Environmental Studies
FACT SHEET
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Investigations: Basic Principles

A student decided to investigate the effect of zero cultivation on soil properties. They had read about an organic farmer who had not mechanically altered the soil in an arable field for 13 years. The farmer seeded directly into untilled soil and, via rotation of crops, claimed he got greater yields, year after year, in that field than from an adjacent field which had been cultivated normally.

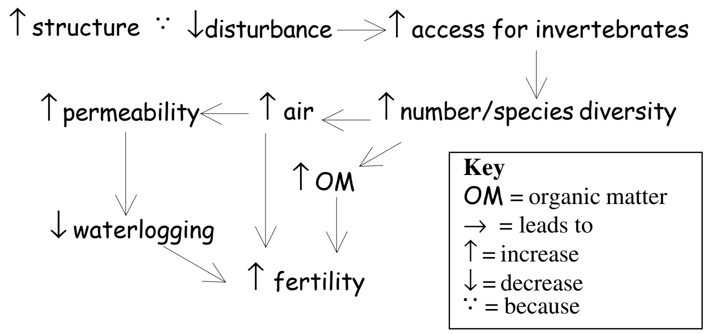
Student aim: To investigate whether the fertility of the soil is different in the two fields.

In the plan the student makes the following predictions:

The untilled field will have:

- Better soil structure
- Greater number and diversity of invertebrates
- Greater organic matter
- Faster infiltration
- Greater fertility

The student's explanation of these predictions is as follows:



The student came up with the following possible null hypotheses. Which is the best and why?

1. There will be no difference in the structure, fertility or infiltration rate of soil in the tilled and untilled field.	It is a null hypothesis – that's good, but there are too many (four) variables! It is fine to measure four, five or six things but your null hypothesis should only have two variables in it - of which one should be tillage.
2. The untilled field will have high species diversity and the tilled field will be more prone to waterlogging.	The null hypothesis must always be that there is no difference/no effect etc - reference to one field having higher species diversity or similar would only be appropriate in a (directional) alternative hypothesis. The other problem is that the student seems to be measuring different things (species diversity / waterlogging) in the different fields.
3. The untilled field will have greater organic matter, species diversity and faster infiltration rate than the tilled field because the structure will be better.	Another possible alternative hypothesis and too many variables. The last part of the sentence is a real problem 'because the structure will be better'. The student will not have enough data on soil structure to be able to test this (the structure of one field against the structure of the other).
4. Tillage has no effect on soil organic matter levels.	A nice null hypothesis with two variables.
5. The greater the tillage, the slower the infiltration rate.	Two variables but an alternative hypothesis.
6. Is mechanically altering soils good or bad?	This is not a hypothesis, it is a question!

So after consulting the teacher the student decided on hypothesis 4.

Null and alternative hypotheses

When you carry out a stats test, you are deciding between two hypotheses:

- **Null Hypothesis (H_0)** - this is what you assume unless you have convincing evidence to reject it. It is **always** of the form "there is no difference/ no relationship/no correlation..." - but essentially, it means that any differences observed are just due to chance.
- **Alternative Hypothesis (H_1)** - this is the "opposite" of the null hypothesis - it is what you hope to establish if your investigation provides enough evidence.

Usually, you should use a **non-directional** alternative hypothesis. This just says that there is a difference - eg "The tilled and untilled fields will have different soil organic matter levels". You should generally use this form of alternative hypothesis unless you have a very good reason not to! This involves a 2-tailed statistical test - this affects the values you get from the tables.

Some alternative hypotheses are **directional** - they specify what sort of difference you are looking for eg "The tilled field will have lower soil organic matter level than the untilled field". You should only choose this sort of alternative hypothesis if you have good scientific reasons for it **before** collecting any data. If you are testing this sort of alternative hypothesis then you have to do a 1-tailed statistical test. You can only do 1-tailed tests using certain statistical tests - such as those for means,medians and correlation (for example, Spearman's Rank, t-test, Mann-Whitney U-test).

Introduction

This would include:

- An explanation of why this investigation matters and why tillage and fertility are being investigated.
- A discussion of what no-tillage and tillaged cultivation means.
- An explanation of why many organic farmers are now converting to zero-tillage methods.
- An explanation of why the investigation is being carried out in this particular area / these fields. A description of the factors, other than tillage (fertiliser applications, crops grown, etc.) which could have affected fertility.
- A description of the role of organic matter in soils and how tillage might, via many other factors, affect organic matter content and ultimately, fertility. This will help the student identify other factors beside organic matter content that they should measure in the field.
- A description or outline of other people's works in this area – try good search engines such as Google, Copernic, Vivisimo and Scirus, as well as textbooks.
- A brief outline of which parts of the specification this investigation is based upon.

Method

The student has decided to measure the following:

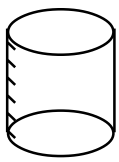
- Soil structure
- Soil pH
- Soil organic matter content
- Infiltration rates
- Invertebrate numbers and species diversity

The method should describe, in the past tense, exactly what was done and where. One year after carrying out these tests, another student should be able to pick up this method and be able to repeat precisely what the first student did.

The methods for each test and the tools and materials used, must be justified. Used a soil auger to get a sample? Why? Why not a spade? How big was the auger and how deep did it go? etc.

Here is the part of the student's method which describes how they worked out the infiltration rate of soils from each of the two fields:

1. A calibrated plastic tube was made from a lemonade bottle. The tube was open at both ends.



2. The tube was placed on the soil surface in the tilled field.
3. Exactly 50cm³ of water was poured in to the tube from a measuring cylinder.
4. The time (seconds) for all of the water to soak in to the soil was recorded.
5. This was repeated at two more sites in the tilled field.
6. The test was then repeated at three sites in the untilled field.

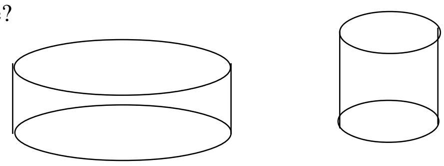
Question: Suggest criticisms of this method

***Hint**: Imagine you are there, by that tilled field right now with an uncut lemonade bottle, a measuring cylinder and some water. Can you repeat the method exactly?*

Answer:

1. The student does not tell you how they identified where in the field the tests were going to be done. You should be able to use the same sampling strategy – but you can't because you don't know what theirs was.

2. Imagine cutting the cylinder. Are all lemonade bottles the same size? They have not told us the measurements, so we can't repeat it. For example, would 50cm³ of water drain from these two tubes at the same rate?



   No. We need to know the area of the ground the tube base covered.

3. Did they remove the grass?

4. How was the water poured in – quickly or slowly and from what height? Does it matter? - probably.

5. What is the student trying to simulate by pouring water in? Rainfall – a watering can with a sprinkler would have been a better simulation.

6. This method has the advantage that the soil is not disturbed, but it provides limited data.

To summarise: The devil is in the detail. It must be replicable exactly – and remember to try to make it REAL (ask yourself what are you simulating?)

Limitations and Shortcomings of Methodology

Many students confuse limitations of methodology with shortcomings of the investigation.

In one part of the investigation the student is attempting to find out whether tillage has had any effect on infiltration rates. A limitation of the method used - pouring water onto the soil and timing how long it takes to disappear - is that this is the only information that can be gathered. If the candidate had taken soil cores back to the lab, they could have measured: the rate of downward movement of the water; its retention; its final depth.

So, a problem - that is inherent and always occurs - with this method is that you get limited data. This is a limitation.

Now imagine that on the day of the sampling it snowed and snowed, making sensible measurements impossible. This is not an inherent problem - it doesn't occur every time - it was just something that went wrong on this particular day - this is a shortcoming.

- A limitation: a problem/weakness of a particular method that occurs/exists every time that particular method is employed.
- A shortcoming: a problem that occurred on that particular day or time.

Data Presentation: **Raw** data ⟶ Appendices
Summary data ⟶Results section

Rule number 1: Sketch out results tables, axes of graph, pie charts, etc. when you do your PLAN. You should know what you are going to record before you leave the classroom.

Rule number 2: Keep tables, graphs, etc. simple and most important of all, remember your null hypothesis.

Here are three tables and three graphs from the student's attempts at summarising their data for their results section

Which of these are useful, if any? *Remember - a good table/graph tells us something useful about the hypotheses within seconds!*

Tilled field					
Invertebrates		Infilltration time	pH	Organic matter %	Structure
Earthworms	7	67	7.0	14	Clay
Beetles	3				
Springtails	16	58	7.0	16	Clay
Grasshopper	1				
Dead fly	1				
Larvae - Unidentified	3	92	6.5	18	Clay
	31	Total: 217 Mean: 72	Mean: 6.6	Mean: 16	Mean: Clay

Poor table!

- Too much data
- Does not compare the tilled field with the untilled one
- Does not help us to form an immediate opinion about the student's null hypothesis.

Field	Mean organic matter (%)
A (Tillled)	16
B (Untilled)	28

Raw data see appendix X page Y

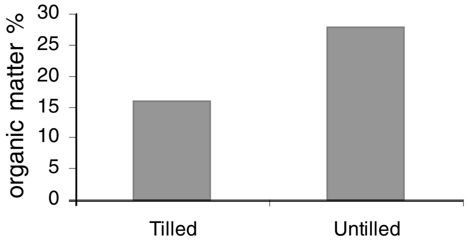
Great table!

- It contains the two variables from the null hypothesis (cultivation against organic matter)
- It tells us straight away that untilled has greater organic matter content.

	Organic matter readings (%)	Mean organic matter (%)
Field A	14, 16, 18, 18, 17, 15	16
Field B	24,28,32, 29, 30, 25	28

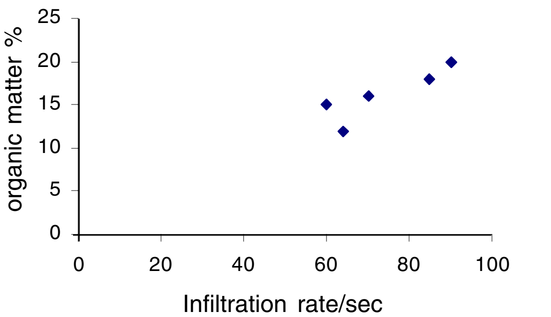
Intermediate table!

- We can see field B has more organic matter – but is that the untilled or tilled field?

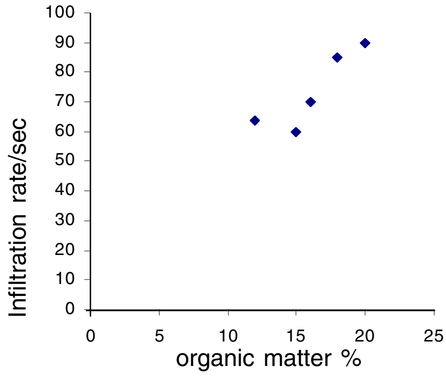


Great!

- It contains the two variables from the null hypothesis (cultivation against organic matter)
- It tells us straight away that untilled has greater organic matter content.



Nonsense. Infiltration rate has been put as the determining variable, i.e. the suggestion is that the x-axis of infiltration rate **determines** the organic matter. Unlikely. It also fails to compare the fields



The axes are the correct way round – organic matter could well influence infiltration rate, but the diagram is not related to the hypothesis being tested!

Choosing a test

Four students suggested the statistical test that should be carried out in this project:

Suggestion 1: Spearman's Rank, because we can see if there is any link between tilling and organic matter	No! We cannot use any form of correlation here because one of the variables - whether the field is tilled or not - is just a "yes/no" answer. For correlation, we need values that can be put in numerical order. Spearman's rank could be used to look at the correlation between organic matter content and infiltration rate - but that is not related to the null hypothesis chosen.
Suggestion 2 Chi-squared, because that will test for a difference between % organic matter in the tilled and untilled soil	No! Chi-squared cannot be used on percentages - it can only be used on numbers of things/people/plants etc. Chi-squared could be used to look at the difference in numbers of a particular invertebrates between the two fields - but that is not related to the null hypothesis chosen.
Suggestion 3: t-test, because we can test whether there is a difference in mean % organic content between the soil in the two fields.	This is the right sort of idea, but we can only use the t-test if we know that our data is likely to be **normally distributed**. This usually only applies to variables like length, weight etc - percentages will usually not be.
Suggestion 4: Mann-Whitney U-test, because it tests for a difference in % organic content between the two fields.	Yes! Mann-Whitney tests for a difference between the two, but doesn't need them to be normally distributed.

Carrying out the test

Here is what the student did to carry out the Mann-Whitney U-test

H_o: There is no difference in % organic matter content in the tilled and untilled soil

H_1: Untilled soil has a higher % organic matter content than tilled soil

These hypotheses are fine - they are specific, and the student has a good scientific reason for choosing the directional alternative, which they have explained at the start of the investigation (page 1)

Tilled	14	16	18	18	17	15
Ranks	11	9	7	7	8	10

Untilled	24	28	32	29	30	25
Ranks	6	4	1	3	2	5

The student hasn't dealt with the tied ranks correctly.
When you get ties, you work out the average of the ranks those pieces of data would have had if they'd been a bit different instead of tied, and give them all that rank.

eg: the two 18 values from field A would have occupied places 7 and 8 if they'd been a bit different. So we give them both rank 7.5
Then the next piece of data - the 17 value - has rank 9, since ranks 7 and 8 have been "used up".

Sum of ranks for tilled = 11+9+7+7+8+10 = 52
Sum of ranks for untilled = 6+4+1+3+2+5 = 21

$U_1 = n_1n_2 + ½ n_1(n_1 + 1) - R_1$
$= (6)(6) + ½(6)(7) - 52 = 0$

$U_2 = n_1n_2 + ½ n_2(n_2 + 1) - R_2$
$= (6)(6) + ½(6)(7) - 21 = 36$

The U-values have been calculated using the right method (although the actual values are wrong because the ranks are wrong)

So U-value is 0

Looking at the tables for sample sizes 6 and 6:
We are doing a 1-tailed test, so the critical value (5%) is 7

The student has correctly identified the test as 1-tailed (directional alternative hypothesis)

Our value is smaller, so we reject the null hypothesis

The correct decision - but beware! For most other tests (exccept for Wilcoxon), you reject the null hypothesis if your value is **higher**

So we have proved tillage reduces organic matter content

No - we have not **proved** it - the 5% significance level means there is still a 5% probabililty that the results are due to chance.

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