PLS 120: Applied Statistics in Agricultural Sciences

Hypothesis Testing and Statistical Analysis

Week 8 Tutorial Guide

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Contents

Important Links

Essential Course Resources

Course Website

All course materials available at:

Course Website Link

Interactive Binder Environment

Access Week 8 lab materials:

Week 8 Binder Link

Welcome to Week 8: Hypothesis Testing and Statistical Analysis

This week, we dive deep into **hypothesis testing methods** - essential skills for making statistical inferences in agricultural and biological research. You'll learn one-sample tests, paired t-tests, and chi-square analysis for comprehensive data analysis!

One-Sample T-Tests

When to Use One-Sample T-Tests

One-sample t-tests compare a sample mean against a known or hypothesized population value, such as testing if crop yield meets a target standard.

3.1.1 One-Sample T-Test Formula

One-Sample T-Test:

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}}$$

Where:
$\overline{x}$ = sample mean
μ_0 = hypothesized population mean
s = sample standard deviation
n = sample size

Degrees of Freedom: $df = n - 1$

R Implementation:

```
t.test(data, mu = hypothesized_value)
t.test(data, mu = 4, alternative = "two.sided")
t.test(data, mu = 4, alternative = "greater")
t.test(data, mu = 4, alternative = "less")
```

Two-Sample T-Tests (Independent and Paired)

Independent Two-Sample T-Tests

Compare means between two independent groups using Welch's t-test for unequal variances.

4.1.1 Independent T-Test Formula

Two-Sample T-Test (Welch's):

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where:
$\overline{x_1}, \overline{x_2}$ = sample means
s_1, s_2 = sample standard deviations
n_1, n_2 = sample sizes

R Implementation:
```
t.test(group1, group2, var.equal = FALSE)
t.test(group1, group2, alternative = "two.sided")
```

Paired T-Tests

For before/after measurements or matched pairs where observations are dependent.

4.2.1 Paired T-Test Formula

Paired T-Test:

$$t = \frac{\overline{d}}{s_d/\sqrt{n}}$$

Where:
$\overline{d}$ = mean of differences
s_d = standard deviation of differences
n = number of pairs

Agricultural Example:
Biodiversity before and after wildfire on same plots

R Implementation:
```
t.test(before, after, paired = TRUE)
t.test(before, after, paired = TRUE, alternative = "less")
```

Hypothesis Testing Methods

Three Approaches to Hypothesis Testing

All methods give the same conclusion but offer different perspectives.

5.1.1 Method Comparison

1. Critical Value Method:
Compare $|t_{stat}|$ with $t_{critical}$
If $|t_{stat}| > t_{critical} \rightarrow$ Reject H_0

2. P-Value Method:
Compare p-value with α (significance level)
If p-value $< \alpha \rightarrow$ Reject H_0

3. R t.test() Function:
Automatically calculates test statistic, p-value, and confidence interval
Provides complete statistical output

P-Value Calculation (Two-tailed):

$$p = 2 \times P(T > |t_{stat}|)$$

Critical Value:

$$t_{critical} = t_{\alpha/2,df}$$

Chi-Square Tests

Chi-Square Test Applications

Chi-square tests analyze categorical data for goodness of fit and independence.

6.1.1 Chi-Square Formulas

Chi-Square Test Statistic:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Where:
`O` = observed frequency
`E` = expected frequency

Goodness of Fit Test:
Tests if observed frequencies match expected distribution
Example: Testing if dice is fair
$df = k - 1$ (k = number of categories)

Test of Independence:
Tests if two categorical variables are independent
Example: Gender vs fruit preference
$df = (r-1)(c-1)$ (r = rows, c = columns)

R Implementation:

```
chisq.test(observed, p = expected_proportions)
chisq.test(contingency_table)
```

Assignment 8 Overview

Assignment Structure (15 points total)

1. **Part 1: Data Import and Visualization (3 points)**
   - Load biodiversity data and check distributions (1 point)
   - Create boxplots and interpret patterns (2 points)
2. **Part 2: Hypothesis Testing (9 points)**
   - Test if wildfire significantly affected biodiversity (3 points)
   - Test if wildfire significantly increased biodiversity (3 points)
   - Test if wildfire significantly reduced biodiversity (3 points)
3. **Part 3: Analysis Limitations (3 points)**
   - Discuss limitations of statistical analysis approach (3 points)

Environmental Applications

Real-World Hypothesis Testing Applications:

- **Wildfire Impact Studies** - Assess ecological effects using before/after data
- **Treatment Effectiveness** - Test agricultural interventions with paired designs
- **Biodiversity Research** - Compare species richness across conditions
- **Climate Change Studies** - Analyze environmental parameter changes
- **Conservation Evaluation** - Test effectiveness of protection measures
- **Soil Health Assessment** - Compare management practices effects
- **Water Quality Monitoring** - Test for changes in contamination levels
- **Crop Performance** - Evaluate variety trials and treatment effects

Hypothesis Formation Guidelines

Proper Hypothesis Setup

9.1.1 Hypothesis Types and Examples

Two-Sided Hypotheses:
$H_0 : \mu_{before} = \mu_{after}$ (no change)
$H_1 : \mu_{before} \neq \mu_{after}$ (any change)
Use when: Testing for any effect (increase or decrease)

One-Sided Hypotheses (Greater):
$H_0 : \mu_{before} \leq \mu_{after}$ (no increase)
$H_1 : \mu_{before} > \mu_{after}$ (increase occurred)
Use when: Testing for specific directional effect

One-Sided Hypotheses (Less):
$H_0 : \mu_{before} \geq \mu_{after}$ (no decrease)
$H_1 : \mu_{before} < \mu_{after}$ (decrease occurred)
Use when: Testing for reduction or decline

Environmental Example:
"Has wildfire significantly reduced biodiversity?"
H_0: Biodiversity unchanged or increased
H_1: Biodiversity decreased after wildfire

Statistical Interpretation

Understanding P-Values and Confidence Intervals

10.1.1 Interpretation Guidelines

P-Value Interpretation:
p-value = Probability of observing test statistic this extreme
or more extreme, assuming H_0 is true

Decision Rules:
If p $< \alpha$ (0.05) $\rightarrow$ Reject H_0 (significant result)
If p $\geq \alpha$ (0.05) $\rightarrow$ Fail to reject H_0 (not significant)

Confidence Interval Interpretation:
95% CI for difference: We are 95% confident the true
difference lies within this interval
If CI excludes 0 $\rightarrow$ Significant difference
If CI includes 0 $\rightarrow$ No significant difference

Effect Size Considerations:
Statistical significance $\neq$ Practical importance
Consider magnitude of difference in real-world context
Large samples can detect tiny, meaningless differences

Data Analysis Workflow

Step-by-Step Hypothesis Testing

1. **Data Exploration**
   - Load and examine data structure
   - Check for missing values and outliers
   - Create visualizations (histograms, boxplots)
   - Assess normality assumptions
2. **Hypothesis Formation**
   - Define research question clearly
   - State null and alternative hypotheses
   - Choose test type (one/two-sided)
   - Set significance level ($\alpha = 0.05$)
3. **Test Selection and Execution**
   - Choose appropriate test (one-sample, paired, independent)
   - Verify test assumptions
   - Perform statistical test using R
   - Calculate effect sizes if needed
4. **Results Interpretation**
   - Interpret p-values and confidence intervals
   - Consider practical significance
   - Draw conclusions in context
   - Discuss limitations and assumptions

Key Concepts Summary

Test Selection Guide

When to Use Each Test:

One-Sample T-Test:
- Compare sample mean to known standard
- Example: Does yield meet target of 60 bu/acre?

Independent Two-Sample T-Test:
- Compare means between unrelated groups
- Example: Organic vs conventional farming yields

Paired T-Test:
- Compare before/after on same subjects
- Example: Biodiversity before/after treatment

Chi-Square Test:
- Analyze categorical data
- Example: Disease presence across varieties

Test Assumptions:
- Independence of observations
- Approximate normality (t-tests)
- Expected frequencies ≥ 5 (chi-square)

Common Analysis Limitations

Statistical Analysis Constraints

Important Limitations to Consider:

- **Sample Size** - Small samples reduce power to detect effects
- **Data Quality** - Measurement errors affect reliability
- **Time Window** - Limited observation period may miss effects
- **Single Parameter Focus** - Relying only on means ignores variability
- **Normality Assumptions** - Violations can affect test validity
- **Independence Assumptions** - Spatial/temporal correlation issues
- **Multiple Testing** - Increased Type I error with many tests
- **Confounding Variables** - Unmeasured factors affecting results
- **Generalizability** - Results may not apply to other contexts
- **Causation vs Correlation** - Statistical association $\neq$ causation

Getting Started

1. Launch Week 8 Binder environment

2. Navigate to `class_activity` folder
3. Open `Week8_Correlation_Analysis.ipynb`
4. Work through hypothesis testing examples
5. Complete Assignment 8 in `assignment` folder

Learning Objectives

By the end of this week, you will be able to:

- Form appropriate null and alternative hypotheses
- Perform one-sample t-tests using multiple methods
- Conduct two-sample and paired t-tests appropriately
- Apply chi-square tests for categorical data analysis
- Interpret statistical results and draw valid conclusions
- Understand limitations of statistical analyses
- Choose appropriate tests for different research questions
- Apply hypothesis testing to environmental research problems

Tips for Success

Best Practices:

- Check test assumptions before analysis (normality, independence)
- Visualize data first using histograms and boxplots
- Choose appropriate test type based on research question
- Interpret results carefully - statistical $\neq$ practical significance
- Consider limitations and discuss them in conclusions
- Use paired tests for before/after or matched data
- Plan hypothesis tests before seeing data
- Always interpret results in scientific context

Common Mistakes to Avoid

Avoid These Errors:

- Confusing paired and independent t-tests
- Misinterpreting p-values as probability hypotheses are true
- Using wrong alternative hypothesis direction
- Ignoring test assumptions (normality, independence)
- Over-interpreting non-significant results
- Switching test type after seeing results
- Forgetting to consider practical significance
- Not discussing analysis limitations
- Using inappropriate tests for data type
- Making causal claims from correlational data

Need Help?

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Zoom Link: Join Office Hours