

Analysis of On-Farm Research

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Objectives of This Workshop

- Design an appropriate experiment for qualitative treatments
 - Qualitative treatment: numerical description has no real meaning
 - Examples: seed color, hybrids, fertilizer type
 - Rate studies are not discussed
- Create a scatter plot of data
- Create a bar chart of treatment means
- Perform an analysis of variance (ANOVA)
- Calculate and use a least significant difference (LSD) to separate treatment means

Why Conduct On-Farm Research?

- You become the local agronomic expert
- You differentiate yourself
- You develop professionally
- You strengthen relationships with university Extension
- You develop customer loyalty



Asking a Good Question

- Become knowledgeable
- Keep your questions simple
- Select factors most limiting crop production in your area
- Consider possible impacts of your research
 - Farmer research advisory group
 - Area for demonstration and small plots
 - Hold meetings to discuss results
 - Work with university Extension scientists

Formulating Your Hypothesis

- What is a hypothesis?
 - A simple statement that captures what you are trying to discover
- Examples
 - Does site-specific management lead to higher yields than current whole-field management?
 - Are there yield differences among three new hybrids?
 - Does taking nitrogen credits from manure lower my yields?

Creating a List of Factors and Levels

- Factors: variables you want in your study
- Levels: various quantities or aspects of a given factor
- This workshop focuses on experiments with only one factor

Creating a List of Factors and Levels

Does site-specific nutrient management lead to higher yields than current whole-field management?

Factor	Levels
Management approach	Whole field nutrient management
	Site-specific nutrient management

Creating a List of Factors and Levels

Are there yield differences among three new hybrids?

Factor	Levels
Hybrid	Hybrid 1
	Hybrid 2
	Hybrid 3

Creating a List of Factors and Levels

Does taking nitrogen credits from manure lower my yields?

Factor	Levels
Management approach	Manure applied and N credits taken Manure applied and no N credit taken

Creating a List of Treatments

- Treatments: specific combinations of factors and levels
- In this workshop, for single factor studies, the levels of the factors define the treatment
 - Site-specific and whole field management
 - Hybrid 1, 2, and 3
 - Crediting or not crediting manure N

Creating a Statistical Hypothesis

- Statistical hypothesis: statement about statistical parameters in your study
- Two types of statistical hypotheses:
 - Null hypothesis
 - Alternate hypothesis

Null Hypothesis

- Null hypothesis usually states that no differences exist among treatment means
- Examples
 - The mean yields from site-specific management and whole-field management are the same
 - The new hybrids of interest all have the same mean yield
 - Mean yields are the same whether or not manure nitrogen is credited

Alternate Hypothesis

- Alternate hypothesis contradicts the null hypothesis
 - The mean yields from site-specific management and whole-field management are NOT the same
 - At least one new hybrid has a mean yield DIFFERENT from the others
 - Mean yields associated with taking manure nitrogen credits are NOT the same as mean yields associated with ignoring nitrogen credits

Error Control in Advance of Analysis

- When you conduct an experiment, you want to be sure that you draw the right conclusions
- Two types of error possible:
 - Type I error
 - Type II error
- Decide what levels of risk you are willing to accept from the outset
- Stick to these during your analysis and interpretation

Type I Error

- Occurs when you find a statistically significant difference among treatment means when in fact, there really was none
- Probability of making a type I error is termed the alpha level, and is denoted by the Greek letter α
- Probability is expressed in decimal form
 - Wanting a 5% chance of making a type I error is denoted as $\alpha = 0.05$.

Type II Error

- Occurs when you find no significant difference among treatment means, when in fact, one existed
- This is usually a less serious error, since it means accepting the status quo rather than the new, riskier management practice

Selecting Acceptable Alpha Levels

- ANOVA
 - Alpha level controls the probability of stating that there was a significant difference among treatment means, when in fact there was none
- LSD
 - Alpha level controls the probability of stating that one treatment mean was different from another, when in fact there was no real difference.

Creating a List of Measurements

- Before conducting the study, be thinking about what measurements should be taken to help you draw the right conclusions
 - Data needed to increase your understanding about what happened in your experiment
 - Deciding what data to collect requires expertise
- Types of data to collect
 - Location
 - Site-characteristics
 - Climatic conditions
 - Cultural practices
 - Experimental unit measurements

Controlling Other Factors


- List factors that may interfere with the treatments you have chosen for your study
- Decide which factors you can control and which you can't
- Controllable factors
 - Create strategies to ensure they are at levels that do not limit yields or quality
- Uncontrollable factors
 - Measure their levels


Experimental Design

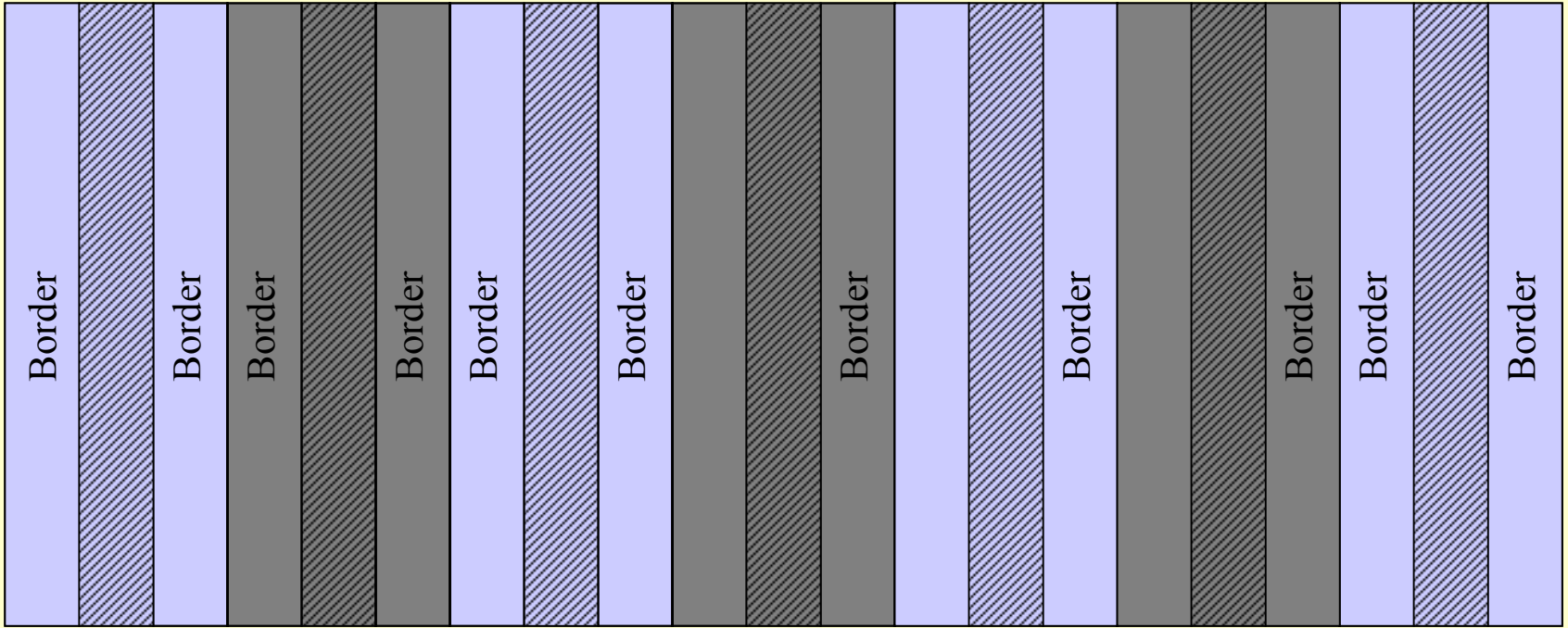
- Experimental units: areas in the field that will contain your treatments
- Width
 - All experimental units should be a uniform width
 - Width has many logistical considerations
 - Allow for border areas

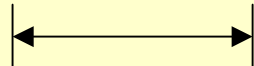
Experimental Unit Width

- Example: Applicator boom width is 60 ft, 8 row harvester, 30 in. rows
 - 8 row harvester with 30 in. rows is 20 ft. wide
 - Applicator spread pattern is 60 ft. wide
 - One pass of the applicator is divided into 3 passes of the harvester


 Usable yield data

 Alternating passes of the applicator

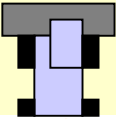



60'

Boom width


20'

Harvest width



Experimental Unit Length

- Length of the experimental units are likely to be close to the length of the field
- Previous studies:
 - Long, narrow strips reduce experimental error
 - Research with wheat and barley under dryland conditions in Pacific Northwest:
 - Length of 750 ft had much less experimental error than plots 250 or 500 ft. long.

Replication

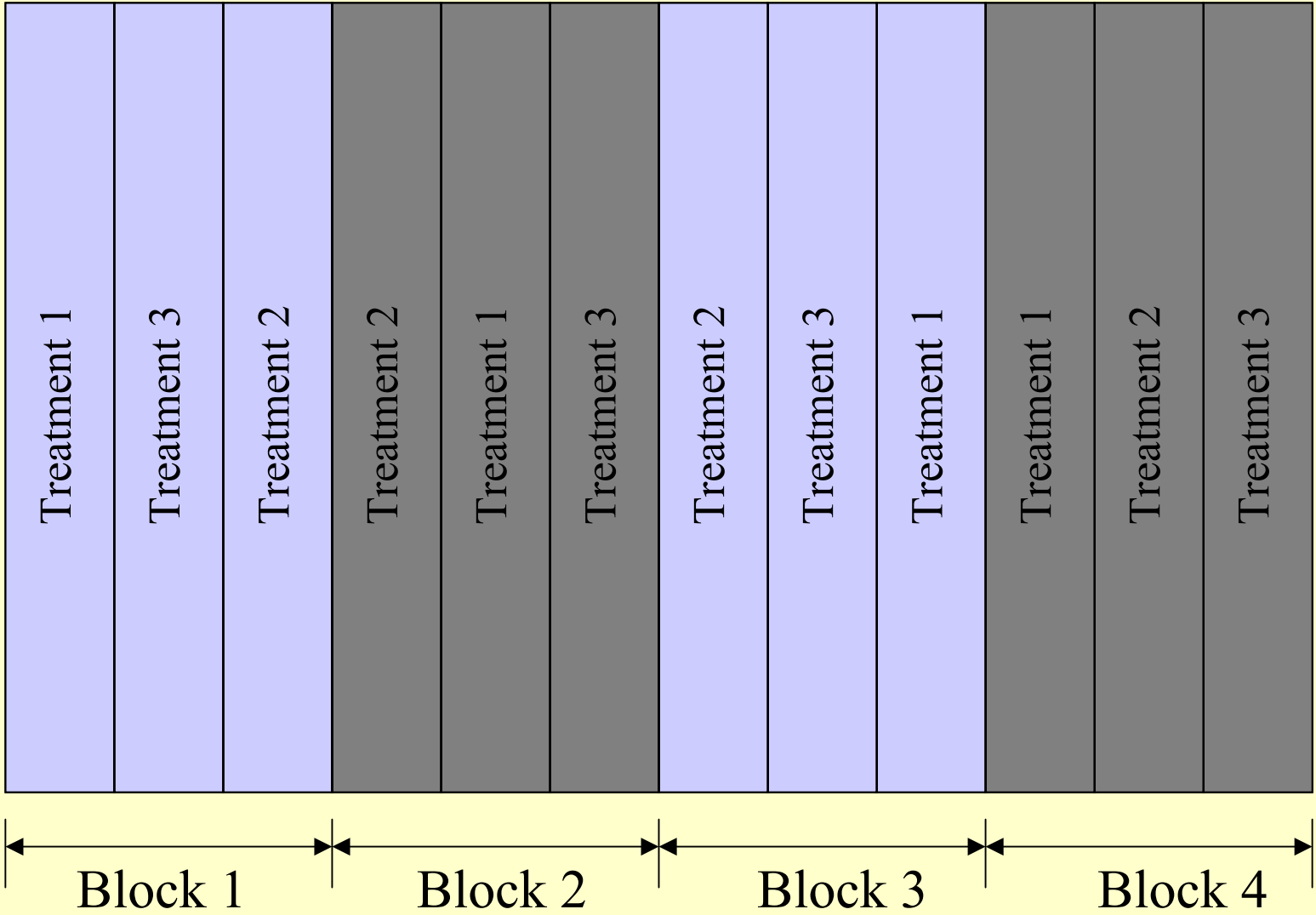
- Replication: repeating the number of times you put the treatment in the field
- Helps you measure the variability in your experiment
- What if you did not replicate?
 - Example
 - Half of the field has treatment 1
 - Remaining half of the field has treatment 2
 - Potential problems?

Randomization

- Randomization: the process of mixing up the order of your treatments
- What if you did not randomize?
 - Example
 - Alternate 2 treatments, one after the other throughout the field
 - Potential problems?

Blocking

- Smaller areas that restrict the randomization of your treatments
- Example
 - 4 Blocks and 3 treatments
 - Each block will contain all 3 treatments in random order
 - Each block will be replicated 4 times
 - Randomized complete block design (RCBD)



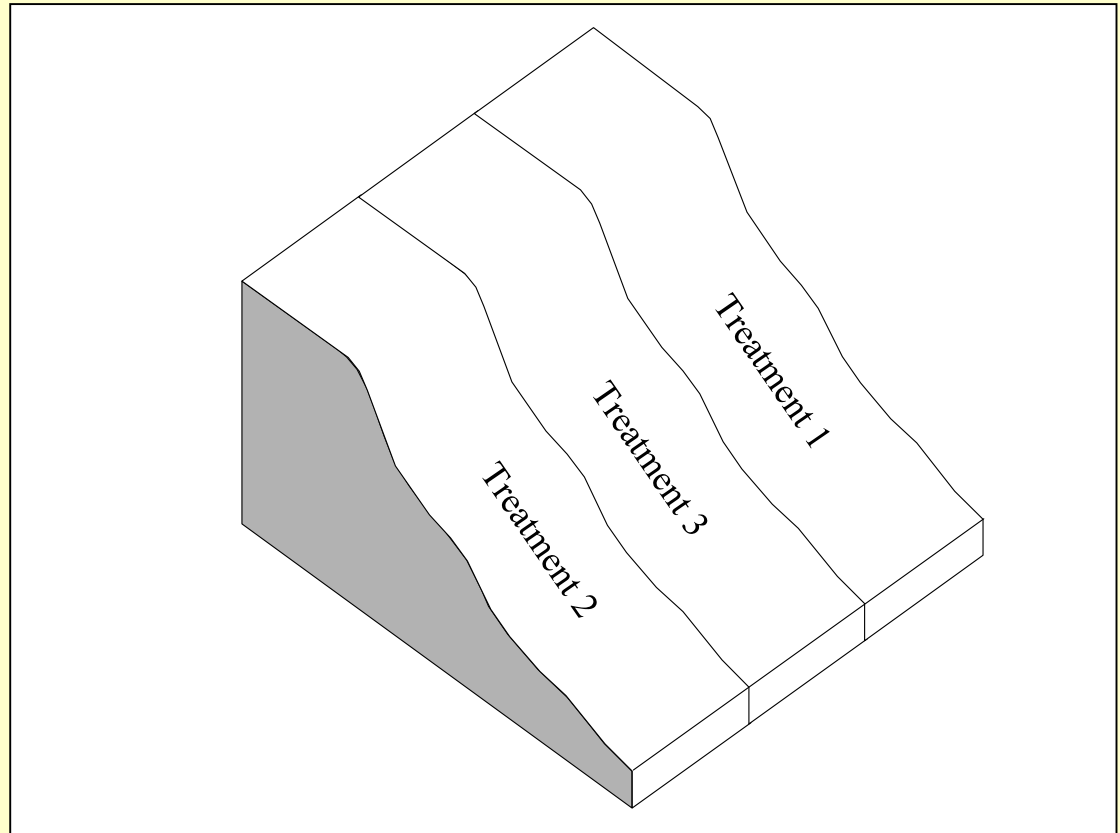
RCBD in Microsoft Excel 2000

- Input the following data into a blank Excel spreadsheet

	A	B	C
1	Block	Treatment	Random
2	1	1	
3	1	2	
4	1	3	
5	2	1	
6	2	2	
7	2	3	
8	3	1	
9	3	2	
10	3	3	
11	4	1	
12	4	2	
13	4	3	

Arranging Experimental Units and Blocks

- Run strips down slope
- Try to put a block in an area of the field that has similar features



Example Data Set

Site-specific management research funded
by the United Soybean Board



Example Data Set

- Hypotheses
 - Is site-specific management better than conventional whole-field management?
 - Is an integrated management approach superior to site-specific management concerned primarily with fertilizer management based on grid sampling?
 - Integrated management is an interdisciplinary approach to manage all information beyond just soil fertility
 - Weeds, insects, etc. managed spatially and temporally

Example Data Set

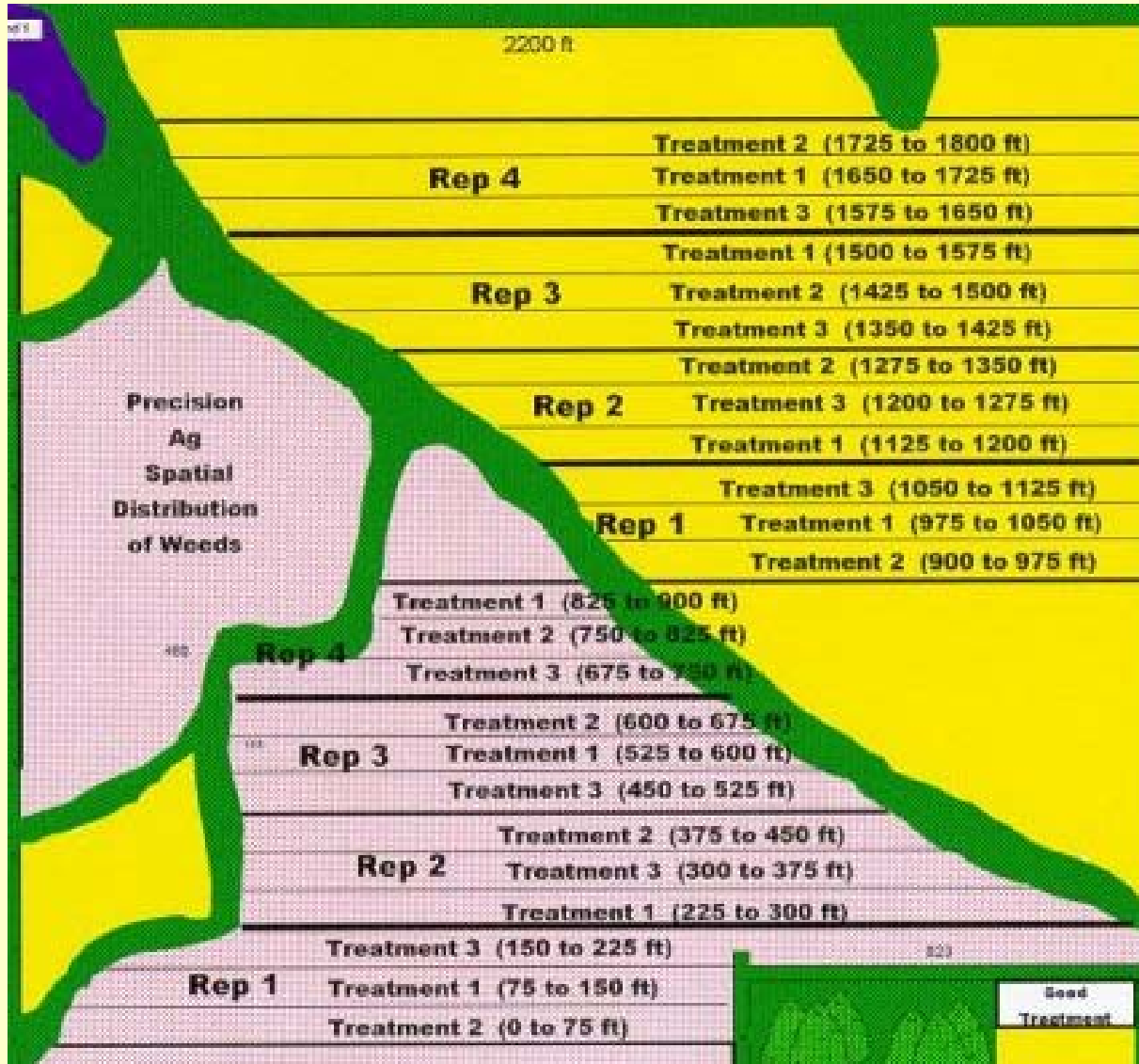
Levels define the treatments

Factor	Levels
Management approach	Whole field management
	Site-specific nutrient management based on grid sampling
	Integrated site-specific management, incorporating temporal and spatial management of all inputs, not just fertilizer

Example Data Set

- Statistical hypothesis
 - Null hypothesis:
The means of all the treatments are equal
 - Alternate hypothesis:
One or more of the treatment means are not equal
- Error control
 - Site-specific management practices are more expensive, so we want to restrict the probability of a type I error
 - Alpha levels for ANOVA and LSD set at 5%

Example Data Set



Example Corn Grain Yield Data

Treatment	Block			
	1	2	3	4
	----- (bu/acre) -----			
Whole field	137.8	158.5	165.9	146.0
Site specific	147.1	153.3	170.5	161.4
Integrated	143.4	147.9	157.9	166.5

Installing the Analysis ToolPak



Entering Data



Entering Data

Microsoft Excel - Book1

File Edit View Insert Format Tools Data GP Tools Window Help

021 =

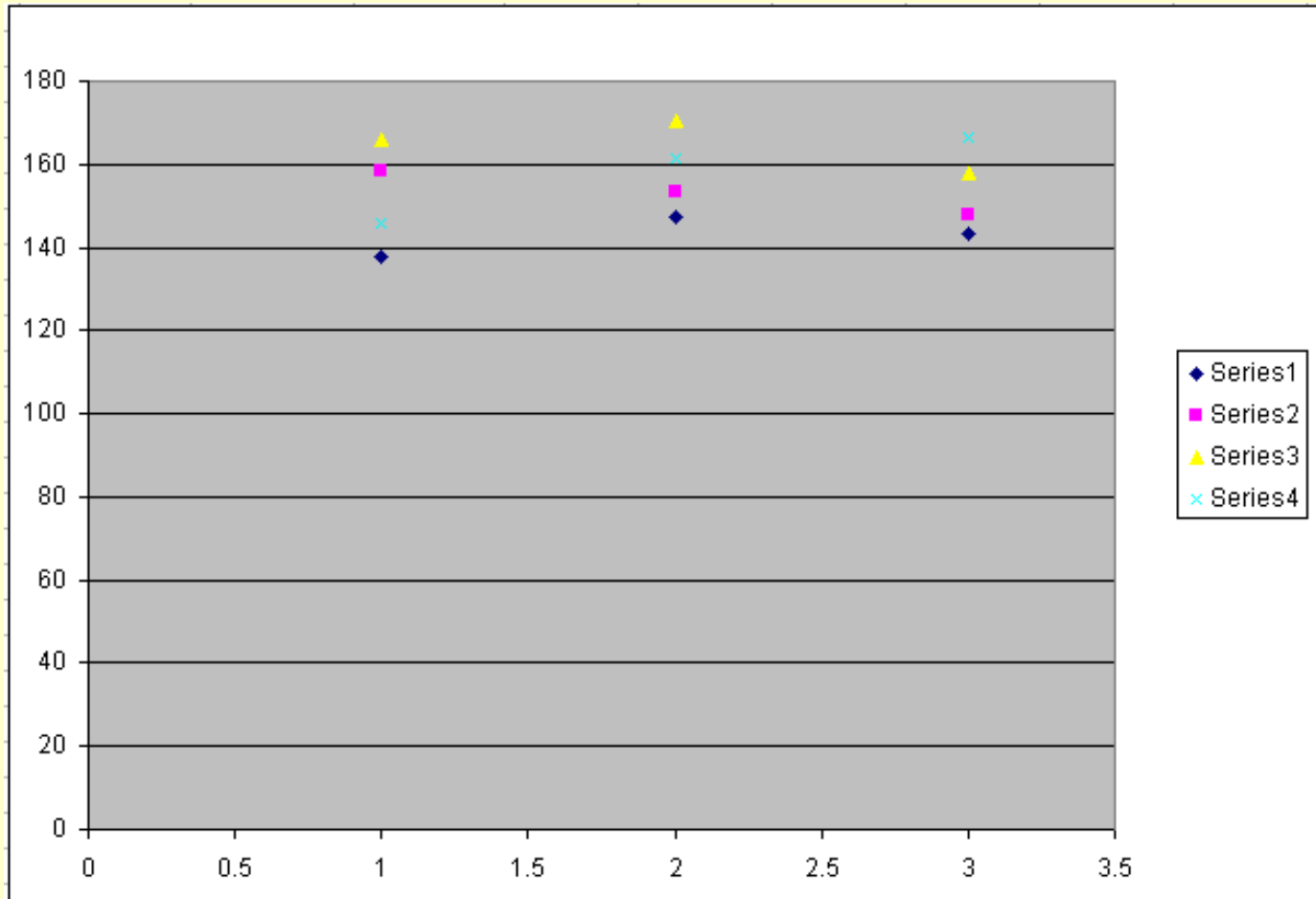
	A	B	C	D	E	F	G	H
1				Blocks				
2		1	2	3	4			
3	Whole field	137.8	158.5	165.9	146			
4	Site specific	147.1	153.3	170.5	161.4			
5	Integrated	143.4	147.9	157.9	166.5			
6								
7								
8								
9								
10								
11								

data / Sheet2 / Sheet3

Creating a Scatter Plot



Scatter Plot



Numerical Descriptive Statistics



Numerical Descriptive Statistics

- Mean
 - Measure of central tendency
 - Sum of all values divided by the number of values
- Standard deviation
 - Measure of variability
 - Considers how far each value is from the mean
 - The greater the standard deviation, the greater the variability

Numerical Descriptive Statistics

	C	D	E	F	G	H
1		Blocks				
2	2	3	4		Mean	Std Dev
3	158.5	165.9	146		=AVERAGE(B3:E3)	
4	153.3	170.5	161.4			
5	147.9	157.9	166.5			

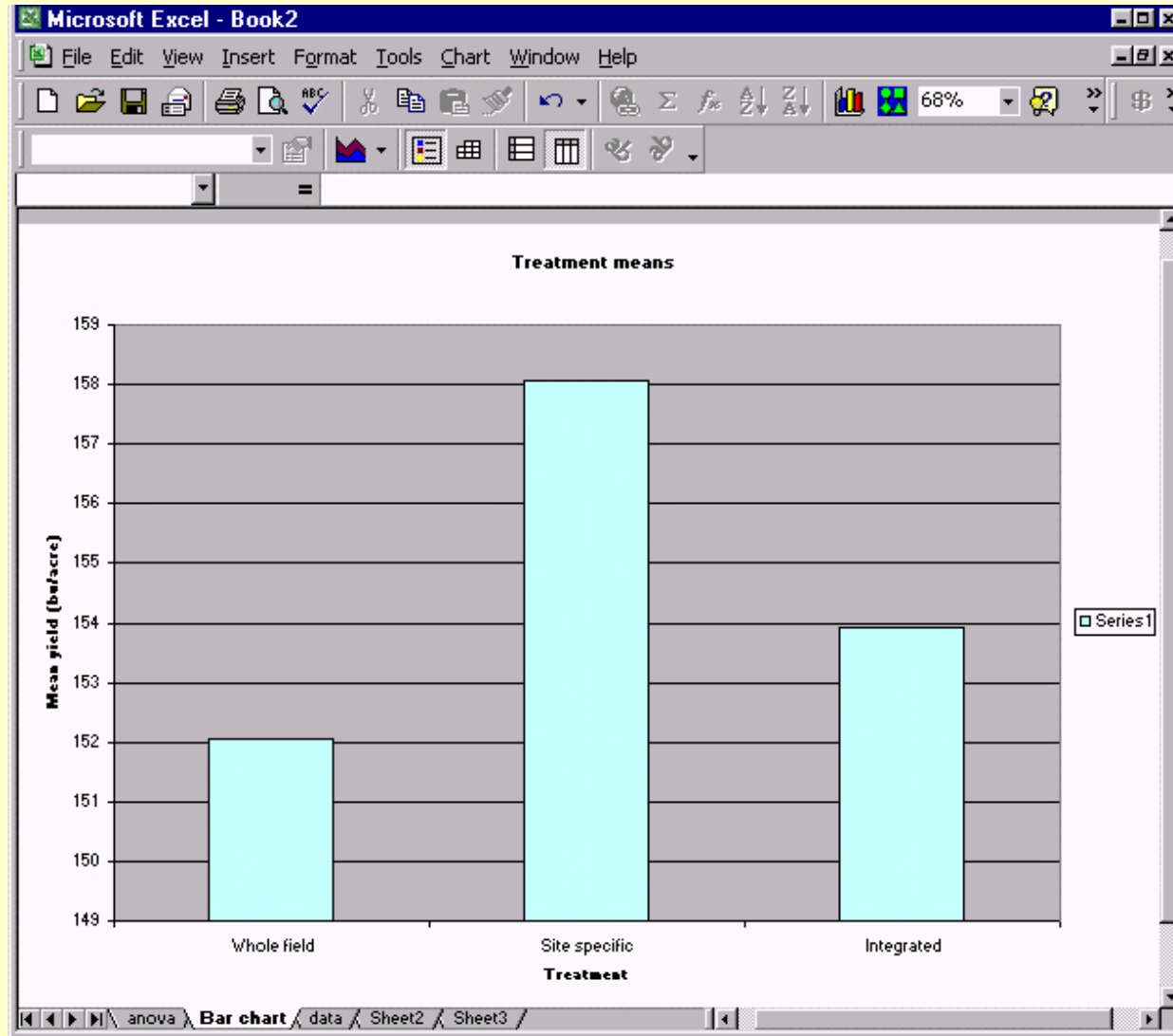
Mean	Std Dev
152.05	=STDEV(B3:E3)

Mean	Std Dev
152.05	12.55773
158.075	10.14376
153.925	10.3442

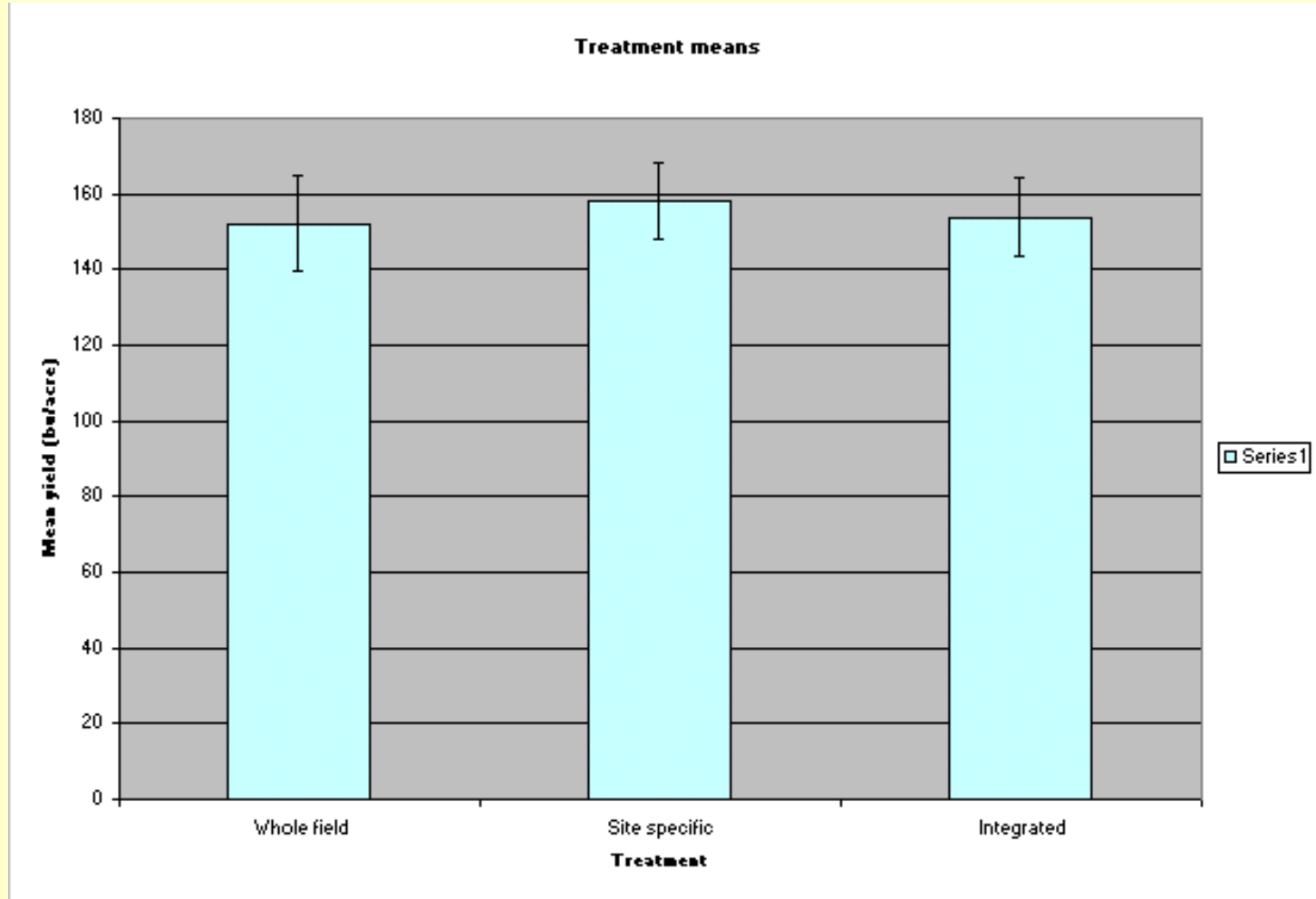
Bar Chart of Treatment Means



Bar Chart of Treatment Means



Adding Standard Deviation to Bar Chart

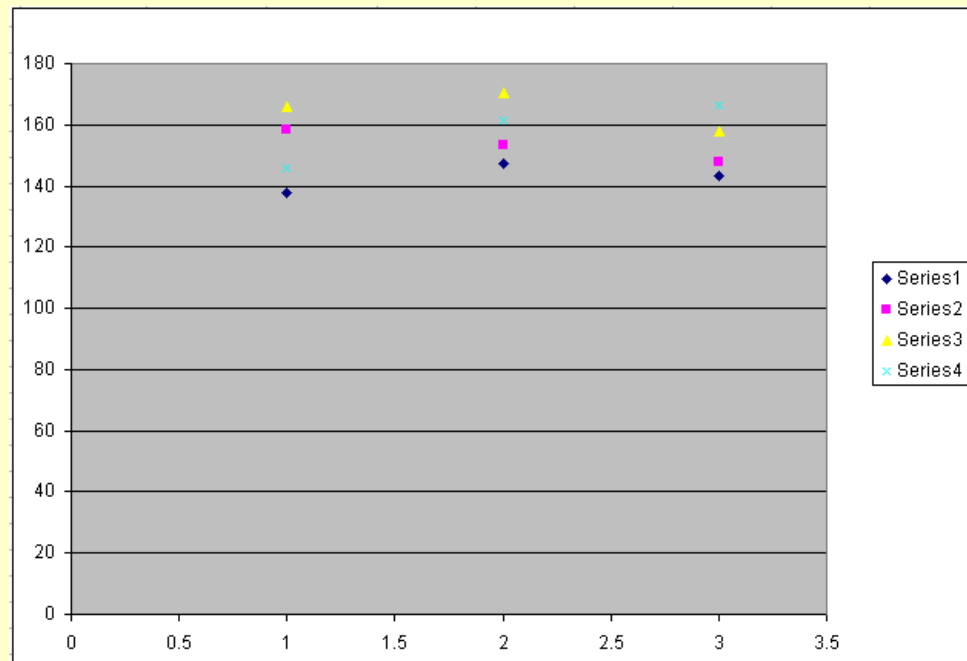


Analysis of Variance



Sources of Variation

- Treatments: means were 152, 158, and 154 bu/acre
- Blocks: means were 143, 153, 165, and 158
- Interaction of treatments and blocks
(experimental error)



How Much Variability Is Associated With This Experiment?

- Variability from our experiment is unique
- Conduct experiment again and again, begin to understand true variability
- True variability may be estimated from our experiment
 - Estimates:
 - Variability in treatment means
 - Variability in block means
 - Variability in experimental error

Which Estimate is Best?

- Experimental error
 - Best estimate of the true variability
 - Considers the variability in each yield point
 - Other estimates based on means, with more limited ability to estimate the true variance
 - This is the standard against which other estimates can be compared
 - Variability in treatment means vs. experimental error
 - Variability in block means vs. experimental error

How Do Estimates of Variability Compare?

Variance of treatment vs. variance of experimental error

- What if variance in treatment means provides a very different estimate?
- Something significant has occurred
 - For variance of treatment means to be a good estimate of the true variance, treatment means must essentially be the same
 - Therefore, if these two variances provide very different estimates of the true variance, not all treatment means are the same
- Procedure: analysis of variance (ANOVA)
 - Null hypothesis: all treatment means are the same
 - Alternate hypothesis: one or more treatment means are not the same

Analysis of Variance

	A	B	C	D	E	F	G
1	Anova: Two-Factor Without Replication						
2							
3	<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
4	Whole field	4	608.2	152.05	157.6967		
5	Site specific	4	632.3	158.075	102.8958		
6	Integrated	4	615.7	153.925	107.0025		
7							
8		1	3	428.3	142.7667	21.92333	
9		2	3	459.7	153.2333	28.09333	
10		3	3	494.3	164.7667	40.65333	
11		4	3	473.9	157.9667	113.9033	
12							
13							
14	ANOVA						
15	<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
16	Rows	76.05167	2	38.02583	0.684955	0.539594	5.143249
17	Columns	769.69	3	256.5633	4.621444	0.052978	4.757055
18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

Understanding the ANOVA Output

Summary

Variation sources

- Treatments:
 - Whole field
 - Site specific
 - Integrated
- Blocks:
1, 2, 3, 4

	A	B	C	D	E	F	G
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19							
20	Total	1178.837	11				
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Understanding the ANOVA Output

Count

How many observations went into summary statistics

- Treatments:
Number of blocks
- Blocks:
Number of treatments

	A	B	C	D	E	F	G
1	Anova: Two-Factor Without Replication						
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Understanding the ANOVA Output

Sum

Sum of all yields
comprising the count

- Treatments:
Each treatment is summed over the blocks
- Blocks:
Each block is summed over the treatments

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9		2	3	459.7	53.2333	28.09333	
10		3	3	494.3	64.7667	40.65333	
11		4	3	473.9	57.9667	113.9033	
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19							
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21							

Understanding the ANOVA Output

Average

Mean of each treatment
or each block

- Treatments:
check with means
calculated in “data”
spreadsheet

	A	B	C	D	E	F	G
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Understanding the ANOVA Output

Variance

Variability associated with each treatment and block

- Square root of the variance is the standard deviation
- Treatments: check square root of the variance and compare with standard deviation in “data” spreadsheet

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anova / Bar chart / data / Sheet2 / Sheet3

Understanding the ANOVA Output

Source of Variation

List of each source of variation

- Treatments (rows)
- Blocks (columns)
- Error (experimental error - the interaction of blocks and treatments)

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20	Total	1178.837	11				
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Understanding the ANOVA Output

SS

Sums of squares

- Part of the calculation of the variance

	A	B	C	D	E	F	G
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Understanding the ANOVA Output

df

Degrees of freedom

- Arises from restrictions on randomization during the design phase
- Treatments (rows):
One less than the number of treatments
- Blocks (columns):
One less than the number of blocks
- Error
Treatment df multiplied by block df
- Total
One less than the total number of experimental units

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14	ANOVA						
15	<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
16	Rows	76.05167	2	38.02583	0.684955	0.539594	5.143249
17	Columns	769.69	3	256.5633	4.621444	0.052978	4.757055
18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

Understanding the ANOVA Output

MS

- Mean square
- Variance associated with each source
 - ➔ Treatment (rows)
 - ➔ Blocks (columns)
 - ➔ Experimental error
 - Commonly referred to as mean square error (MSE)

	A	B	C	D	E	F	G
1	Anova: Two-Factor Without Replication						
2							
3	<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
4	Whole field	4	608.2	152.05	157.6967		
5	Site specific	4	632.3	158.075	102.8958		
6	Integrated	4	615.7	153.925	107.0025		
7							
8		1	3	428.3	142.7667	21.92333	
9		2	3	459.7	153.2333	28.09333	
10		3	3	494.3	164.7667	40.65333	
11		4	3	473.9	157.9667	113.9033	
12							
13							
14	ANOVA						
15	<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
16	Rows	76.05167	2	38.02583	0.684955	0.539594	5.143249
17	Columns	769.69	3	256.5633	1.621444	0.052978	4.757055
18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

Understanding the ANOVA Output

F

Result of an F-test

- Compares variances
- Treatment (rows):
MS for treatment
divided by MSE
- Blocks (columns):
F-test is not valid even
though a result is
given

	A	B	C	D	E	F	G
1	Anova: Two-Factor Without Replication						
2							
3	<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
4	Whole field	4	608.2	152.05	157.6967		
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17	Columns	769.69	3	256.5633	4.621444	0.052978	4.757055
18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

Understanding the ANOVA Output

F crit

Interpretation of F-test

- ➔ Critical value of F-test
- ➔ Determined by alpha level and df
- ➔ F-test must be greater than or equal to the critical value for there to be significance at the specified alpha level
- ➔ Blocks (columns): Critical value given, but is not valid

	A	B	C	D	E	F	G
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18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

anova Bar chart data Sheet2 Sheet3

Understanding the ANOVA Output

P-value

Probability of making a type I error if the experimental result of the F-test is used as the critical value

- Alpha level calculated from the results of the experiment
- Blocks (columns): P-value is not valid

	A	B	C	D	E	F	G
1	Anova: Two-Factor Without Replication						
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3	<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
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13							
14	ANOVA						
15	<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
16	Rows	76.05167	2	38.02583	0.684955	0.539594	5.143249
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18	Error	333.095	6	55.51583			
19							
20	Total	1178.837	11				
21							

Least Significant Difference (LSD)



LSD

- ANOVA determined whether or not all treatment means were essentially the same
- ANOVA does not indicate which treatment means are different
- LSD procedure compares means and separates the different ones
 - Only one value calculated
 - LSD is smallest difference between two means that can be considered significantly different at the given alpha level

LSD

- If difference between two treatment means exceeds the LSD, they are significantly different
- Otherwise, they are considered to be the same
- LSD is valid for qualitative treatments only
- Two steps to calculating LSD:
 - Critical t value (multiplicative coefficient)
 - LSD (uses critical t value)

Critical t Value

- Uses TINV function in Excel
- Syntax:
=TINV(alpha level, df of mean square error)
=TINV(0.05, 6) for our example

22		
23	Critical t value	=TINV(0.05,6)
24		

LSD Calculation

- Formula uses SQRT function (square root)
- Syntax:
=SQRT(number)
- LSD formula:
=critical t value*SQRT(2*MSE/number of blocks)
=B23*SQRT(2*D18/4) in our example

23	Critical t value	2.446914	
24	LSD(0.05)	=B23*SQRT(2*D18/4)	

Controlling Error in Using LSD

- Probability of making a type I error increase the more comparisons you make
- Limit the number of comparisons to treatments that are of particular interest
- Protected LSD
 - Do comparisons only if ANOVA determined significance
 - Wise to do this if there is a good chance the null hypothesis is true

23	Critical t value	2.446914
24	LSD(0.05)	12.89176