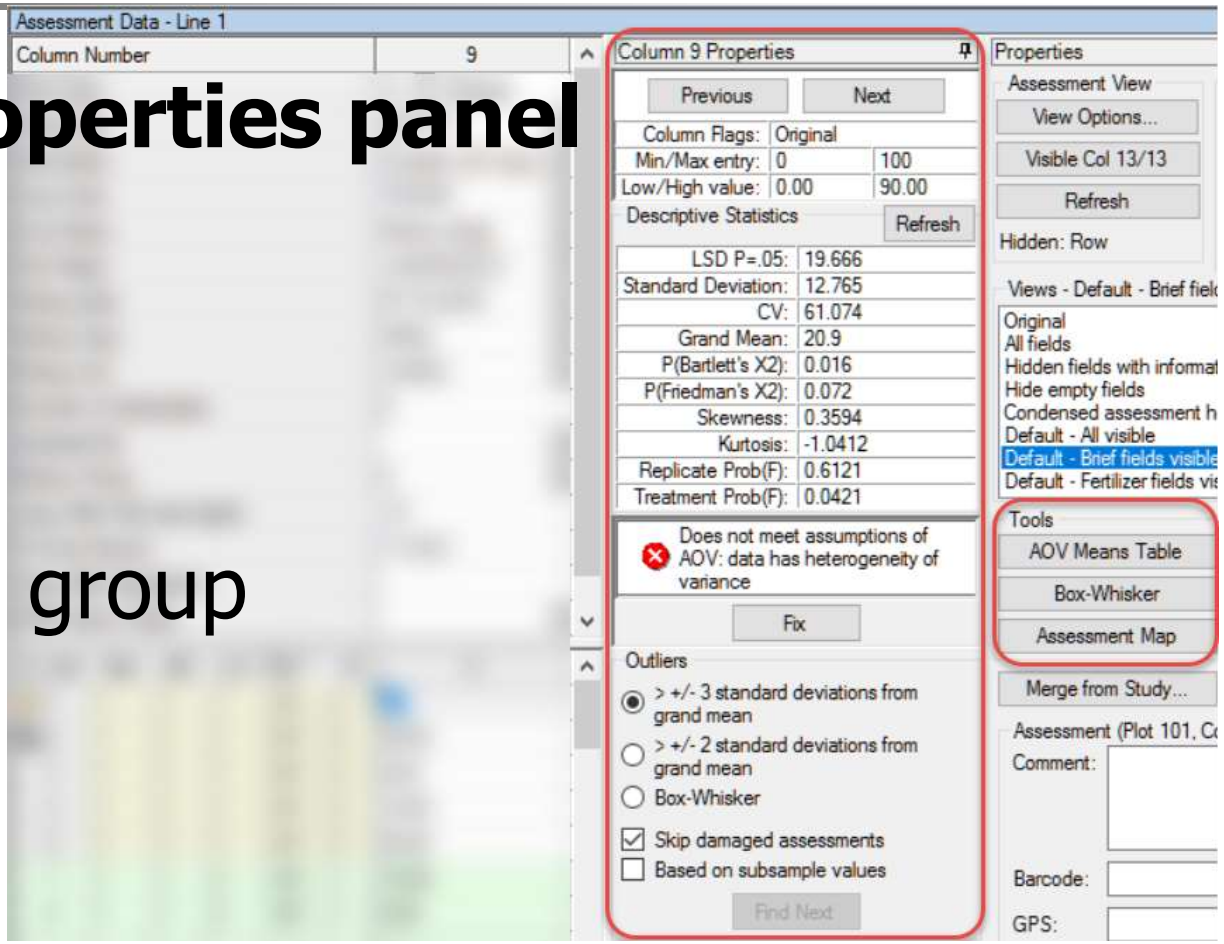
Assessment Data Review

- Check for measurement or entry mistakes
  - If possible, perform immediately after making the assessment, while it is still feasible to verify and correct any mistake
  - If do check "later", only option may be to mark any questionable measurement as missing data, losing 1 error DF for each missing data point
- Goal: preserve error DF for better precision

Assessment Data Review Tools

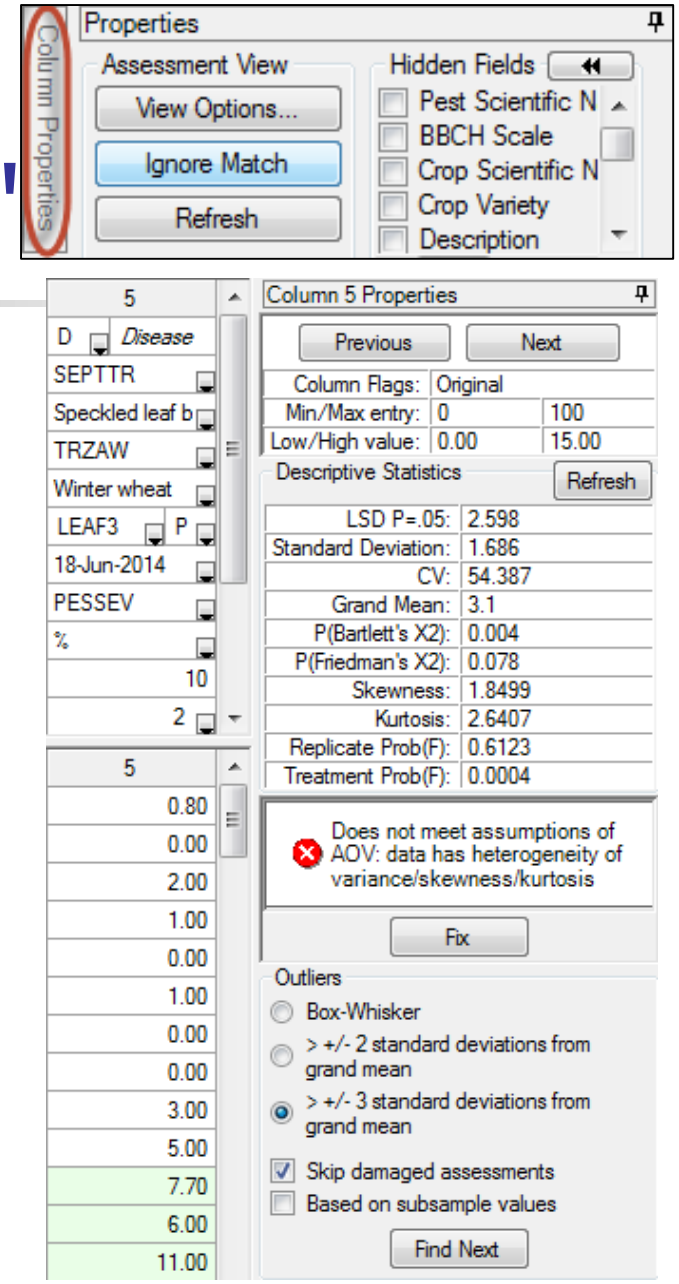
- **Column Properties panel**

- Tools button group



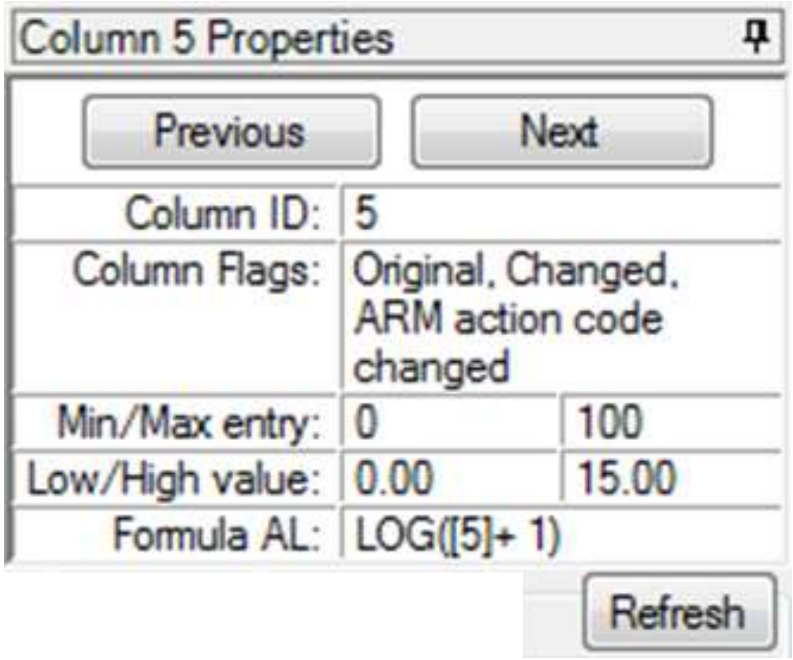
Assessment Data "Column Properties"

- "Pop-out" editor panel
- Presents analysis of the current data column
- Offers to attempt auto-fix for any violations of AOV assumptions
- Find statistical outliers



Assessment "Column Properties"

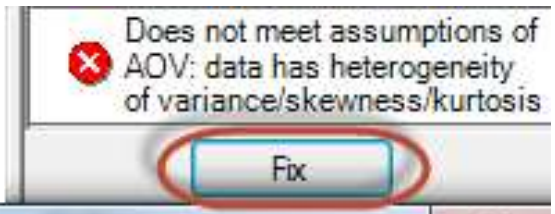
- Column navigation
- Column description
- Min & Max limits
- Actual value **range**
- Transformation formula description
- Click "Refresh" to update after changing current data column

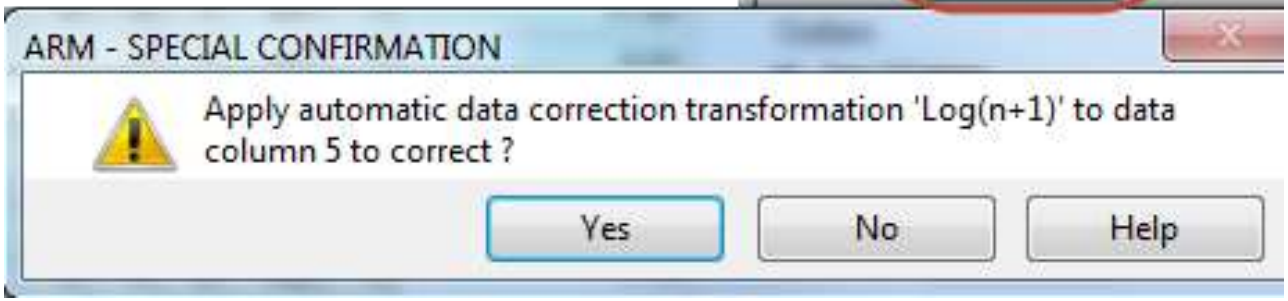


Assessment "Column Properties"

- **Descriptive statistics** from full AOV of data
- Displays **violations** of AOV assumptions
- "**Fix**" prompts if can resolve violations

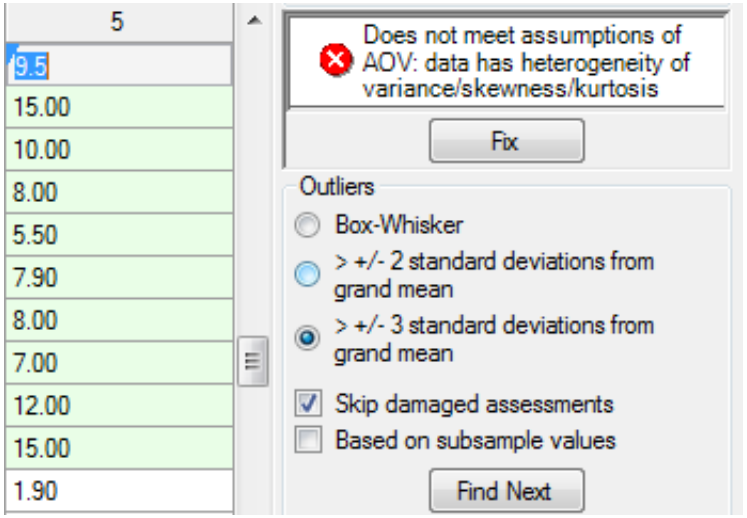
LSD P=.05:	2.598
Standard Deviation:	1.686
CV:	54.387
Grand Mean:	3.1
P(Bartlett's X2):	0.004
P(Friedman's X2):	0.078
Skewness:	1.8499
Kurtosis:	2.6407
Replicate Prob(F):	0.6123
Treatment Prob(F):	0.0004





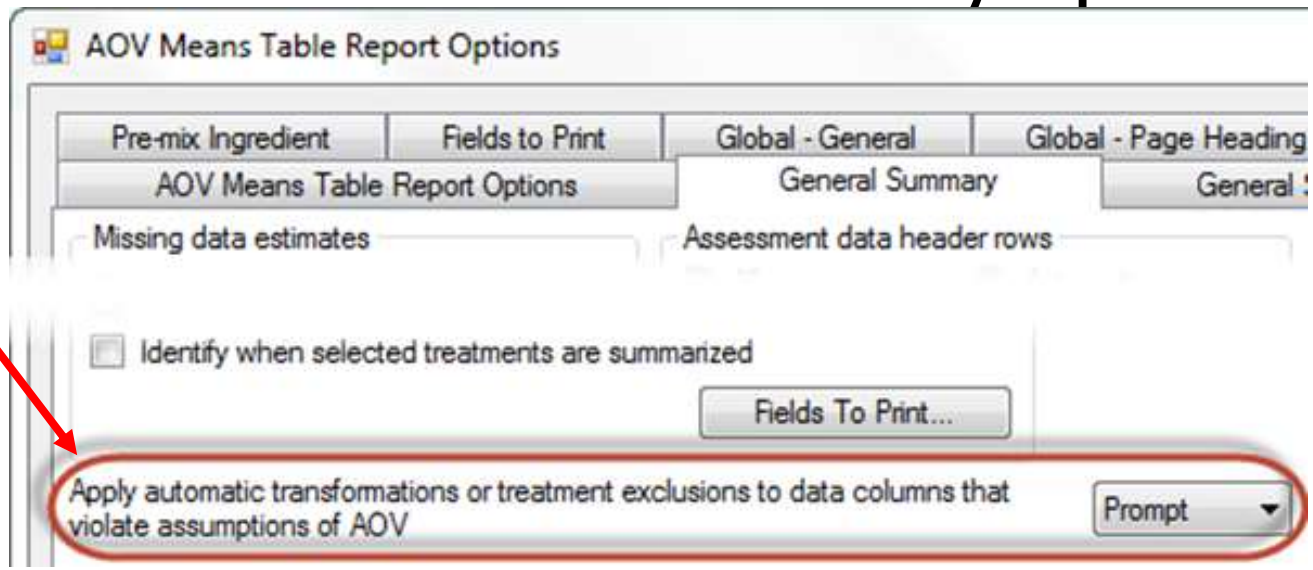
Assessment "Column Properties"

- **Search for outliers** in current data column using a standard outlier test
- "Find Next" locates each statistical outlier
- "Damaged" drops value from outlier test and AOV



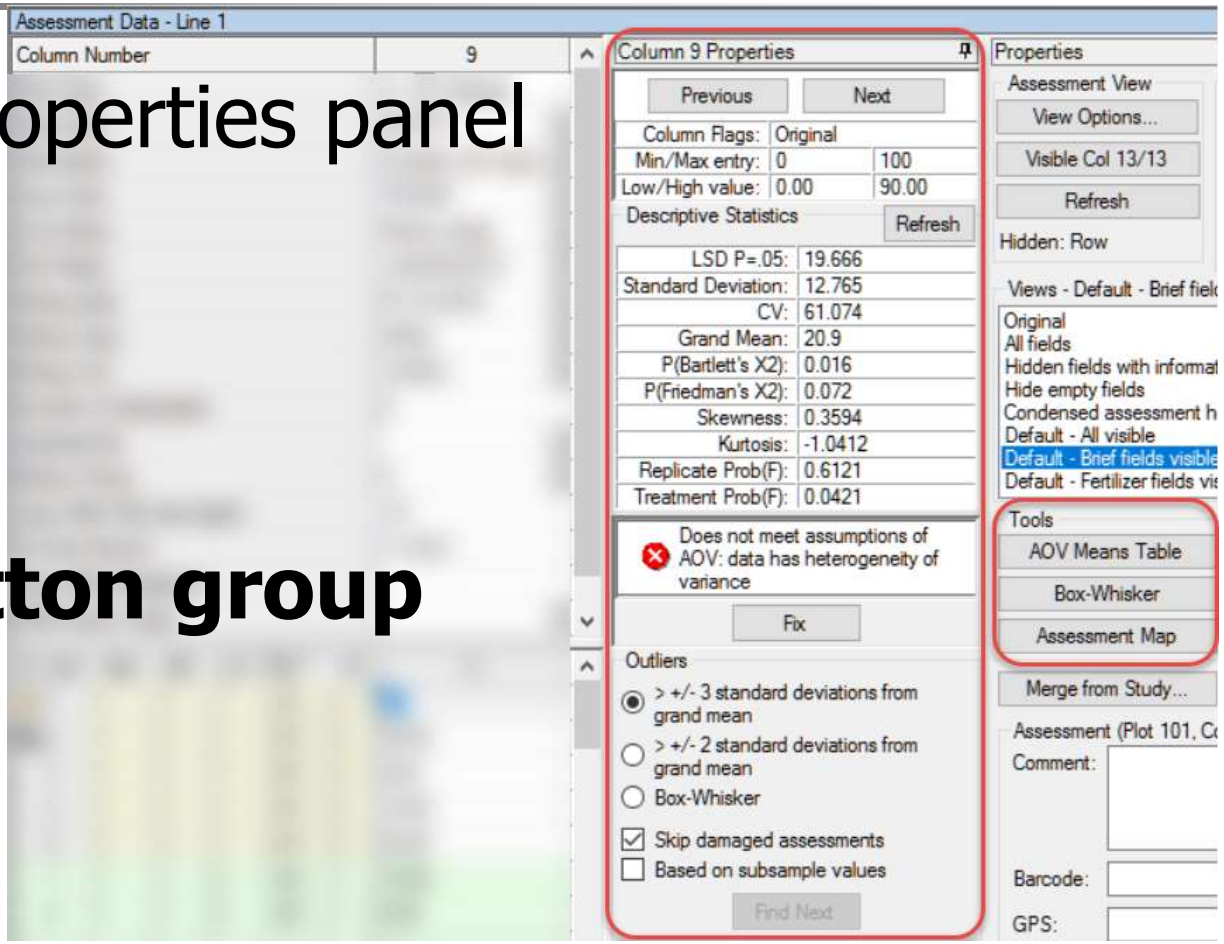
Assessment "Column Properties"

- **If** you will **consistently** review every assessment using Column Properties
- **Then** it is safe to set this summary option to 'No':



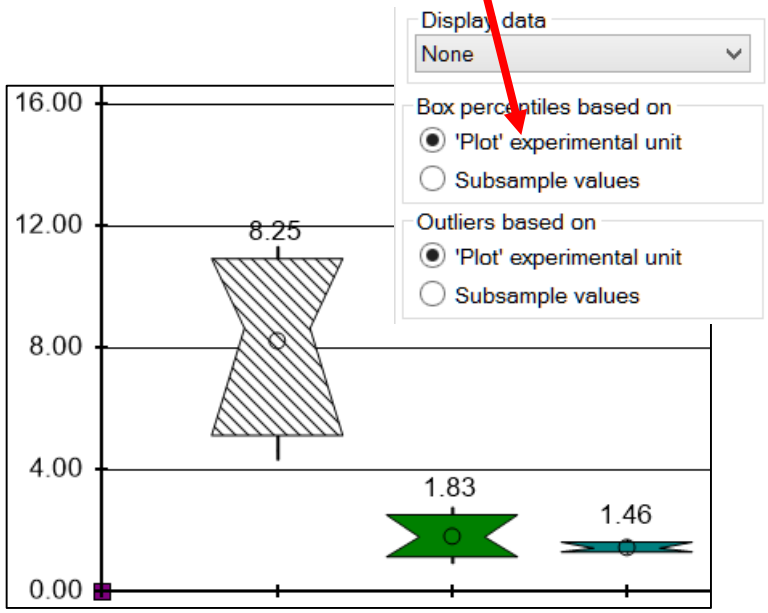
Assessment Data Review Tools

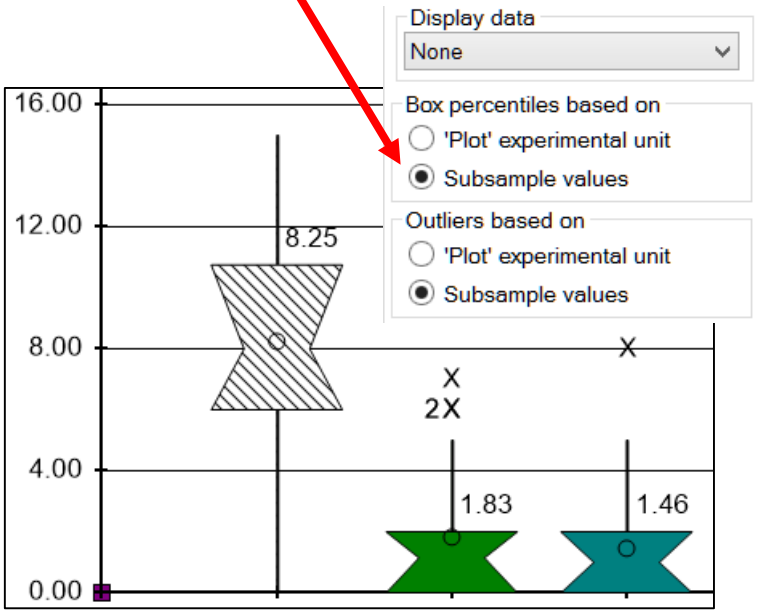
- Column Properties panel
- **Tools button group**



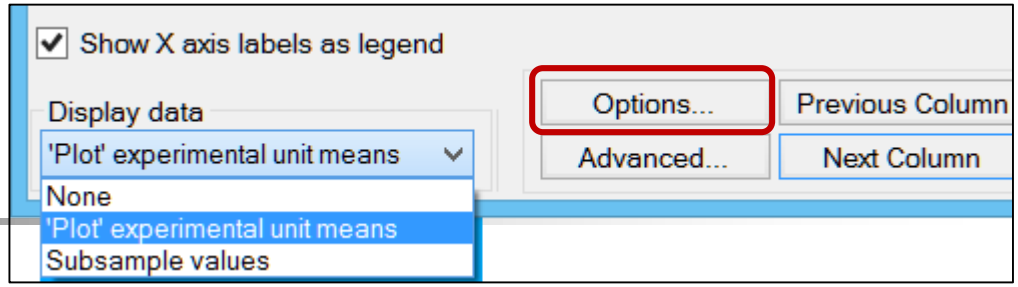
Box-Whisker Graph

'Box percentiles' and 'Outliers based on' options of '**Plot**' or 'Subsamples' for box-whisker

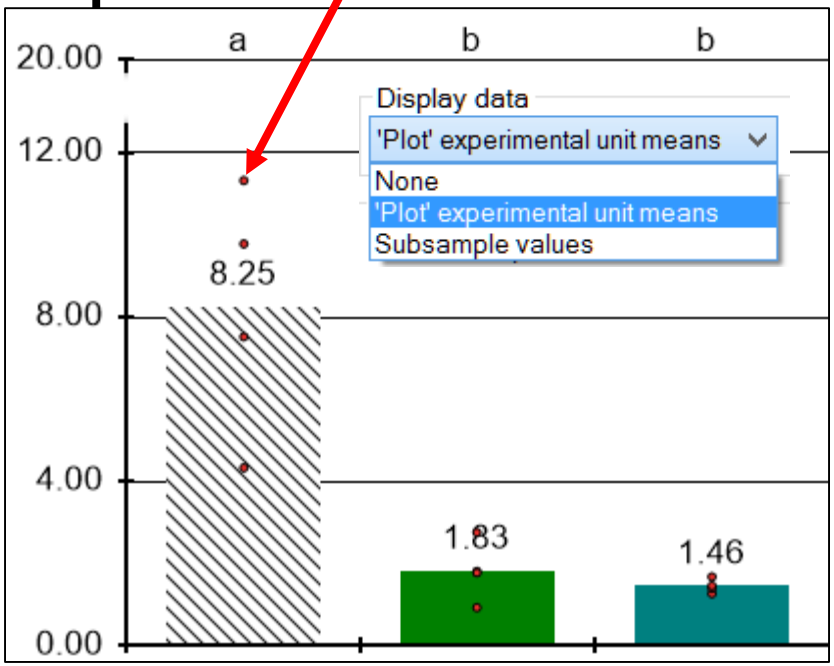


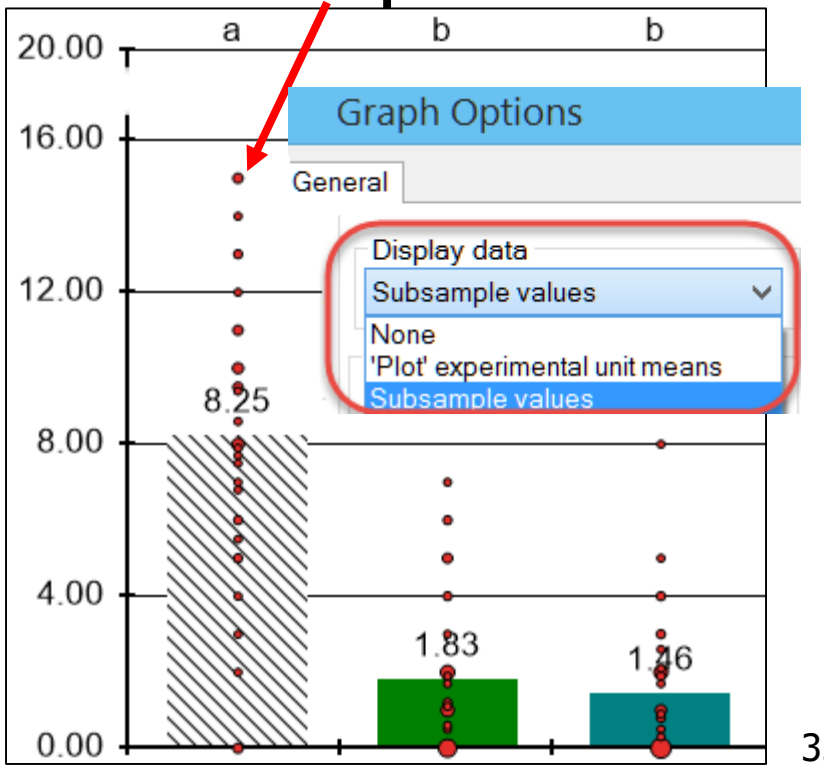


Graphs



Use 'Display data' option to add scatter graph showing plot or individual subsample values as points

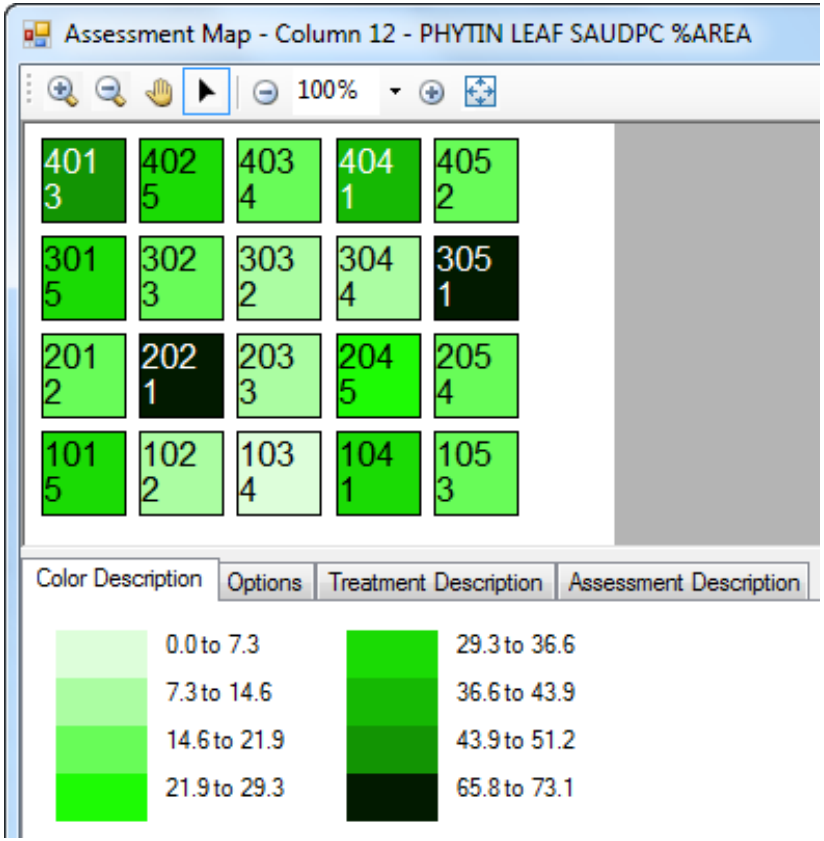




Assessment Map

"Heat map" shows response differences per assessment data column by color intensity:

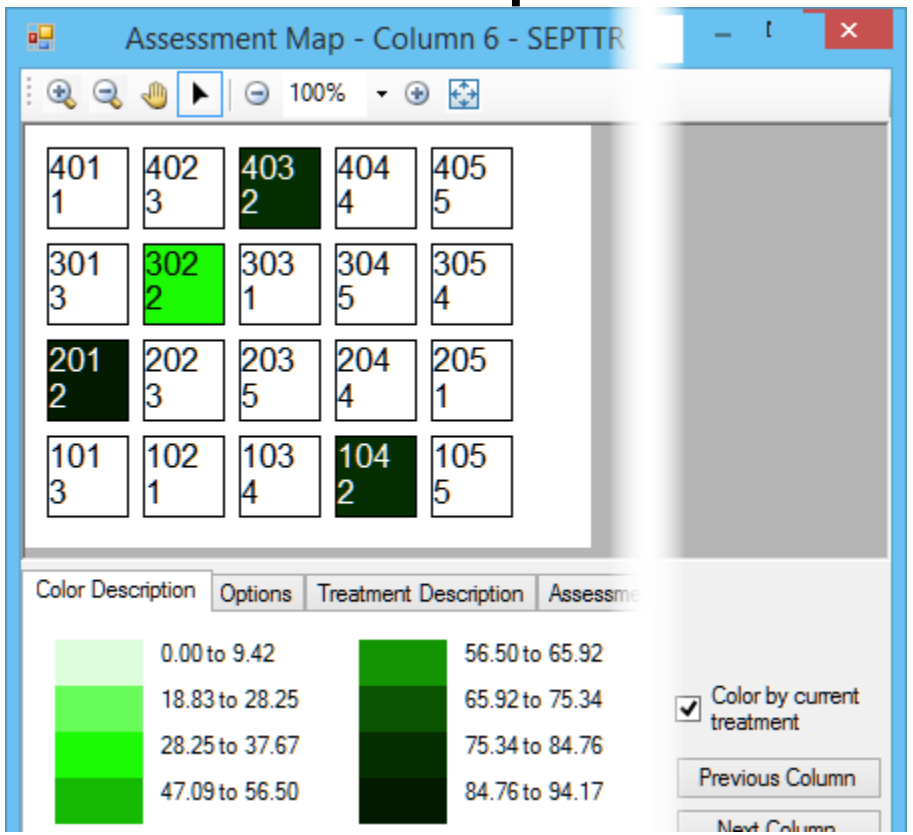
- Treatment consistency
- Possible site variations as dark or light zones
- Plot problems



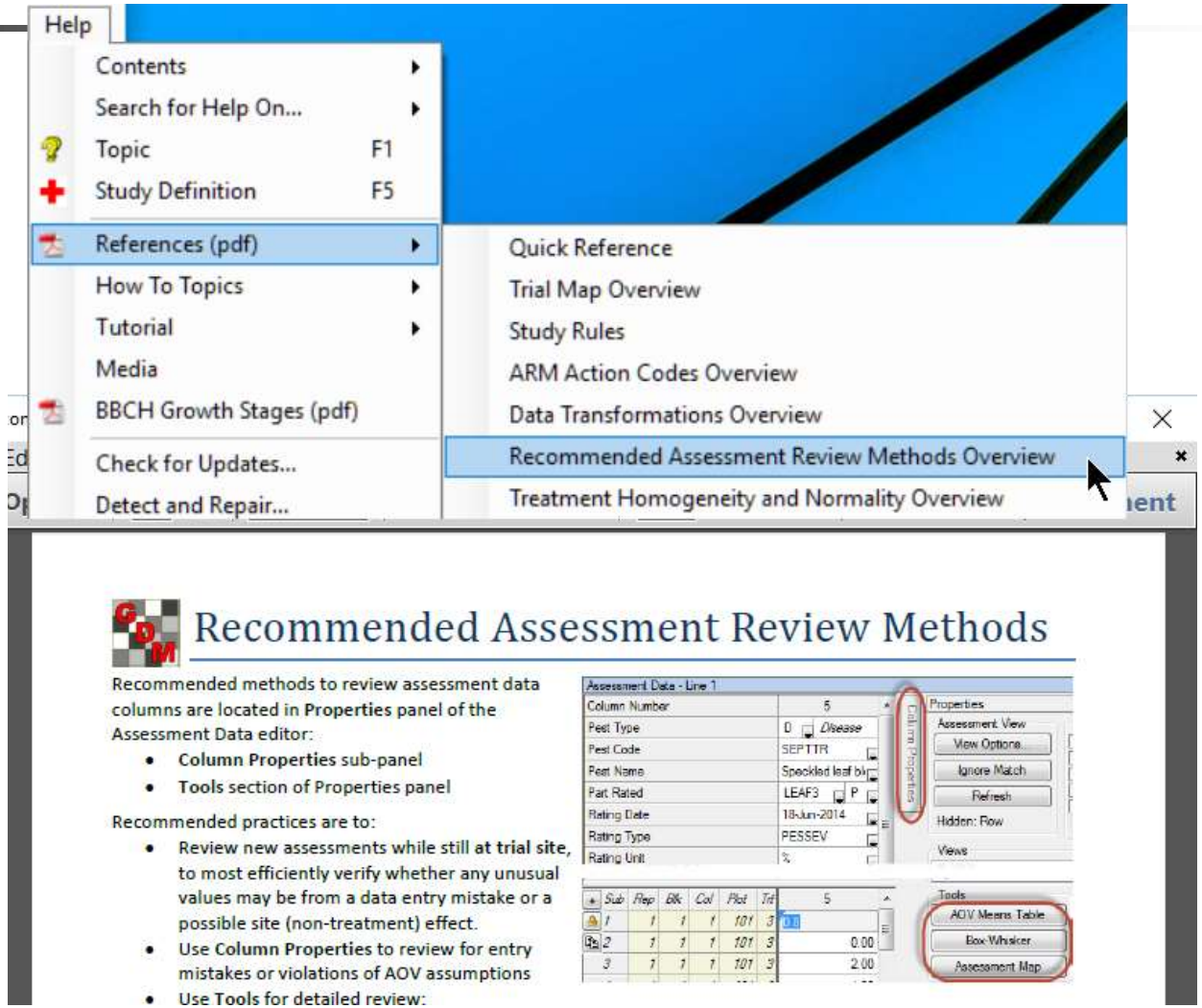
Assessment Map

'Color by current treatment' option:

- Easily review variation in each treatment
- Simpler to find position in each replicate for trial with many treatments



More Information in ARM Help



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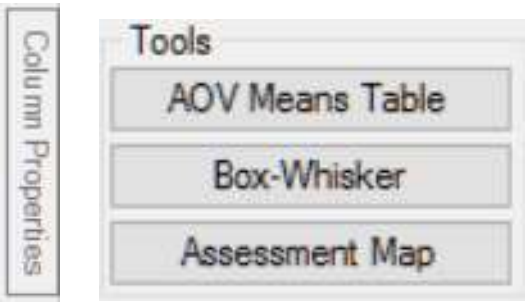
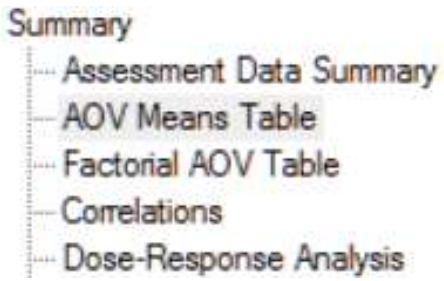
- Data Review
- **Statistical Analysis**





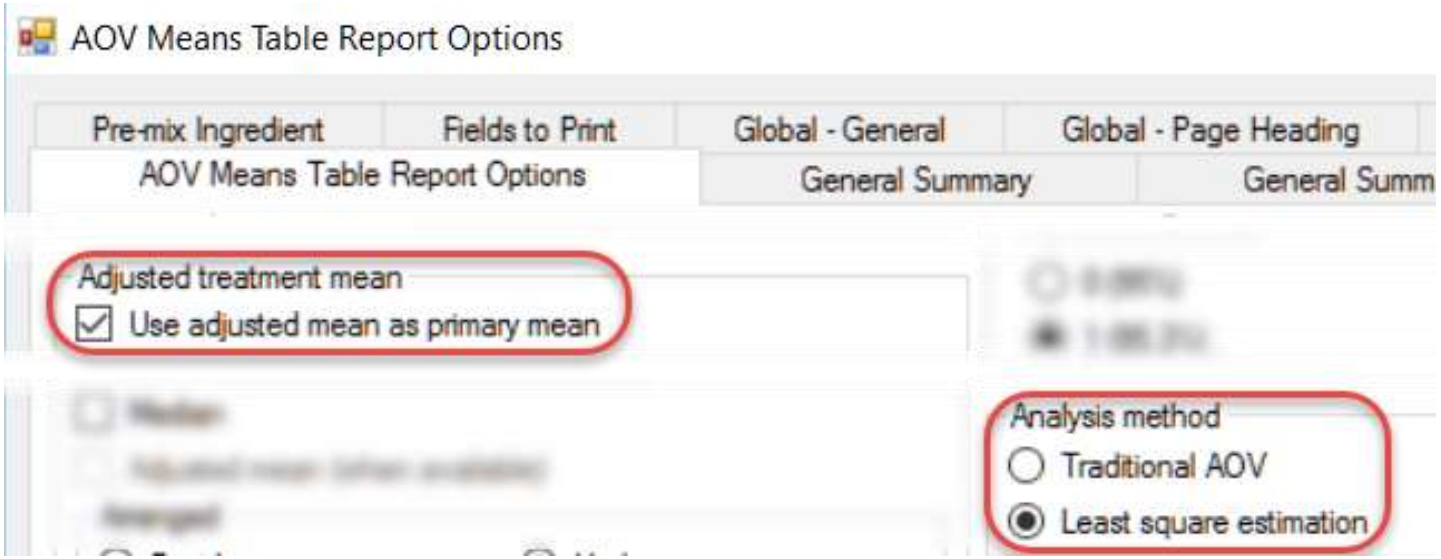
Statistical Analysis Best Practices

- Use "**Least squares**" analysis options on AOV and Factorial AOV Reports
- Use "**Post-hoc power analysis**" to better plan follow-up experiments
- Do "**protected**" mean comparison tests
- **Be careful** using LSD to hand-compare treatment pairs on AOV Means when a data correction transformation is applied

AOV Means Table Report Options

"Analysis method" options:

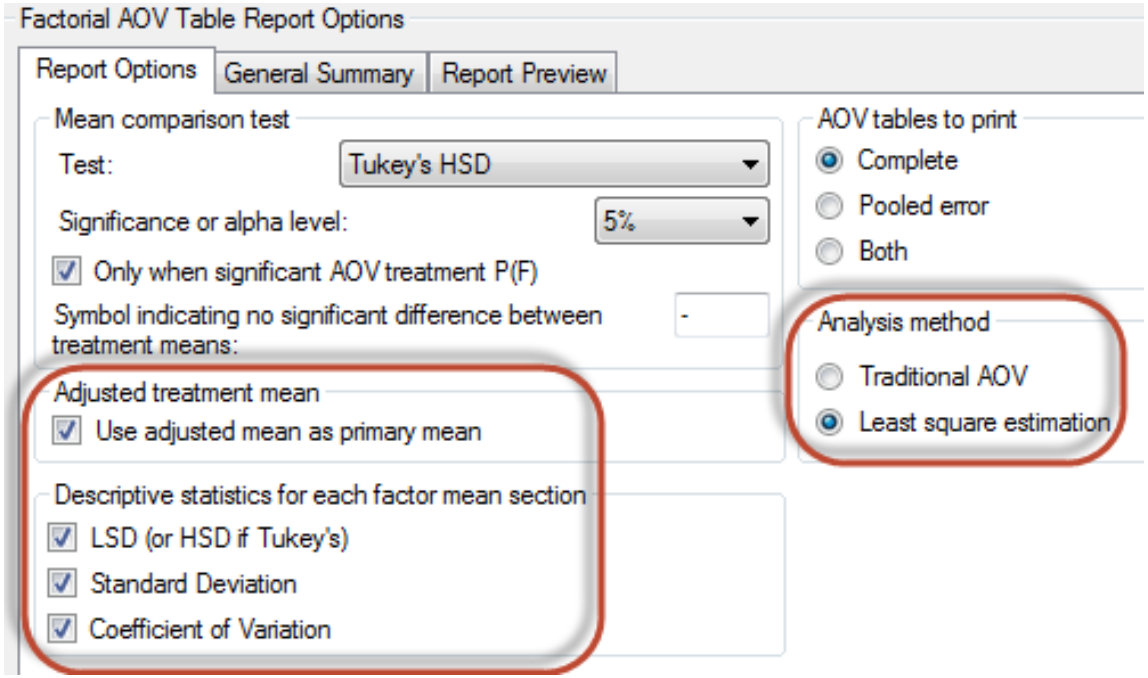
- Least square estimation (like SAS GLM)
- Print adjusted means



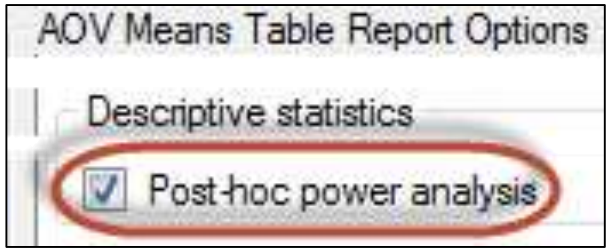
Factorial AOV Report Options

"Analysis method" options:

- Least square estimation (like SAS GLM)
- Print adjusted means (if missing data)



Post-hoc Power Analysis (for Follow-Up Experiments)



- Optional descriptive statistic 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 (for Follow-Up Experiments)

- In example, LSD can distinguish a 25% mean difference, yet largest existing difference is 18%
- Current AOV Trt P(F) is 0.2979, 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

"Protected" Mean Comparison Test

- Mean comparison test is only performed on assessment data columns when the α Signif. Level >= AOV Treatment Prob(F)

αSL=0.05

Trt No.	9*
1	2.50 b
2	22.50 ab
3	33.00 a
4	29.00 ab
5	17.50 ab
LSD P=.05	19.666
CV	61.07
Replicate F	0.626
Replicate Prob(F)	0.6121
Treatment F	3.466
Treatment Prob(F)	0.0421

αSL=0.01

Trt No.	9*
1	2.50 -
2	22.50 -
3	33.00 -
4	29.00 -
5	17.50 -
LSD P=.01	27.570
CV	61.07
Replicate F	0.626
Replicate Prob(F)	0.6121
Treatment F	3.466
Treatment Prob(F)	0.0421

AOV Means Table Report

If data is transformed by square root, log, or arcsine SQR %: shows range of LSD values used to compare the largest and smallest **non-zero** means - is a range because they are all **non-linear** transformations

Pest Code		SEPTTR LEAF3 P	SEPTTR LEAF2 P
Part Rated		LEAF3 P	LEAF2 P
Rating Date		Jun-18-2014	Jul-2-2014
Rating Type		PESSEV	PESSEV
Rating Unit		%	%
Days After First/Last Applic.		64 15	78 29
ARM Action Codes		AL	AA
Trt No.	Treatment Name	Rate Rate Unit	5*	7*
1	Untreated Check		6.89 a	15.14 a
2	Tub	0.5 l/ha	1.28 b	1.23 bc
3	Tub	1 l/ha	1.04 b	0.40 c
4	Tilt 250	0.5 l/ha	1.60 b	1.51 bc
5	Mico 60 Fungol	1.5 l/ha 1.25 l/ha	1.19 b	3.09 b
LSD P=.05			1.878 - 3.785	1.218 - 4.299
CV			39.69t	23.81t

AOV Means Table Report

Example using this log transform:

- Compare 6.89 vs. 1.60 using LSD≈3.785
  (largest mean vs. next largest)
- Compare 1.04 vs. 1.19 using LSD≈1.878
  (smallest mean vs. next smallest)

Rating Type Rating Unit ARM Action	PESSEV % AL
Trt Treatm No. Name	5*
1 Untreat	6.89 a
2 Tub	1.28 b
3 Tub	1.04 b
4 Tilt 250	1.60 b
5 Mico 6(Fungol	1.19 b
LSD P=.05	1.878 - 3.785

Additional Information, See Statistical Handbook 3rd Edition

A Statistical Handbook for Agricultural Field Trials Specialists: A handy companion for use with ARM data management tools

Available as an eBook from:

- Amazon: https://www.amazon.com/Statistical-Handbook-Agricultural-Trials-Specialists-ebook/dp/B01KIHJRWQ/ also offered in Print
- Kobo: https://store.kobobooks.com/en-us/ebook/a-statistical-handbook-for-agricultural-field-trials-specialists

Thank You

Contact us with questions at

GDM.ARM.Support@gdmdata.com