Spray Bottle Measurements

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```r
library(tidyverse)
```

```
## -- Attaching packages ----------------- tidyverse 1.3.0 --

## v ggplot2 3.3.2     v purrr   0.3.4
## v tibble  3.0.3     v dplyr   1.0.1
## v tidyr   1.1.1     v stringr 1.4.0
## v readr   1.3.1     v forcats 0.5.0

## -- Conflicts -------------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```r
theme_set(theme_classic())
```

Abstract

To adequately estimate the amount of water delivered to two nursery pots for a growth experiment with Capsicum Annuum (bell peppers) we needed a method of determining the amount of water delivered without using any common scientific measuring equipment. This was necessary to avoid the negative impacts of too much or too little water which could hinder the growth of the individuals in the study. Once calculated we would be able to adjust our watering schedule with proper deliverance range to better regulate the water uptake and transport of the vascular plants in this study. The systematic delivery of an approximately constant amount of water to the nursery pots also helps to control for alternative variables in this small study and ensure the healthy growth of each plant.

Background

In conjunction with the growth experiment on capsicum annum Bell Peppers that intends to determine how well older seeds germinate and grow when compared to newer seeds in a similar indoor environment it was necessary to determine the amount of water delivered to each nursery pot. Unfortunately, for the purposes of this experiment, we did not have access to common scientific measuring equipment such as graduated cylinders, volumetric flasks, pipettes, beakers, balances, and so on. However, we did have access to a spray bottle, a basic ruler, and a Petri dish to accurately estimate the amount of water required.

Although seemingly unconventional, we decided to use a Petri dish and a ProSafe spray bottle to calculate the volume of water using Archimedes equation for the volume of a cylinder, some measurements, and a little math. By using this equipment, we should be able to accurately estimate the amount of water delivered to each nursery pot and avoid the cost of purchasing any common scientific equipment. Importantly the spray bottle is the same container used to deliver the water to the plants daily and the same process for dispensing the water to the nursery pods was followed during this experiment. there were no differences in how water was delivered. the only change was in what we delivered the water to, which in this case it happened to be a Petri dish.

In the interest of reproducing this experiment note that any watertight container could function as the Petri dish. The same principle applies to the Prosafe sprayer. Any sprayer will do so long as it is the same piece of equipment used to dispense the water to the nursery pots. Additionally, ensure that you repeat the exact process of dispensing the water to the watertight container for measurement purposes as we have done here.

Introduction

In this experiment we will determine the amount of liquid water delivered daily to two nursery pots containing five capsicum annum Bell Peppers seeds in each. The estimated amount of liquid water delivered daily will be used to adjust the watering schedule as needed for optimum growth. By recording the dimensions (diameter and height) of water within a cylindrical water-tight container, we can calculate the volume dispensed from a typical routine spray.

Through the regulation of the amount of water delivered, we attempt to control the amount of water uptake in the plants in each nursery pot. Since water is the primary fluid that allows for photosynthesis to occur and for nutrient transport throughout the plant's vascular structure this could be seen an effective tool for later growth comparisons; given that, all other variables remain relatively constant.

Our main purpose with this experiment is to determine the amount of liquid water delivered daily to the two nursery pots but there is another component. We are creating a standard process for estimating the amount of water dispensed from the sprayer itself and thereby solving the problem for any future experiments that utilize this particular sprayer. When evaluating how much water would be delivered in the future, our intent is that it could be measured by the number of sprays rather than performing this experiment again. Throughout the duration of the growth experiment for capsicum annum Bell Peppers we will reevaluate how much water should be delivered to each nursery pot to promote healthy vascular development.

Materials

Our materials include, a computer, ProSafe sprayer bottle, one liter of water, a Petri dish, and a standard twelve-inch or 30-centimeter ruler. Statistical analysis, data visualizations, and all other reporting aspects were completed using the programming language R and the following packages:

```r
library(tidyverse)
```

Alternatively, a calculator and paper could be used to take the place of R. For some, it may also be useful to have a separate container for emptying the Petri dish upon completion of each measurement as utilized in this experiment. These measurements were stored in a spreadsheet within Google Drive. Upon completion, this spreadsheet was made openly accessible as a comma separated values list to anyone with the link via publishing it to the web. The original spreadsheet can be found through that same link here.

To include specifics of the equipment, the models used here are a ProSafe brand 24-ounce liquid sprayer and a common plastic Helix brand 12-inch or 30-centimeter ruler. Our Petri dish is Micrology Laboratories brand meant for quick Coliscan EasyGel biological assessments in water quality. It is 8.5 centimeters at its interior diameter and is 1.4 centimeters tall.

Methods

To estimate the volume of liquid delivered to each nursery pot we sprayed the Petri dish in the same manner that we would spray the nursery pot and then measured the height of the stabilized water in the Petri dish. We also measured the diameter of the interior of the Petri dish where water would be contained. From there, we used Archimedes equation to find the volume of a cylinder to determine the overall volume of liquid water delivered to the petri dish. There was a total of 52 trials each with 50 sprays. As an additional metric for statistical analysis, we also recorded the time spent on each trial. We can break the process down into several steps.

Step 1: Gather Equipment

We begin by bringing together all the equipment that will be necessary for completing the experiment. this includes the bottle, the water tight container, and additional water. If desired, add to this list an additional large container for emptying the watertight container. it will need to be large enough for all trials to fit into it.

Fill the spray bottle as it would be filled under normal circumstances ensuring that you have enough water to refill the bottle at least two more times. Although you may only use one full bottle for all trials it is important to have enough additional water on hand to alleviate abnormalities. This is especially true if doing time trials. Any potential refills of the bottle itself should be minimized.

Step 2: Preparations

It is during this step that you establish the number of trials to be completed. We also clean the petri dish, removing any dirt, dust, or debris before the spraying process can begin. In this step, compile a spreadsheet such that during the measuring process the only factor necessary for recording is to measure the height of the water from the base of the Petri dish two its meniscus. For our purposes we labeled the column headers with the titles trial, sprays, diameter, height, time, minutes, seconds, and milliseconds. Under which we included the numbers 1 through 52 in cells two through fifty-three under the column titled “trial” as well as the numbers 50 and 8.5 beneath the columns Sprays and diameter respectively in the same cell range. Note that, the time columns of time, minutes, seconds, and milliseconds need only be included if they are being used.

Step 3: Adjust Nozzle

Here we check and adjust the spray nozzle. It is imperative that we ensure that the nozzle matches the spray size and intensity as the process used when spraying the nursery pods under normal circumstances. If the nozzle was not interfered with since performing normal circumstances, then no adjustment is needed. The intent here is to replicate the normal spraying process to get accurate results.

Step 4: Establish Process

Before beginning the process of spraying we wanted to establish the full sequence of events from spray to recording. For us, this was simplified into the following 6 steps. The first and last are optional depending on the researcher’s preference in time variables as they are not essential to our volumetric calculations. Our process went as follows:

```
1.  (optional) start timer
2.  complete 50 sprays
3.  measure 50 sprays
4.  record the height
```

```
5.  empty the Petri dish
6.  (optional) lap timer
```

In this process steps two through six were repeated until we reached the total number of trials. Times were not recorded until after all laps and thus trials, had finished. During this process, any issues that occurred could not be solved immediately because the process was still in motion. Once established there was no interfering. This was done to minimize the difference in trial times.

Step 5: Review

Given the presence of data in the spreadsheet, we can then validate it for typos and other errors. If there are any problems, we would consider repeating these steps to ensure an accurate estimation of a normal amount of water from 50 sprays.

Analysis

After performing the spraying and collection process, fifty-two trials were recorded, in which the last 36 trails were timed. All measurements were recorded in centimeters and were not altered throughout this experiment. The data is accessed through the openly accessible spreadsheet published from Google drive and separated by data pertaining to volume and the calculations necessary for it and data pertaining to time required during the trials. We can see the breakdown of this below where the ProSafe sprayer bottle data named sprays is read into R and separated.

```
sprays <- read.csv("https://docs.google.com/spreadsheets/d/e/2PACX-1vQVaaUdUL1IOLL9FLuloyLBed_zyaZJZU1P
vol <- sprays[,1:4]
time <- sprays[,c(1, 5:8)]
```

The first four columns are data that pertains to the trial and the volumetric calculations. for this it is given its own data frame named Vol. we will use this to perform the final volume calculation and determine how much water was delivered 2 the nursery pots. The first four rows of Vol are displayed.

```
head(vol, 4)
```

```
##   Trial Sprays Diameter Height
## 1     1     50      8.5    0.6
## 2     2     50      8.5    0.8
## 3     3     50      8.5    0.7
## 4     4     50      8.5    0.8
```

As a separate portion for later analysis time trial data was recorded. this is contained in the last three columns of this sprays dataframe but we will also need the first column with the trial number. Thus those columns were extracted and given their own database named time. A sample showing the four rows of this database is shown.

```
time[36:40,]
```

```
##    Trial    Time Minutes Seconds Milliseconds
## 36    36 01:09.4       1       9           39
## 37    37 01:19.7       1      19           67
## 38    38 01:06.2       1       6           22
## 39    39 01:45.2       1      45           15
## 40    40 01:14.5       1      14           48
```

however, we will not be performing the analysis of time trials during this experiment. Our purpose is to determine the amount of water delivered to two nursery pods for the growth experiment of capsicum annuum Bell Peppers. This time trial data was collected for later analysis. No conclusions will be made but the process has now been recorded for future study.

to estimate the amount of water dispensed from the sprayer into the Petri dish within each trial we used Archimedes equation for the volume of a cylinder. In this case the container that we were using to hold and measure the amount of liquid present was a short cylinder. This makes Archimedes equation a good fit as demonstrated below.

$$V = \pi * r^2 * h$$

Where R is the radius of the interior of the Petri dish at the boundaries of where water is held and H is the height of the water and its meniscus once filled and stabilized we can find volume. Since our measurements were taken in centimeters we can equate the volume as cubic centimeters. This equation was applied to all trials in the Vol data frame. the first four rows are shown with the completed calculations along with the programming used.

```
vol <- vol %>%
  mutate(Volume = pi*(Diameter/2)*Height)
head(vol, 4)
```

```
##   Trial Sprays Diameter Height    Volume
## 1     1     50      8.5    0.6  8.011061
## 2     2     50      8.5    0.8 10.681415
## 3     3     50      8.5    0.7  9.346238
## 4     4     50      8.5    0.8 10.681415
```

At its most basic the mean might represent the best average volume of all sprays from the trials. however, we are going to include some additional statistics to see the full picture. this includes finding the median to compare with the mean average, as well as the maximum and minimum of the trials, and determining if there are any outliers from what we would consider normal. the following lines were used to perform these calculations.

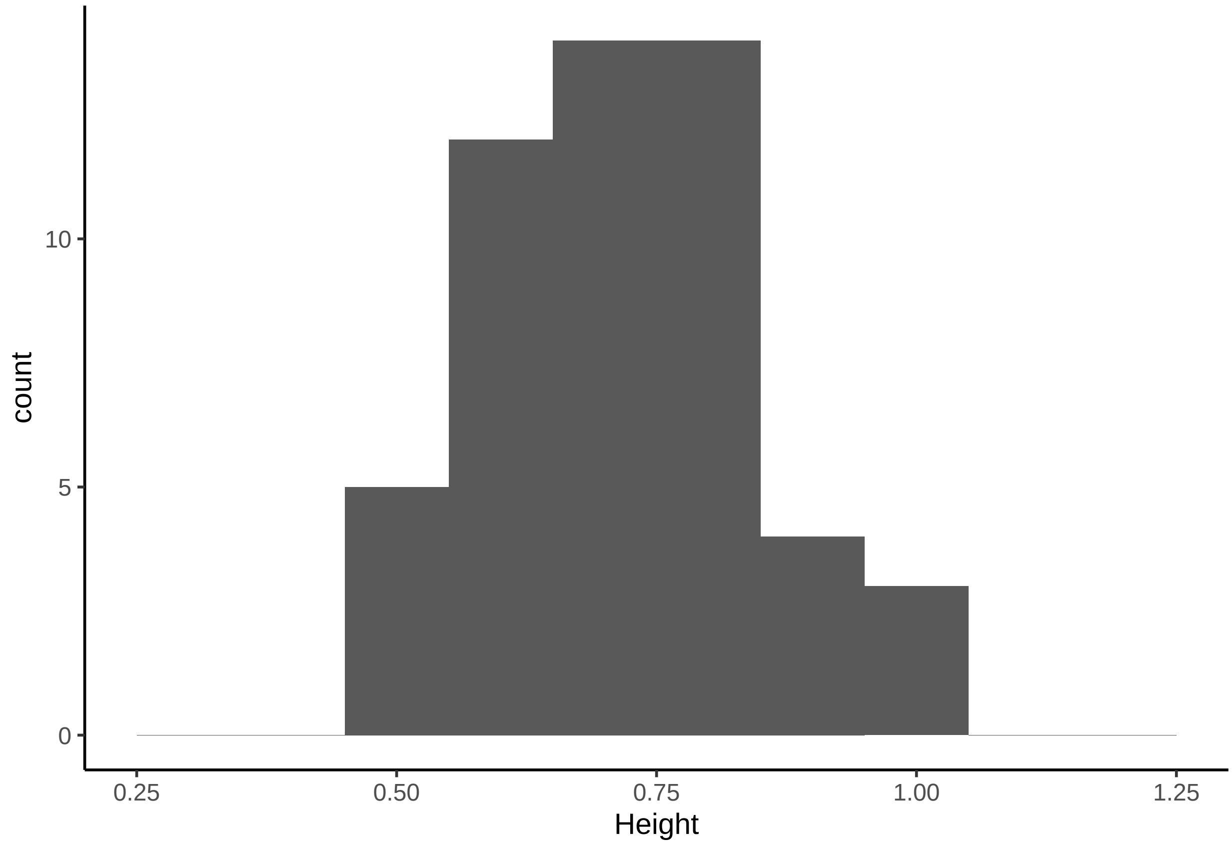
```
vol_summary <- summary(vol$Volume)
vol_var <- var(vol$Volume)
M <- median(vol$Volume)
X <- mean(vol$Volume)
n <- sum(complete.cases(vol$Volume))
s <- sd(vol$Volume)
mx <- max(vol$Volume)
mn <- min(vol$Volume)
rng <- (mx - mn)
up_rng <- (mx - X)
lo_rng <- (X - mn)
```

Based on the 52 trials in this experiment the mean average volume is about 9.577. This is slightly larger than our median average volume of 9.346. If we review the data we notice that there seem to be more height entries in a smaller range for heights equal to or less than 0.7. In contrast, there are fewer values from 0.8 upwards in height which also contains a wider range than height recorded at 0.7 and below.

We confirm this by subtracting the minimum volume from the mean volume and mean volume from the maximum volume which we will call the lower and upper range respectively. Since volume was calculated directly from the differences in height, every conversion to volume contains exactly the same proportions as the height measurements. It is clear that the lower range of 2.901 is smaller than the upper range of 3.774.

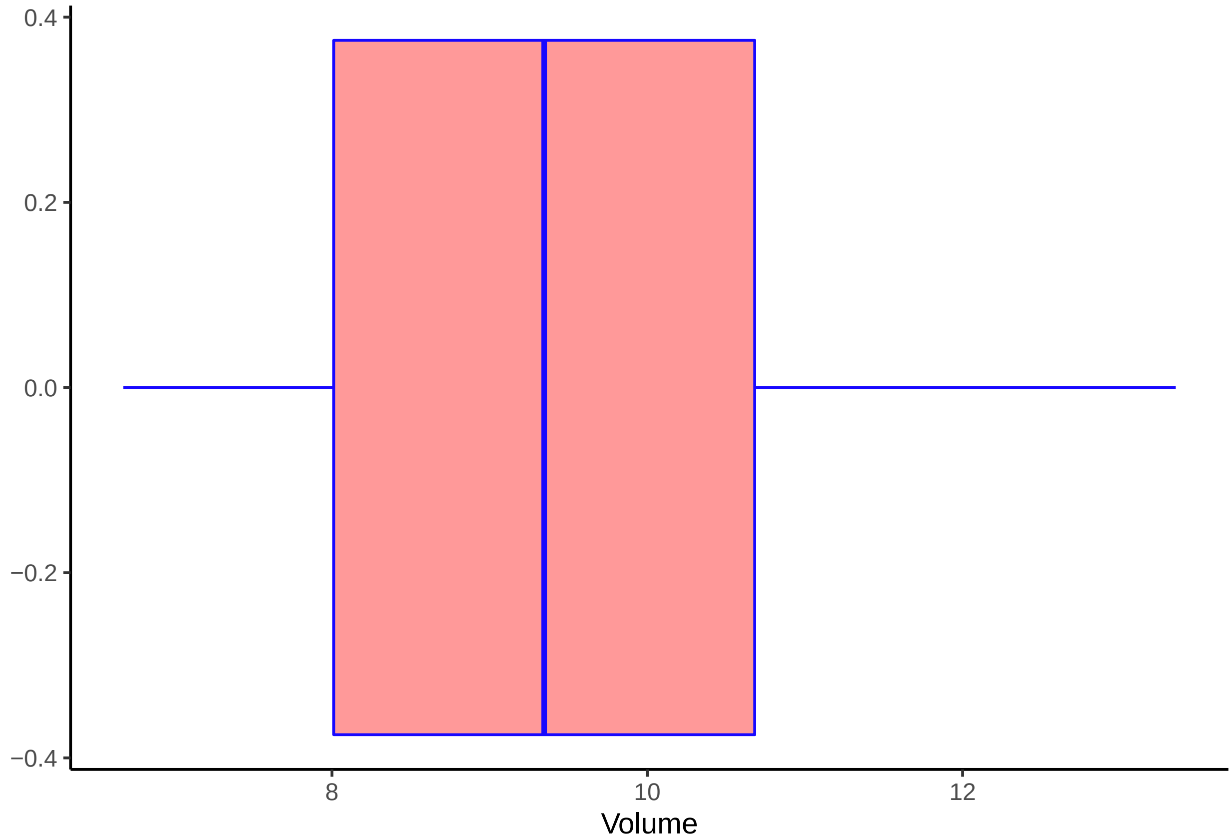
Additionally, since the median is robust and considers the occurrence of values not the influence of higher low values it appears lower than the mean because there are more values that occur in this lower range. We can see this if we count the number of times each height in centimeters occurs and plot them as a histogram.

```
ggplot(vol, aes(Height)) +
  geom_histogram(binwidth = .1) + xlim(.25, 1.25)
```



Recall that the Heights were the only measurement that differed between trials. these changes between trials and height can be credited for creating the differences in our final volumes for each trial. Using this histogram, it is easier to identify the slight weight towards the lower end of the distribution in trials for this experiment. We also confirm the shape extent and approximate normality of the distribution with a boxplot.

```
ggplot(vol, aes(Volume)) +
  geom_boxplot(color = "#1808ff", fill = "#ff9999")
```



Based on this we can interpret the plot to say that it is approximately normal there are no outliers. we can also estimate that the average is a little above 9, indicating that our volume delivered to the nursery pots is approximately the same. we can also see the distance between the mean and the minimum is smaller than the distance between the mean and the maximum. however, the overall distribution is fairly equally distributed.

Although we cannot guarantee that the average volume of water dispensed from the sprayer will remain the same if we were to complete more trials, we can estimate its potential value with a level of confidence over an interval. Given that this was an experiment with only 52 trials further trials might increase the accuracy of results but only to a small degree and the results would likely remain with this interval. Here we Indicate a level of confidence at 95% that could be practical when interpreting results.

The equation for this confidence interval is as follows Where X is the means of volume, Sigma or S is the standard deviation for trial volumes, n is the number of trials, and Z is the critical value. a margin of error calculation is shown as well with the same variables excluding the mean of the volumes, X. We include the variables and values used when calculating this confidence interval for clarity.

$$CI = \bar{X} \pm Z_c * \frac{\sigma}{\sqrt{n})}$$

```
X <- mean(vol$Volume)
Z <- 1.96
s <- sd(vol$Volume)
n <- as.numeric(sum(complete.cases(vol$Volume)))
uci <- X+Z*(s / (sqrt(n)))
lci <- X-Z*(s / (sqrt(n)))
moe <- Z*(s / (sqrt(n)))
```

Due to our units remaining centimeters throughout the process, we can make interpretations directly from the analysis. Conveniently, 1 cubic centimeter is equal to 1 milliliter of the same liquid. during this experiment we remain in centimeters and thus can interpret our results in milliliters. No conversion from cubic centimeters is needed and no further analysis is necessary.

Conclusion

From this experiment we can say with 95% confidence that the amount of water delivered in each nursery pot is between 9.102mL and 9.102mL. The average amount of water delivered to the nursery pots is estimated to be 9.577mL. Our margin of error is 0.475mL. Theoretically, If all sprays were approximately equal in the amount of water dispersed, we would estimate that approximately 0.192mL are dispersed by one spray. Given the approximately normal distribution of our data, this seems an acceptable assumption.

Discussion

How might this effect the plants in the nursery? Should the amount of water delivered be increased or decreased? What were your sources of error? How did you attempt to correct these and what would a future experiment need to do better?