Week 10: Experimental design

ANTH 674: Research Design & Analysis in Anthropology

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Lecture outline

1. Review of interactions w/ continuous IVs
2. What is experimental design?
   - Broadly used to encompass sampling design
3. How do experiments account for uncontrolled variation in DV?
   1. Replication
   2. Adequate spacing between replicates
   3. Randomization
   4. Blocking
4. Two-factor experiments
5. Moving from ANOVA to regression

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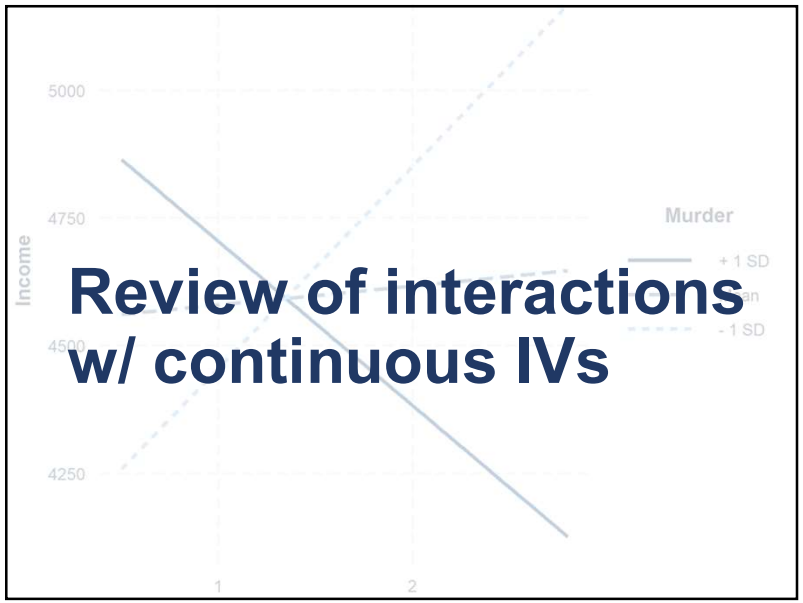

Review of interactions w/ continuous IVs

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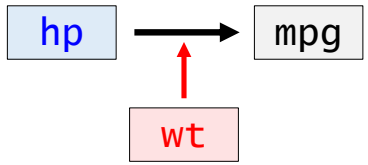
Interaction w/ continuous IVs

- $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \varepsilon$
- Changing intercepts **AND** slopes, just like in ANCOVA
- E.g., `mpg ~ hp * wt`
- Intercept and slope of `mpg ~ hp` will change as `wt` increases



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Interaction w/ continuous IVs

- $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \varepsilon$
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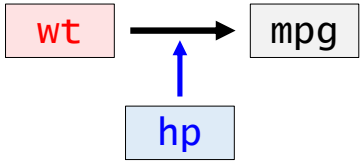
- E.g., `mpg ~ hp * wt`
- Intercept and slope of `mpg ~ wt` will change as `hp` increases



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Interaction w/ continuous IVs

- `mpg = 49.81 - 0.12hp - 8.22wt + 0.03hp*wt`
- If `hp = 0`, `mpg = 49.81 - 8.22wt`
- If `hp = 1`, `mpg = 49.81 - 0.12 - 8.22wt + 0.03wt`
- If `hp = 1`, `mpg = 49.69 - 8.19wt`

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Interaction w/ continuous IVs

- `mpg = 49.81 - 0.12hp - 8.22wt + 0.03hp*wt`
- If `wt = 0`, `mpg = 49.81 - 0.12hp`
- If `wt = 1`, `mpg = 49.81 - 8.22 - 0.12hp + 0.03hp`
- If `wt = 1`, `mpg = 41.59 - 0.09hp`

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Interaction w/ continuous IVs

- `mpg = 49.81 - 0.12hp - 8.22wt + 0.03hp*wt`
- `49.81` is intercept when both IVs equal zero
- Focusing on `mpg ~ wt`
  - `-0.12` is change in intercept as `hp` increases by one
  - `-8.22` is slope when `hp` is zero
  - `0.03` is change in slope as `hp` increases by one

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Interaction w/ continuous IVs

- `mpg = 49.81 - 0.12hp - 8.22wt + 0.03hp*wt`
- `49.81` is intercept when both IVs equal zero
- Focusing on `mpg ~ hp`
  - `-8.22` is change in intercept as `wt` increases by one
  - `-0.12` is slope when `wt` is zero
  - `0.03` is change in slope as `wt` increases by one

Interaction term is symmetrical!
Affects both slopes in the same way

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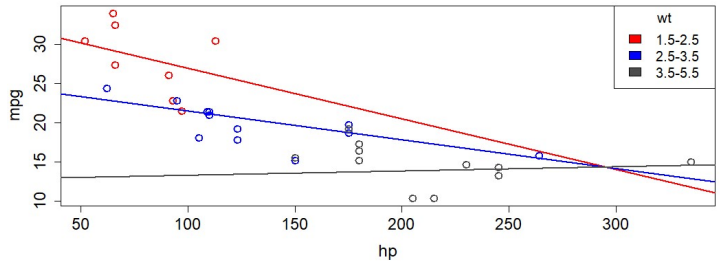
Interaction w/ continuous IVs

- Focusing on `mpg ~ hp`
  - `-8.22` is change in intercept as `wt` increases by one
  - `0.03` is change in slope as `wt` increases by one



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Questions?

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What is experimental design?

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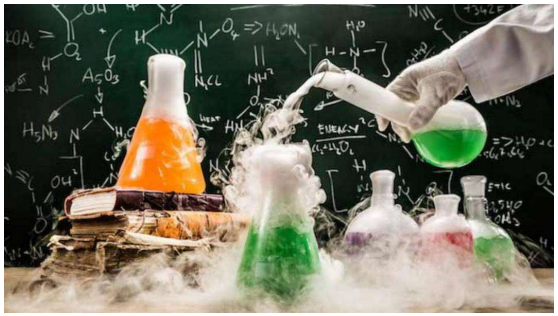
What is experimental design?

- What do you think of when I say “experiment”?



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What is experimental design?

- Planning the logical structure of your experiment to anticipate statistical issues
- Good ED recognizes sources of unmeasured variation & plans statistics around them
  - Increases statistical power
  - Analysis of data goes hand-in-hand w/ ED
- If there are serious problems w/ ED, very difficult to correct afterwards w/ statistics
- Important to think through ED **before** data collection (clear research question helps **a lot**)!

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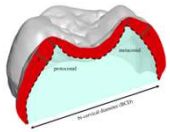
Not only experiments!



- Sampling design
- E.g., Interested in primate enamel thickness as it relates to diet
  - How many primate species to sample in museum?
  - How many individuals per species?
  - How many species or individuals per diet?
  - From what regions/years should I sample?
- Also applies to collecting data from literature if there’s a lot of data to sample from

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Not only experiments!

- If not much data, have no choice but to use all of it, so sampling design not as applicable
- E.g., how hominin brain size evolution was affected by climate change
- Must use statistics to account for a lot of the things we’ll be talking about

Everything that follows applies to experimental **AND** sampling design!

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Main goal of experiments

- **To see if and how one or more IVs affect a DV**
- Controls for other factors affecting DV, thereby isolating IV's effect on DV
- E.g., how does nitrogen affect plant growth rate?

Control	Treatment	
0N	+N	Good experimental design?
Sandy soil	"Regular" soil	

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Main goal of experiments

- **To see if and how one or more IVs affect a DV**
- Controls for other factors affecting DV, thereby isolating IV's effect on DV
- E.g., How does diet affect primate enamel thickness?

Hard food	Soft food	
Sandy soil	"Regular" soil	Good "experimental" design?

Uncontrolled factor confounded w/ IV—not good!

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Good ED accounts for:

1. Confounding factors
   - Randomization, blocking
2. Experimenter bias
   - Randomization
3. Noise and variation in data
   - Replication
4. Non-independence in data
   - Adequate spacing between replicates, randomization

Basically, **clearly** outline your research question & think about all the factors that can screw up your analyses and inference!

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Two main types of experiments

Manipulative	**Natural**
• Experimenter varies IV & measures DV	• Uses natural variation in IV & measures DV
• E.g., manipulating N levels → plant growth	• E.g., measure areas w/ different N levels
• Expensive and time-consuming	• Cheaper and faster
• Good for controlling confounding factors	• More difficult to control confounders
• Too "artificial"?	• More "realistic"?

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Questions?

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How to account for uncontrolled variation in ED

Warmer Cooler

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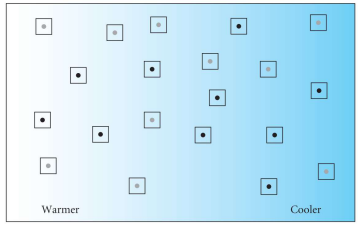
ED strategies

1. Replication
2. Adequate spacing between replicates
3. Randomization
4. Blocking



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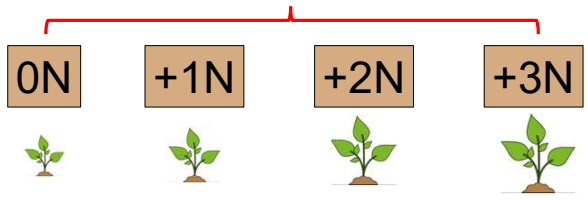
Basic experimental design

- One or more factors
- One or more levels w/in each factor

Interested in plant growth rate ~ N level

One factor: nitrogen; 4 levels: 0, +1, +2, +3



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1. Replication

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Replication

Multiple observations w/in each level of a factor

16 total measurements

One factor: nitrogen; 4 levels: 0, +1, +2, +3

Four replicates each

0N	+1N	+2N	+3N
0N	+1N	+2N	+3N
0N	+1N	+2N	+3N
0N	+1N	+2N	+3N

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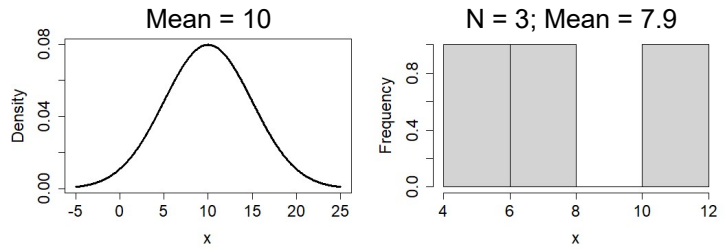
Why replicate?

- **To average out individual variation among observations w/in a treatment level**
- Same reason why a small sample may not be representative of the population



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How many replicates?

- Ultimately determined by money, effort, and time, so usually there's a max. # measurements
- A trade-off between number of factors, levels, and replicates

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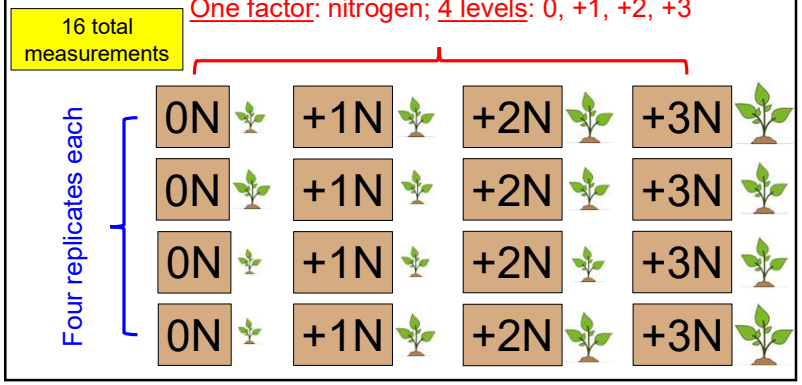
Replication

- If I had two levels, I could have eight replicates



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How many replicates?

- Ultimately determined by money, effort, and time, so usually there's a max # measurements
- Is a trade-off between number of factors, levels, and replicates
- Depends on your question!
  - Usually 1–3 factors is most that is manageable
  - Usually 2–5 levels is adequate
- Gotelli & Ellison's "Rule of 10": absent other information, need 10 replicates
- If data are variable and effect sizes (i.e., mean differences) are small, need more replicates

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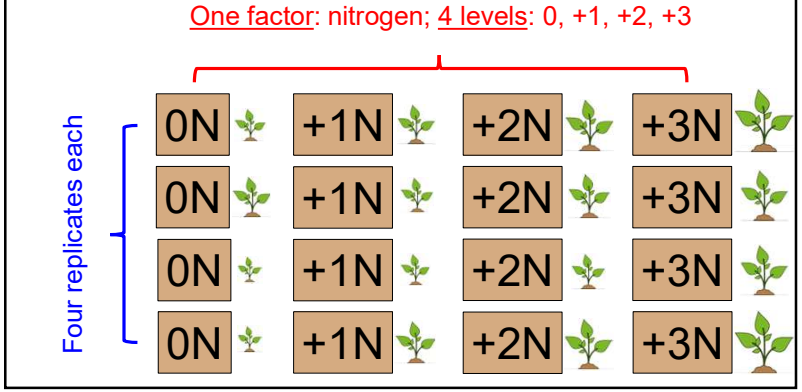
Which statistical test?

- This is a one-way ANOVA: `aov(plant ~ N)`



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Questions?

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2. Adequate spacing

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Adequate spacing

- Virtually everything is temporally, spatially, and phylogenetically autocorrelated
- Tobler's first law of geography: "everything is related to everything else, but near things are more related than distant things"
- This non-independence artificially inflates sample size, making P-values too small (increases Type I error)

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A spatial example

Seedlings in shade are smaller (size is spatially autocorrelated)

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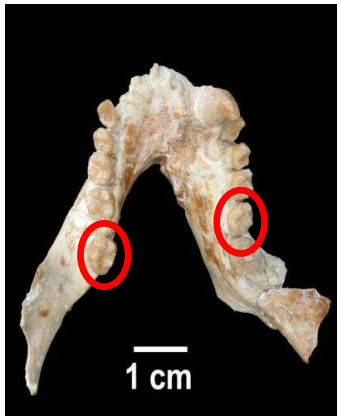
An extreme example



- Independent replicates?
- **NO!** Products of the same genetics, habitat, diet, & whatever processes affected this individual
- Replicates are not truly independent (i.e, **"pseudoreplication"**)

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Adequate spacing

- Adequate spacing in time and/or space ensures replicates are truly independent
- How much time or space? Depends on process of interest
  - E.g., predation of mantis requires less spacing than lion predation
- Only worry about this if you care about P-values

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Questions?

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3. Randomization

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Randomization

- **Randomly assign replicates to treatment levels**
- Must be truly random!
  - Use random number generator, e.g., `sample()`
  - Coin flips, roll a die
- Counteracts experimenter bias, confounding factors, and non-independence
- Replication and randomization only effective when used together

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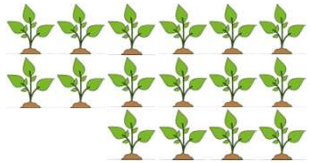
Randomization



- Take individual plants and randomly assign them to treatment levels

0N	+1N	+2N	+3N
0N	+1N	+2N	+3N
0N	+1N	+2N	+3N
0N	+1N	+2N	+3N

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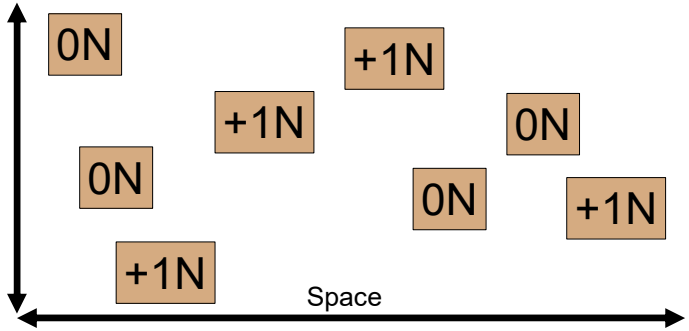
Battling non-independence

- Random distribution ensures levels that are close are canceled by levels that are far



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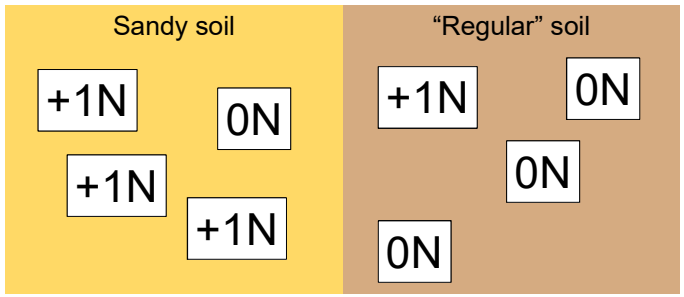
Battling confounding factors

- Plots are randomly distributed
- Assigning treatments to plots is random
- Assigning individuals to treatments is random



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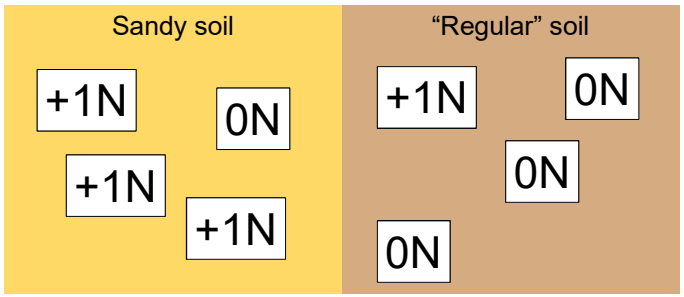
Battling confounding factors

- Treatments found in both soil types now
- Treatment is now independent of confounder
- Works for "known unknown" confounders too!



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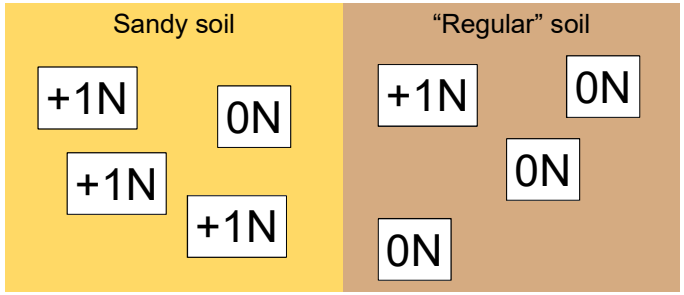
Which statistical test?

- One-way ANOVA: `aov(plant ~ N)`
- Can include soil type as covariate to increase power (move DV variation from error term to covar.)
- Two-way ANOVA: `aov(plant ~ soil + N)`



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Questions?

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4. Blocking

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Blocking

- In soil example, three "+1N" and only one "0N" in sandy soil (uneven sample sizes)
- Blocking solves this issue (**randomized block design**)
- **Block: delineated area or time period w/in which environment is homogeneous**
- Environmental variation between blocks must be greater than w/in blocks

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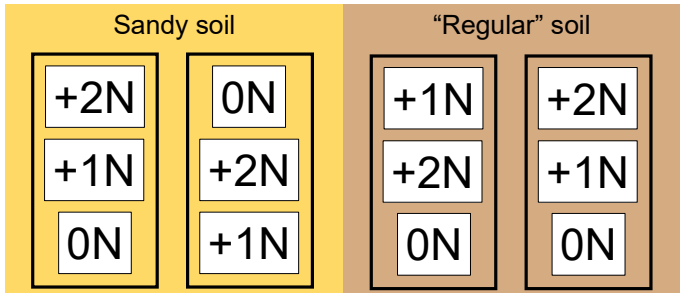
Blocking

- Each treatment level assigned to a block but randomized within
- Replicates randomly assigned to levels



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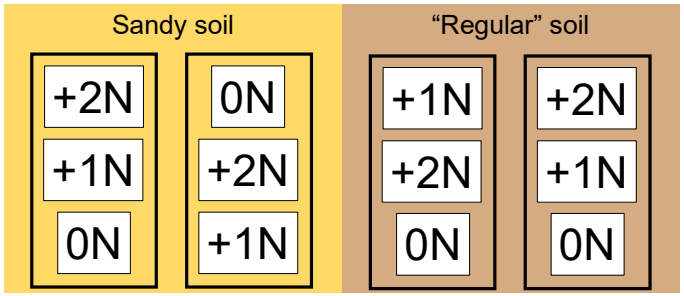
Blocking

- Treatment now independent of known and unknown (spatially autocorrelated) confounders



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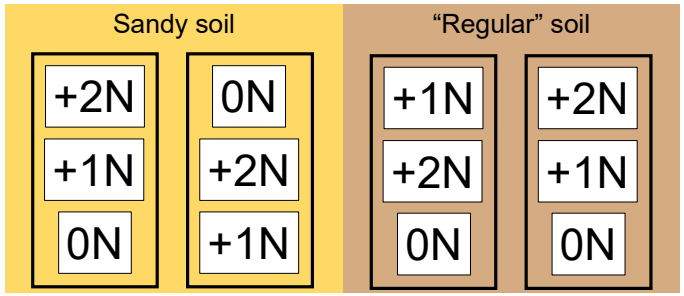
Which statistical test?

- Can include block as covariate to increase power
- Two-way ANOVA: `aov(plant ~ block + N)`



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Caveats for blocking

- Assumes that there is no interaction between blocks & treatments
  (e.g., effects of +2N > +1N > 0N for all blocks)
- What if this is not the case? Need two-factor experiment

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Questions?

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Two-factor experiments

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Two-factor experiments

- Interested in how DV responds to manipulating **TWO** factors simultaneously
- Every level of factor 1 *must* be combined w/ every level of factor 2 (**fully crossed** or **orthogonal** design)
- Can look at interaction between factors 1 & 2
- With blocking, this becomes a **split-plot design**

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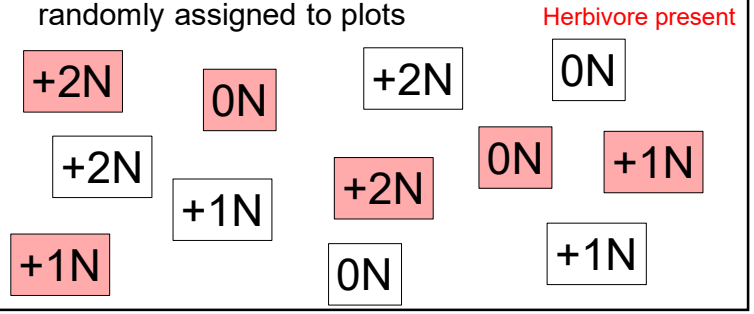
Two-factor experiments

- E.g., Plant growth rate ~ nitrogen level **AND** presence of herbivores
- Plots randomly distributed, treatments randomly assigned to plots, replicates randomly assigned to plots



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Which statistical test?

- This is a two-way ANOVA w/ an interaction between the IVs (often interested in how effect of IV1 on DV is affected by IV2)
- If you have unequal # replicates among levels for the two factors, ANOVA can be problematic
  (http://onlinestatbook.com/2/analysis_of_variance/unequal.html)
  (https://mcfromnz.wordpress.com/2011/03/02/anova-type-iiiiii-ss-explained/)

Confounding factors all over again!

	0N	+1N
Herb. absent	1	10
Herb. present	10	1

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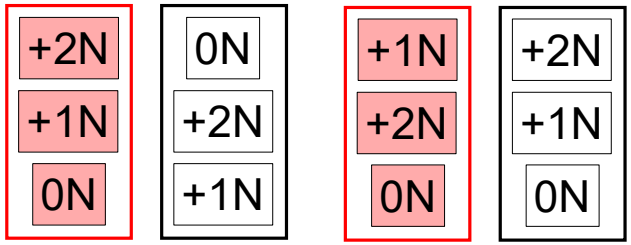
Split-plot design

- All N treatment levels (i.e., subplot factor) are represented in each block, which is itself a different herbivore treatment (i.e., whole-plot factor)

Herbivore present



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Questions?

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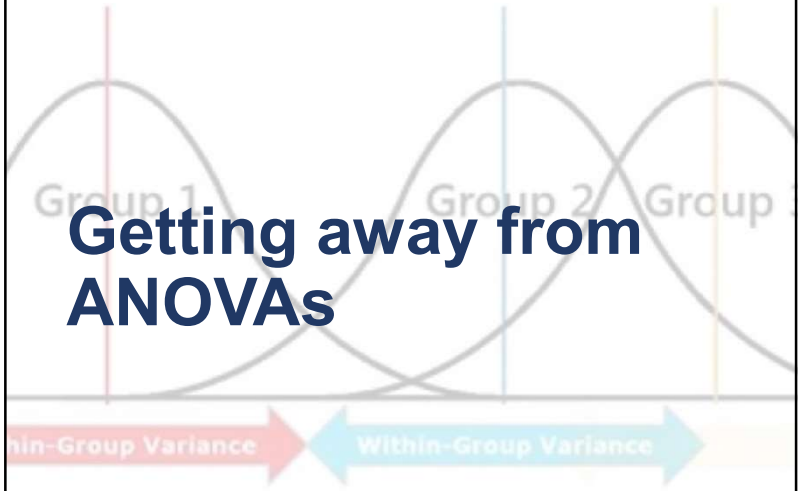
Getting away from ANOVAs



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Getting away from ANOVAs

- Thus far, I have presented IVs as categorical factors w/ different levels
- Indeed, ANOVA was invented by R.A. Fisher in the context of agricultural experiments
- But many times, different levels w/in a factor can be converted to continuous data

0N	+1N	+2N	+3N	···	+20N
0H	1H	2H	3H	4H	···	20H

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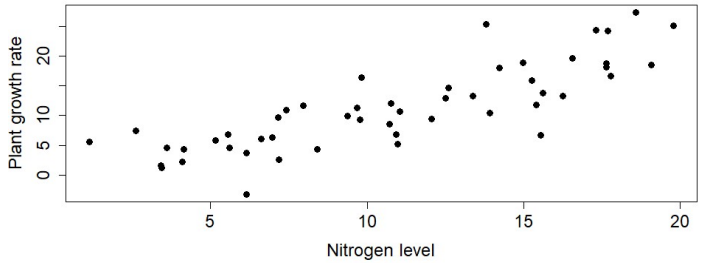
Regression

- Becomes regression instead of ANOVA
  - Can get change in DV ~ change in IV (slope)
  - Do predictions
  - Get goodness of fit (R^2)



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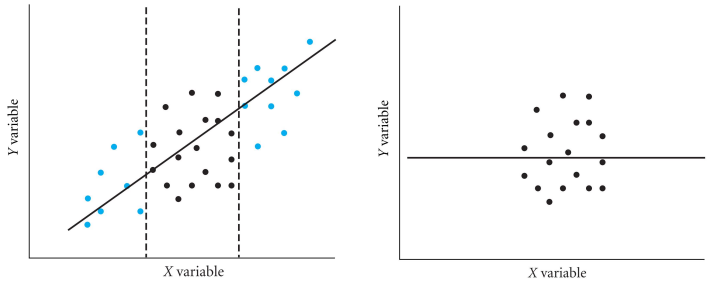
Regression

- Make sure IV is sampled over large enough range to get full range of response in DV



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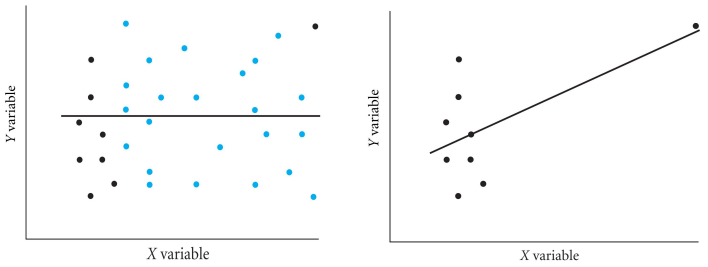
Regression

- Make sure IV is sampled uniformly within its range



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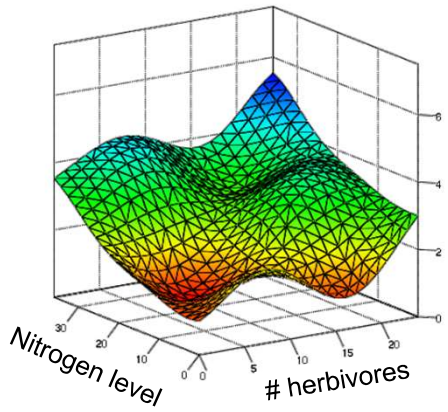
Can get a response surface



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Questions?

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Summary

- Experiments account for sources of uncontrolled variation in DV → more powerful tests
- Accounts for confounding factors, non-independence, & noise in DV w/ replication, randomization, spacing btw plots, & blocking
- Try to make IV continuous rather than categorical
- In the end, it's all about thinking hard to account for confounding factors in your own research!

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Statistics vignette

Brain cancer death rates in the US (example from Ellenberg, 2014)

Top 5 States	Bottom 5 States
• South Dakota	• Wyoming
• Nebraska	• Vermont
• Alaska	• North Dakota
• Delaware	• Hawaii
• Maine	• District of Columbia

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Statistics vignette

Brain cancer death rates in the US (e

What's going on?
What do these ten states have in common?

Top 5

• South Dakota	• Wyoming
• Nebraska	• Vermont
• Alaska	• North Dakota
• Delaware	• Hawaii
• Maine	• District of Columbia

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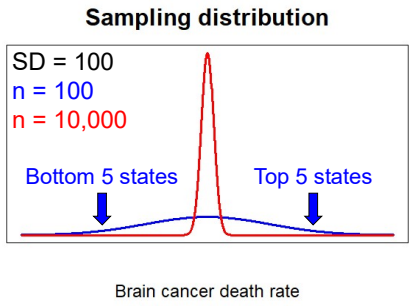
Small population sizes!

- Leads to noisy death rate estimates
  (related to Law of Large Numbers & standard errors)

$$SE = \frac{SD}{\sqrt{n}}$$



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