Data Wrangling

Brynleigh Payne

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Brynleigh Github

Seemless data wrangeling

The tidyverse is a bunch of packages and functions written by the same folks that manage Rstudio. The tidyverse builds upon base R to allow for easier use of large datasets.

If you do not have the tidyverse installed please install it and load it `install.pakcages("tidyverse")`

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----------------------- tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.5.1     v tibble    3.2.1
## v lubridate 1.9.3     v tidyr     1.3.1
## v purrr     1.0.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

When you load in the tidyverse notice that it loads in 8 different packages. You will not have to load these individually.

More info and cheet sheets can be found here: https://tidyr.tidyverse.org/index.html

Lets demonstrate some of the most useful functionality of some tidyverse functions. **Note** that this tutorial does not cover everything and **self-learning** may be required for specific functionality. We will cover the following:

- Data wrangling & manipulation
    - mutate()
    - select()
    - filter()
    - the pipe %>%
    - summarise()
    - group_by()
    - joining
    - pivotting
    - Integration with plotting

For this tutorial I will use the same microbiome dataset we used in previous classes for `ggplot`, except this dataset includes all fungi in the Phylum Ascomycota, not just one family.

```
microbiome.fungi <- read.csv("PLPA5820/PLPA5820/07_ggplot/Bull_richness.csv")
str(microbiome.fungi)
```

```
## 'data.frame':    287 obs. of  16 variables:
##  $ SampleID      : chr  "Corn2017LeafObjective2Collection1T1R1CAH2" "Corn2017LeafObjective2Collecti
##  $ Crop          : chr  "Corn" "Corn" "Corn" "Corn" ...
##  $ Objective     : chr  "Objective 2" "Objective 2" "Objective 2" "Objective 2" ...
##  $ Collection    : int  1 1 1 1 1 1 1 1 1 1 ...
##  $ Compartment   : chr  "Leaf" "Leaf" "Leaf" "Leaf" ...
##  $ DateSampled   : chr  "6/26/17" "6/26/17" "6/26/17" "6/26/17" ...
##  $ GrowthStage   : chr  "V6" "V6" "V6" "V6" ...
##  $ Treatment     : chr  "Conv." "Conv." "Conv." "Conv." ...
##  $ Rep           : chr  "R1" "R1" "R1" "R1" ...
##  $ Sample        : chr  "A" "B" "C" "A" ...
##  $ Fungicide     : chr  "C" "C" "C" "F" ...
##  $ Target_organism: chr  "Fungi" "Fungi" "Fungi" "Fungi" ...
##  $ Location      : chr  "Kellogg Biological Station" "Kellogg Biological Station" "Kellogg Biologica
##  $ Experiment    : chr  "LTER" "LTER" "LTER" "LTER" ...
##  $ Year          : int  2017 2017 2017 2017 2017 2017 2017 2017 2017 2017 ...
##  $ richness      : int  9 6 5 7 4 2 3 8 4 4 ...
```

Lets start exploring the data.

Sometimes you may want to only select certain columns of your data. This is accomplished with the select function..

select() Note: colon indicates "selecting through"

```
microbiome.fungi2 <- select(microbiome.fungi, SampleID, Crop, Compartment:Fungicide, richness)
str(microbiome.fungi2)
```

```
## 'data.frame':    287 obs. of  10 variables:
##  $ SampleID   : chr  "Corn2017LeafObjective2Collection1T1R1CAH2" "Corn2017LeafObjective2Collection1T
##  $ Crop       : chr  "Corn" "Corn" "Corn" "Corn" ...
##  $ Compartment: chr  "Leaf" "Leaf" "Leaf" "Leaf" ...
##  $ DateSampled: chr  "6/26/17" "6/26/17" "6/26/17" "6/26/17" ...
##  $ GrowthStage: chr  "V6" "V6" "V6" "V6" ...
##  $ Treatment  : chr  "Conv." "Conv." "Conv." "Conv." ...
##  $ Rep        : chr  "R1" "R1" "R1" "R1" ...
##  $ Sample     : chr  "A" "B" "C" "A" ...
##  $ Fungicide  : chr  "C" "C" "C" "F" ...
##  $ richness   : int  9 6 5 7 4 2 3 8 4 4 ...
```

Note the syntax. I listed all the column headers I wanted, but at the end I used `Compartment:Fungicide` because all these were in order and I can use the column to select them all.

filter() This is a convenient function that allows you to subset data fairly easily. However, I'm not sure how its much easier than other subset function

```r
head(filter(microbiome.fungi2, Treatment == "Conv."))
```

```
##                                     SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1CCB3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R1FAC3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R1FBD3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R1FCE3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness
## 1          V6     Conv.  R1      A         C        9
## 2          V6     Conv.  R1      B         C        6
## 3          V6     Conv.  R1      C         C        5
## 4          V6     Conv.  R1      A         F        7
## 5          V6     Conv.  R1      B         F        4
## 6          V6     Conv.  R1      C         F        2
```

```r
# A more complex using &
head(filter(microbiome.fungi2, Treatment == "Conv." & Fungicide == "C"))
```

```
##                                     SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1CCB3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R2CAF3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R2CBG3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R2CCH3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness
## 1          V6     Conv.  R1      A         C        9
## 2          V6     Conv.  R1      B         C        6
## 3          V6     Conv.  R1      C         C        5
## 4          V6     Conv.  R2      A         C        3
## 5          V6     Conv.  R2      B         C        8
## 6          V6     Conv.  R2      C         C        4
```

```r
# Another more complex example using or |
head(filter(microbiome.fungi2, Sample == "A" | Sample == "B")) # samples A or B
```

```
##                                     SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1FAC3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R1FBD3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R2CAF3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R2CBG3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness
## 1          V6     Conv.  R1      A         C        9
## 2          V6     Conv.  R1      B         C        6
## 3          V6     Conv.  R1      A         F        7
## 4          V6     Conv.  R1      B         F        4
## 5          V6     Conv.  R2      A         C        3
## 6          V6     Conv.  R2      B         C        8
```

mutate()   Mutate allows us to quickly create new columns.

```
# Note: Creating a new column in base R
microbiome.fungi2$logRich <- log(microbiome.fungi2$richness)
# Create a new column called logRich
head(mutate(microbiome.fungi2, logRich = log(richness)))
```

```
##                                   SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1CCB3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R1FAC3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R1FBD3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R1FCE3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness   logRich
## 1          V6     Conv.  R1      A         C        9 2.1972246
## 2          V6     Conv.  R1      B         C        6 1.7917595
## 3          V6     Conv.  R1      C         C        5 1.6094379
## 4          V6     Conv.  R1      A         F        7 1.9459101
## 5          V6     Conv.  R1      B         F        4 1.3862944
## 6          V6     Conv.  R1      C         F        2 0.6931472
```

```
# Creating a new column which combines Crop and Treatment
head(mutate(microbiome.fungi2, Crop_Treatment = paste(Crop, Treatment)))
```

```
##                                   SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1CCB3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R1FAC3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R1FBD3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R1FCE3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness   logRich Crop_Treatment
## 1          V6     Conv.  R1      A         C        9 2.1972246    Corn Conv.
## 2          V6     Conv.  R1      B         C        6 1.7917595    Corn Conv.
## 3          V6     Conv.  R1      C         C        5 1.6094379    Corn Conv.
## 4          V6     Conv.  R1      A         F        7 1.9459101    Corn Conv.
## 5          V6     Conv.  R1      B         F        4 1.3862944    Corn Conv.
## 6          V6     Conv.  R1      C         F        2 0.6931472    Corn Conv.
```

the pipe %>%   We can also combine multiple functions together. This is an important concept and is very powerful. It helps to try to visualize what you are doing to your data at each step. Basically the pipe allows you to input the previous data from the right side of the pipe into the function on the left (or next line).

In

We will combine all previous steps into one large string of functions.

When we do this we do not have to specify the data in each function. The data from the previous step is transfered to the next step.

```
select(microbiome.fungi, SampleID, Crop, Compartment:Fungicide, richness) # before
```

```
##                                             SampleID Crop Compartment DateSampled
## 1   Corn2017LeafObjective2Collection1T1R1CAH2 Corn         Leaf     6/26/17
## 2   Corn2017LeafObjective2Collection1T1R1CBA3 Corn         Leaf     6/26/17
## 3   Corn2017LeafObjective2Collection1T1R1CCB3 Corn         Leaf     6/26/17
## 4   Corn2017LeafObjective2Collection1T1R1FAC3 Corn         Leaf     6/26/17
## 5   Corn2017LeafObjective2Collection1T1R1FBD3 Corn         Leaf     6/26/17
## 6   Corn2017LeafObjective2Collection1T1R1FCE3 Corn         Leaf     6/26/17
## 7   Corn2017LeafObjective2Collection1T1R2CAF3 Corn         Leaf     6/26/17
## 8   Corn2017LeafObjective2Collection1T1R2CBG3 Corn         Leaf     6/26/17
## 9   Corn2017LeafObjective2Collection1T1R2CCH3 Corn         Leaf     6/26/17
## 10  Corn2017LeafObjective2Collection1T1R2FAA4 Corn         Leaf     6/26/17
## 11  Corn2017LeafObjective2Collection1T1R2FBB4 Corn         Leaf     6/26/17
## 12  Corn2017LeafObjective2Collection1T1R2FCC4 Corn         Leaf     6/26/17
## 13  Corn2017LeafObjective2Collection1T1R5CAD4 Corn         Leaf     6/26/17
## 14  Corn2017LeafObjective2Collection1T1R5CBE4 Corn         Leaf     6/26/17
## 15  Corn2017LeafObjective2Collection1T1R5CCF4 Corn         Leaf     6/26/17
## 16  Corn2017LeafObjective2Collection1T1R5FAG4 Corn         Leaf     6/26/17
## 17  Corn2017LeafObjective2Collection1T1R5FBH4 Corn         Leaf     6/26/17
## 18  Corn2017LeafObjective2Collection1T1R5FCA5 Corn         Leaf     6/26/17
## 19  Corn2017LeafObjective2Collection1T1R6CAB5 Corn         Leaf     6/26/17
## 20  Corn2017LeafObjective2Collection1T1R6CBC5 Corn         Leaf     6/26/17
## 21  Corn2017LeafObjective2Collection1T1R6CCD5 Corn         Leaf     6/26/17
## 22  Corn2017LeafObjective2Collection1T1R6FAE5 Corn         Leaf     6/26/17
## 23  Corn2017LeafObjective2Collection1T1R6FBF5 Corn         Leaf     6/26/17
## 24  Corn2017LeafObjective2Collection1T1R6FCG5 Corn         Leaf     6/26/17
## 25  Corn2017LeafObjective2Collection1T2R1CAH5 Corn         Leaf     6/26/17
## 26  Corn2017LeafObjective2Collection1T2R1CBA6 Corn         Leaf     6/26/17
## 27  Corn2017LeafObjective2Collection1T2R1CCB6 Corn         Leaf     6/26/17
## 28  Corn2017LeafObjective2Collection1T2R1FAC6 Corn         Leaf     6/26/17
## 29  Corn2017LeafObjective2Collection1T2R1FBE6 Corn         Leaf     6/26/17
## 30  Corn2017LeafObjective2Collection1T2R1FCD6 Corn         Leaf     6/26/17
## 31  Corn2017LeafObjective2Collection1T2R2CAF6 Corn         Leaf     6/26/17
## 32  Corn2017LeafObjective2Collection1T2R2CBG6 Corn         Leaf     6/26/17
## 33  Corn2017LeafObjective2Collection1T2R2CCH6 Corn         Leaf     6/26/17
## 34  Corn2017LeafObjective2Collection1T2R2FAA7 Corn         Leaf     6/26/17
## 35  Corn2017LeafObjective2Collection1T2R2FBB7 Corn         Leaf     6/26/17
## 36  Corn2017LeafObjective2Collection1T2R2FCC7 Corn         Leaf     6/26/17
## 37  Corn2017LeafObjective2Collection1T2R5CAD7 Corn         Leaf     6/26/17
## 38  Corn2017LeafObjective2Collection1T2R5CBE7 Corn         Leaf     6/26/17
## 39  Corn2017LeafObjective2Collection1T2R5CCF7 Corn         Leaf     6/26/17
## 40  Corn2017LeafObjective2Collection1T2R5FAG7 Corn         Leaf     6/26/17
## 41  Corn2017LeafObjective2Collection1T2R5FBH7 Corn         Leaf     6/26/17
## 42  Corn2017LeafObjective2Collection1T2R5FCA8 Corn         Leaf     6/26/17
## 43  Corn2017LeafObjective2Collection1T2R6CAB8 Corn         Leaf     6/26/17
## 44  Corn2017LeafObjective2Collection1T2R6CBC8 Corn         Leaf     6/26/17
## 45  Corn2017LeafObjective2Collection1T2R6CCD8 Corn         Leaf     6/26/17
## 46  Corn2017LeafObjective2Collection1T2R6FAE8 Corn         Leaf     6/26/17
## 47  Corn2017LeafObjective2Collection1T2R6FBF8 Corn         Leaf     6/26/17
## 48  Corn2017LeafObjective2Collection1T2R6FCG8 Corn         Leaf     6/26/17
## 49  Corn2017LeafObjective2Collection2T1R1CAC9 Corn         Leaf      7/5/17
## 50  Corn2017LeafObjective2Collection2T1R1CBD9 Corn         Leaf      7/5/17
## 51  Corn2017LeafObjective2Collection2T1R1CCE9 Corn         Leaf      7/5/17
## 52  Corn2017LeafObjective2Collection2T1R1FAH8 Corn         Leaf      7/5/17
## 53  Corn2017LeafObjective2Collection2T1R1FBA9 Corn         Leaf      7/5/17
```

```
## 54    Corn2017LeafObjective2Collection2T1R1FCB9 Corn           Leaf      7/5/17
## 55  Corn2017LeafObjective2Collection2T1R2CAA10 Corn           Leaf      7/5/17
## 56  Corn2017LeafObjective2Collection2T1R2CBC10 Corn           Leaf      7/5/17
## 57  Corn2017LeafObjective2Collection2T1R2CCD10 Corn           Leaf      7/5/17
## 58   Corn2017LeafObjective2Collection2T1R2FAF9 Corn           Leaf      7/5/17
## 59   Corn2017LeafObjective2Collection2T1R2FBG9 Corn           Leaf      7/5/17
## 60   Corn2017LeafObjective2Collection2T1R2FCH9 Corn           Leaf      7/5/17
## 61  Corn2017LeafObjective2Collection2T1R5CAH10 Corn           Leaf      7/5/17
## 62  Corn2017LeafObjective2Collection2T1R5CBA11 Corn           Leaf      7/5/17
## 63  Corn2017LeafObjective2Collection2T1R5CCC11 Corn           Leaf      7/5/17
## 64  Corn2017LeafObjective2Collection2T1R5FAE10 Corn           Leaf      7/5/17
## 65  Corn2017LeafObjective2Collection2T1R5FBF10 Corn           Leaf      7/5/17
## 66  Corn2017LeafObjective2Collection2T1R5FCG10 Corn           Leaf      7/5/17
## 67  Corn2017LeafObjective2Collection2T1R6CAB11 Corn           Leaf      7/5/17
## 68  Corn2017LeafObjective2Collection2T1R6CBG11 Corn           Leaf      7/5/17
## 69  Corn2017LeafObjective2Collection2T1R6CCH11 Corn           Leaf      7/5/17
## 70  Corn2017LeafObjective2Collection2T1R6FAD11 Corn           Leaf      7/5/17
## 71  Corn2017LeafObjective2Collection2T1R6FBE11 Corn           Leaf      7/5/17
## 72  Corn2017LeafObjective2Collection2T1R6FCF11 Corn           Leaf      7/5/17
## 73  Corn2017LeafObjective2Collection2T2R1CAD12 Corn           Leaf      7/5/17
## 74  Corn2017LeafObjective2Collection2T2R1CBE12 Corn           Leaf      7/5/17
## 75  Corn2017LeafObjective2Collection2T2R1CCF12 Corn           Leaf      7/5/17
## 76  Corn2017LeafObjective2Collection2T2R1FAA12 Corn           Leaf      7/5/17
## 77  Corn2017LeafObjective2Collection2T2R1FBB12 Corn           Leaf      7/5/17
## 78  Corn2017LeafObjective2Collection2T2R1FCC12 Corn           Leaf      7/5/17
## 79   Corn2017LeafObjective2Collection2T2R2CAB1 Corn           Leaf      7/5/17
## 80   Corn2017LeafObjective2Collection2T2R2CBC1 Corn           Leaf      7/5/17
## 81   Corn2017LeafObjective2Collection2T2R2CCD1 Corn           Leaf      7/5/17
## 82  Corn2017LeafObjective2Collection2T2R2FAG12 Corn           Leaf      7/5/17
## 83  Corn2017LeafObjective2Collection2T2R2FBH12 Corn           Leaf      7/5/17
## 84   Corn2017LeafObjective2Collection2T2R2FCA1 Corn           Leaf      7/5/17
## 85   Corn2017LeafObjective2Collection2T2R5CAH1 Corn           Leaf      7/5/17
## 86   Corn2017LeafObjective2Collection2T2R5CBA2 Corn           Leaf      7/5/17
## 87   Corn2017LeafObjective2Collection2T2R5CCB2 Corn           Leaf      7/5/17
## 88   Corn2017LeafObjective2Collection2T2R5FAE1 Corn           Leaf      7/5/17
## 89   Corn2017LeafObjective2Collection2T2R5FBF1 Corn           Leaf      7/5/17
## 90   Corn2017LeafObjective2Collection2T2R5FCG1 Corn           Leaf      7/5/17
## 91   Corn2017LeafObjective2Collection2T2R6CAF2 Corn           Leaf      7/5/17
## 92   Corn2017LeafObjective2Collection2T2R6CBG2 Corn           Leaf      7/5/17
## 93   Corn2017LeafObjective2Collection2T2R6CCH2 Corn           Leaf      7/5/17
## 94   Corn2017LeafObjective2Collection2T2R6FAC2 Corn           Leaf      7/5/17
## 95   Corn2017LeafObjective2Collection2T2R6FBD2 Corn           Leaf      7/5/17
## 96   Corn2017LeafObjective2Collection2T2R6FCE2 Corn           Leaf      7/5/17
## 97   Corn2017LeafObjective2Collection3T1R1CAA3 Corn           Leaf     7/31/17
## 98   Corn2017LeafObjective2Collection3T1R1CBB3 Corn           Leaf     7/31/17
## 99   Corn2017LeafObjective2Collection3T1R1CCC3 Corn           Leaf     7/31/17
## 100  Corn2017LeafObjective2Collection3T1R1FAD3 Corn           Leaf     7/31/17
## 101  Corn2017LeafObjective2Collection3T1R1FBE3 Corn           Leaf     7/31/17
## 102  Corn2017LeafObjective2Collection3T1R1FCF3 Corn           Leaf     7/31/17
## 103  Corn2017LeafObjective2Collection3T1R2CAG3 Corn           Leaf     7/31/17
## 104  Corn2017LeafObjective2Collection3T1R2CBH3 Corn           Leaf     7/31/17
## 105  Corn2017LeafObjective2Collection3T1R2CCA4 Corn           Leaf     7/31/17
## 106  Corn2017LeafObjective2Collection3T1R2FAB4 Corn           Leaf     7/31/17
## 107  Corn2017LeafObjective2Collection3T1R2FBC4 Corn           Leaf     7/31/17
```

```
## 108 Corn2017LeafObjective2Collection3T1R2FCD4 Corn        Leaf     7/31/17
## 109 Corn2017LeafObjective2Collection3T1R5CAE4 Corn        Leaf     7/31/17
## 110 Corn2017LeafObjective2Collection3T1R5CBF4 Corn        Leaf     7/31/17
## 111 Corn2017LeafObjective2Collection3T1R5CCG4 Corn        Leaf     7/31/17
## 112 Corn2017LeafObjective2Collection3T1R5FAH4 Corn        Leaf     7/31/17
## 113 Corn2017LeafObjective2Collection3T1R5FBA5 Corn        Leaf     7/31/17
## 114 Corn2017LeafObjective2Collection3T1R5FCB5 Corn        Leaf     7/31/17
## 115 Corn2017LeafObjective2Collection3T1R6CAC5 Corn        Leaf     7/31/17
## 116 Corn2017LeafObjective2Collection3T1R6CBD5 Corn        Leaf     7/31/17
## 117 Corn2017LeafObjective2Collection3T1R6CCE5 Corn        Leaf     7/31/17
## 118 Corn2017LeafObjective2Collection3T1R6FAF5 Corn        Leaf     7/31/17
## 119 Corn2017LeafObjective2Collection3T1R6FBG5 Corn        Leaf     7/31/17
## 120 Corn2017LeafObjective2Collection3T1R6FCH5 Corn        Leaf     7/31/17
## 121 Corn2017LeafObjective2Collection3T2R1CAB6 Corn        Leaf     7/31/17
## 122 Corn2017LeafObjective2Collection3T2R1CBC6 Corn        Leaf     7/31/17
## 123 Corn2017LeafObjective2Collection3T2R1CCD6 Corn        Leaf     7/31/17
## 124 Corn2017LeafObjective2Collection3T2R1FAE6 Corn        Leaf     7/31/17
## 125 Corn2017LeafObjective2Collection3T2R1FBF6 Corn        Leaf     7/31/17
## 126 Corn2017LeafObjective2Collection3T2R1FCG6 Corn        Leaf     7/31/17
## 127 Corn2017LeafObjective2Collection3T2R2CAH6 Corn        Leaf     7/31/17
## 128 Corn2017LeafObjective2Collection3T2R2CBA7 Corn        Leaf     7/31/17
## 129 Corn2017LeafObjective2Collection3T2R2CCB7 Corn        Leaf     7/31/17
## 130 Corn2017LeafObjective2Collection3T2R2FAC7 Corn        Leaf     7/31/17
## 131 Corn2017LeafObjective2Collection3T2R2FBD7 Corn        Leaf     7/31/17
## 132 Corn2017LeafObjective2Collection3T2R2FCE7 Corn        Leaf     7/31/17
## 133 Corn2017LeafObjective2Collection3T2R5CAF7 Corn        Leaf     7/31/17
## 134 Corn2017LeafObjective2Collection3T2R5CBG7 Corn        Leaf     7/31/17
## 135 Corn2017LeafObjective2Collection3T2R5CCH7 Corn        Leaf     7/31/17
## 136 Corn2017LeafObjective2Collection3T2R5FAA8 Corn        Leaf     7/31/17
## 137 Corn2017LeafObjective2Collection3T2R5FBB8 Corn        Leaf     7/31/17
## 138 Corn2017LeafObjective2Collection3T2R5FCC8 Corn        Leaf     7/31/17
## 139 Corn2017LeafObjective2Collection3T2R6CAD8 Corn        Leaf     7/31/17
## 140 Corn2017LeafObjective2Collection3T2R6CBE8 Corn        Leaf     7/31/17
## 141 Corn2017LeafObjective2Collection3T2R6CCF8 Corn        Leaf     7/31/17
## 142 Corn2017LeafObjective2Collection3T2R6FAG8 Corn        Leaf     7/31/17
## 143 Corn2017LeafObjective2Collection3T2R6FBH8 Corn        Leaf     7/31/17
## 144 Corn2017LeafObjective2Collection3T2R6FCA9 Corn        Leaf     7/31/17
## 145                                 T1R1AR4L    Soy        Leaf     8/16/18
## 146                                 T1R1BR4L    Soy        Leaf     8/16/18
## 147                                 T1R1CAR3L   Soy        Leaf      8/3/18
## 148                                 T1R1CAR6L   Soy        Leaf     8/27/18
## 149                                 T1R1CBR3L   Soy        Leaf      8/3/18
## 150                                 T1R1CBR6L   Soy        Leaf     8/27/18
## 151                                 T1R1CCR3L   Soy        Leaf      8/3/18
## 152                                 T1R1CCR6L   Soy        Leaf     8/27/18
## 153                                 T1R1CR4L    Soy        Leaf     8/16/18
## 154                                 T1R1FAR3L   Soy        Leaf      8/3/18
## 155                                 T1R1FAR4L   Soy        Leaf     8/16/18
## 156                                 T1R1FAR6L   Soy        Leaf     8/27/18
## 157                                 T1R1FBR3L   Soy        Leaf      8/3/18
## 158                                 T1R1FBR4L   Soy        Leaf     8/16/18
## 159                                 T1R1FBR6L   Soy        Leaf     8/27/18
## 160                                 T1R1FCR3L   Soy        Leaf      8/3/18
## 161                                 T1R1FCR4L   Soy        Leaf     8/16/18
```

```
## 162                              T1R1FCR6L  Soy        Leaf      8/27/18
## 163                              T1R2CAR3L  Soy        Leaf       8/3/18
## 164                              T1R2CAR4L  Soy        Leaf      8/16/18
## 165                              T1R2CAR6L  Soy        Leaf      8/27/18
## 166                              T1R2CBR3L  Soy        Leaf       8/3/18
## 167                              T1R2CBR4L  Soy        Leaf      8/16/18
## 168                              T1R2CBR6L  Soy        Leaf      8/27/18
## 169                              T1R2CCR3L  Soy        Leaf       8/3/18
## 170                              T1R2CCR4L  Soy        Leaf      8/16/18
## 171                              T1R2CCR6L  Soy        Leaf      8/27/18
## 172                              T1R2FAR3L  Soy        Leaf       8/3/18
## 173                              T1R2FAR4L  Soy        Leaf      8/16/18
## 174                              T1R2FAR6L  Soy        Leaf      8/27/18
## 175                              T1R2FBR3L  Soy        Leaf       8/3/18
## 176                              T1R2FBR4L  Soy        Leaf      8/16/18
## 177                              T1R2FBR6L  Soy        Leaf      8/27/18
## 178                              T1R2FCR3L  Soy        Leaf       8/3/18
## 179                              T1R2FCR4L  Soy        Leaf      8/16/18
## 180                              T1R2FCR6L  Soy        Leaf      8/27/18
## 181                              T1R5CAR3L  Soy        Leaf       8/3/18
## 182                              T1R5CAR4L  Soy        Leaf      8/16/18
## 183                              T1R5CAR6L  Soy        Leaf      8/27/18
## 184                              T1R5CBR3L  Soy        Leaf       8/3/18
## 185                              T1R5CBR4L  Soy        Leaf      8/16/18
## 186                              T1R5CBR6L  Soy        Leaf      8/27/18
## 187                              T1R5CCR3L  Soy        Leaf       8/3/18
## 188                              T1R5CCR4L  Soy        Leaf      8/16/18
## 189                              T1R5CCR6L  Soy        Leaf      8/27/18
## 190                              T1R5FAR3L  Soy        Leaf       8/3/18
## 191                              T1R5FAR4L  Soy        Leaf      8/16/18
## 192                              T1R5FAR6L  Soy        Leaf      8/27/18
## 193                              T1R5FBR3L  Soy        Leaf       8/3/18
## 194                              T1R5FBR4L  Soy        Leaf      8/16/18
## 195                              T1R5FBR6L  Soy        Leaf      8/27/18
## 196                              T1R5FCR3L  Soy        Leaf       8/3/18
## 197                              T1R5FCR4L  Soy        Leaf      8/16/18
## 198                              T1R5FCR6L  Soy        Leaf      8/27/18
## 199                              T1R6CAR3L  Soy        Leaf       8/3/18
## 200                              T1R6CAR4L  Soy        Leaf      8/16/18
## 201                              T1R6CAR6L  Soy        Leaf      8/27/18
## 202                              T1R6CBR3L  Soy        Leaf       8/3/18
## 203                              T1R6CBR4L  Soy        Leaf      8/16/18
## 204                              T1R6CBR6L  Soy        Leaf      8/27/18
## 205                              T1R6CCR3L  Soy        Leaf       8/3/18
## 206                              T1R6CCR4L  Soy        Leaf      8/16/18
## 207                              T1R6CCR6L  Soy        Leaf      8/27/18
## 208                              T1R6FAR3L  Soy        Leaf       8/3/18
## 209                              T1R6FAR4L  Soy        Leaf      8/16/18
## 210                              T1R6FAR6L  Soy        Leaf      8/27/18
## 211                              T1R6FBR3L  Soy        Leaf       8/3/18
## 212                              T1R6FBR4L  Soy        Leaf      8/16/18
## 213                              T1R6FBR6L  Soy        Leaf      8/27/18
## 214                              T1R6FCR3L  Soy        Leaf       8/3/18
## 215                              T1R6FCR4L  Soy        Leaf      8/16/18
```

```
## 216                              T1R6FCR6L  Soy      Leaf     8/27/18
## 217                              T2R1CAR3L  Soy      Leaf      8/3/18
## 218                              T2R1CAR4L  Soy      Leaf     8/16/18
## 219                              T2R1CAR6L  Soy      Leaf     8/27/18
## 220                              T2R1CBR3L  Soy      Leaf      8/3/18
## 221                              T2R1CBR4L  Soy      Leaf     8/16/18
## 222                              T2R1CBR6L  Soy      Leaf     8/27/18
## 223                              T2R1CCR3L  Soy      Leaf      8/3/18
## 224                              T2R1CCR4L  Soy      Leaf     8/16/18
## 225                              T2R1CCR6L  Soy      Leaf     8/27/18
## 226                              T2R1FAR3L  Soy      Leaf      8/3/18
## 227                              T2R1FAR4L  Soy      Leaf     8/16/18
## 228                              T2R1FAR6L  Soy      Leaf     8/27/18
## 229                              T2R1FBR3L  Soy      Leaf      8/3/18
## 230                              T2R1FBR4L  Soy      Leaf     8/16/18
## 231                              T2R1FBR6L  Soy      Leaf     8/27/18
## 232                              T2R1FCR3L  Soy      Leaf      8/3/18
## 233                              T2R1FCR4L  Soy      Leaf     8/16/18
## 234                              T2R2CAR3L  Soy      Leaf      8/3/18
## 235                              T2R2CAR4L  Soy      Leaf     8/16/18
## 236                              T2R2CAR6L  Soy      Leaf     8/27/18
## 237                              T2R2CBR3L  Soy      Leaf      8/3/18
## 238                              T2R2CBR4L  Soy      Leaf     8/16/18
## 239                              T2R2CBR6L  Soy      Leaf     8/27/18
## 240                              T2R2CCR3L  Soy      Leaf      8/3/18
## 241                              T2R2CCR4L  Soy      Leaf     8/16/18
## 242                              T2R2CCR6L  Soy      Leaf     8/27/18
## 243                              T2R2FAR3L  Soy      Leaf      8/3/18
## 244                              T2R2FAR4L  Soy      Leaf     8/16/18
## 245                              T2R2FAR6L  Soy      Leaf     8/27/18
## 246                              T2R2FBR3L  Soy      Leaf      8/3/18
## 247                              T2R2FBR4L  Soy      Leaf     8/16/18
## 248                              T2R2FBR6L  Soy      Leaf     8/27/18
## 249                              T2R2FCR3L  Soy      Leaf      8/3/18
## 250                              T2R2FCR4L  Soy      Leaf     8/16/18
## 251                              T2R2FCR6L  Soy      Leaf     8/27/18
## 252                              T2R5CAR3L  Soy      Leaf      8/3/18
## 253                              T2R5CAR4L  Soy      Leaf     8/16/18
## 254                              T2R5CAR6L  Soy      Leaf     8/27/18
## 255                              T2R5CBR3L  Soy      Leaf      8/3/18
## 256                              T2R5CBR4L  Soy      Leaf     8/16/18
## 257                              T2R5CBR6L  Soy      Leaf     8/27/18
## 258                              T2R5CCR3L  Soy      Leaf      8/3/18
## 259                              T2R5CCR4L  Soy      Leaf     8/16/18
## 260                              T2R5CCR6L  Soy      Leaf     8/27/18
## 261                              T2R5FAR3L  Soy      Leaf      8/3/18
## 262                              T2R5FAR4L  Soy      Leaf     8/16/18
## 263                              T2R5FAR6L  Soy      Leaf     8/27/18
## 264                              T2R5FBR3L  Soy      Leaf      8/3/18
## 265                              T2R5FBR4L  Soy      Leaf     8/16/18
## 266                              T2R5FBR6L  Soy      Leaf     8/27/18
## 267                              T2R5FCR3L  Soy      Leaf      8/3/18
## 268                              T2R5FCR4L  Soy      Leaf     8/16/18
## 269                              T2R5FCR6L  Soy      Leaf     8/27/18
```

```
## 270                                      T2R6CAR3L  Soy       Leaf       8/3/18
## 271                                      T2R6CAR4L  Soy       Leaf      8/16/18
## 272                                      T2R6CAR6L  Soy       Leaf      8/27/18
## 273                                      T2R6CBR3L  Soy       Leaf       8/3/18
## 274                                      T2R6CBR4L  Soy       Leaf      8/16/18
## 275                                      T2R6CBR6L  Soy       Leaf      8/27/18
## 276                                      T2R6CCR3L  Soy       Leaf       8/3/18
## 277                                      T2R6CCR4L  Soy       Leaf      8/16/18
## 278                                      T2R6CCR6L  Soy       Leaf      8/27/18
## 279                                      T2R6FAR3L  Soy       Leaf       8/3/18
## 280                                      T2R6FAR4L  Soy       Leaf      8/16/18
## 281                                      T2R6FAR6L  Soy       Leaf      8/27/18
## 282                                      T2R6FBR3L  Soy       Leaf       8/3/18
## 283                                      T2R6FBR4L  Soy       Leaf      8/16/18
## 284                                      T2R6FBR6L  Soy       Leaf      8/27/18
## 285                                      T2R6FCR3L  Soy       Leaf       8/3/18
## 286                                      T2R6FCR4L  Soy       Leaf      8/16/18
## 287                                      T2R6FCR6L  Soy       Leaf      8/27/18
##      GrowthStage Treatment Rep Sample Fungicide richness
## 1             V6     Conv.  R1      A         C        9
## 2             V6     Conv.  R1      B         C        6
## 3             V6     Conv.  R1      C         C        5
## 4             V6     Conv.  R1      A         F        7
## 5             V6     Conv.  R1      B         F        4
## 6             V6     Conv.  R1      C         F        2
## 7             V6     Conv.  R2      A         C        3
## 8             V6     Conv.  R2      B         C        8
## 9             V6     Conv.  R2      C         C        4
## 10            V6     Conv.  R2      A         F        4
## 11            V6     Conv.  R2      B         F        3
## 12            V6     Conv.  R2      C         F        5
## 13            V6     Conv.  R5      A         C        5
## 14            V6     Conv.  R5      B         C        4
## 15            V6     Conv.  R5      C         C       10
## 16            V6     Conv.  R5      A         F        4
## 17            V6     Conv.  R5      B         F        6
## 18            V6     Conv.  R5      C         F        6
## 19            V6     Conv.  R6      A         C        2
## 20            V6     Conv.  R6      B         C        1
## 21            V6     Conv.  R6      C         C        6
## 22            V6     Conv.  R6      A         F        1
## 23            V6     Conv.  R6      B         F        4
## 24            V6     Conv.  R6      C         F        2
## 25            V6   No-till  R1      A         C        6
## 26            V6   No-till  R1      B         C        3
## 27            V6   No-till  R1      C         C        4
## 28            V6   No-till  R1      A         F       15
## 29            V6   No-till  R1      B         F        5
## 30            V6   No-till  R1      C         F        9
## 31            V6   No-till  R2      A         C        5
## 32            V6   No-till  R2      B         C        5
## 33            V6   No-till  R2      C         C        6
## 34            V6   No-till  R2      A         F       15
## 35            V6   No-till  R2      B         F        3
```

10

```
## 36          V6   No-till  R2    C        F        2
## 37          V6   No-till  R5    A        C        9
## 38          V6   No-till  R5    B        C        9
## 39          V6   No-till  R5    C        C        3
## 40          V6   No-till  R5    A        F        8
## 41          V6   No-till  R5    B        F        1
## 42          V6   No-till  R5    C        F       12
## 43          V6   No-till  R6    A        C       11
## 44          V6   No-till  R6    B        C        7
## 45          V6   No-till  R6    C        C        7
## 46          V6   No-till  R6    A        F        6
## 47          V6   No-till  R6    B        F        6
## 48          V6   No-till  R6    C        F        3
## 49          V8   Conv.    R1    A        C       19
## 50          V8   Conv.    R1    B        C       11
## 51          V8   Conv.    R1    C        C       10
## 52          V8   Conv.    R1    A        F        4
## 53          V8   Conv.    R1    B        F        3
## 54          V8   Conv.    R1    C        F       10
## 55          V8   Conv.    R2    A        C       14
## 56          V8   Conv.    R2    B        C        7
## 57          V8   Conv.    R2    C        C       14
## 58          V8   Conv.    R2    A        F        3
## 59          V8   Conv.    R2    B        F        4
## 60          V8   Conv.    R2    C        F        2
## 61          V8   Conv.    R5    A        C        7
## 62          V8   Conv.    R5    B        C       17
## 63          V8   Conv.    R5    C        C       10
## 64          V8   Conv.    R5    A        F        4
## 65          V8   Conv.    R5    B        F        6
## 66          V8   Conv.    R5    C        F        3
## 67          V8   Conv.    R6    A        C       17
## 68          V8   Conv.    R6    B        C        5
## 69          V8   Conv.    R6    C        C       10
## 70          V8   Conv.    R6    A        F        2
## 71          V8   Conv.    R6    B        F        8
## 72          V8   Conv.    R6    C        F        6
## 73          V8   No-till  R1    A        C       10
## 74          V8   No-till  R1    B        C       19
## 75          V8   No-till  R1    C        C       19
## 76          V8   No-till  R1    A        F        4
## 77          V8   No-till  R1    B        F        7
## 78          V8   No-till  R1    C        F        6
## 79          V8   No-till  R2    A        C       18
## 80          V8   No-till  R2    B        C       11
## 81          V8   No-till  R2    C        C       11
## 82          V8   No-till  R2    A        F        6
## 83          V8   No-till  R2    B        F        8
## 84          V8   No-till  R2    C        F       10
## 85          V8   No-till  R5    A        C       17
## 86          V8   No-till  R5    B        C       13
## 87          V8   No-till  R5    C        C       15
## 88          V8   No-till  R5    A        F       11
## 89          V8   No-till  R5    B        F        8
```

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## 90          V8    No-till  R5  C      F       6
## 91          V8    No-till  R6  A      C       6
## 92          V8    No-till  R6  B      C      13
## 93          V8    No-till  R6  C      C      21
## 94          V8    No-till  R6  A      F      10
## 95          V8    No-till  R6  B      F       7
## 96          V8    No-till  R6  C      F       6
## 97          V15     Conv.  R1  A      C      15
## 98          V15     Conv.  R1  B      C      16
## 99          V15     Conv.  R1  C      C      12
## 100         V15     Conv.  R1  A      F      15
## 101         V15     Conv.  R1  B      F      14
## 102         V15     Conv.  R1  C      F      10
## 103         V15     Conv.  R2  A      C      11
## 104         V15     Conv.  R2  B      C      12
## 105         V15     Conv.  R2  C      C      12
## 106         V15     Conv.  R2  A      F      17
## 107         V15     Conv.  R2  B      F      16
## 108         V15     Conv.  R2  C      F       8
## 109         V15     Conv.  R5  A      C      22
## 110         V15     Conv.  R5  B      C      26
## 111         V15     Conv.  R5  C      C      11
## 112         V15     Conv.  R5  A      F      23
## 113         V15     Conv.  R5  B      F      17
## 114         V15     Conv.  R5  C      F       5
## 115         V15     Conv.  R6  A      C      16
## 116         V15     Conv.  R6  B      C      10
## 117         V15     Conv.  R6  C      C      10
## 118         V15     Conv.  R6  A      F       8
## 119         V15     Conv.  R6  B      F      12
## 120         V15     Conv.  R6  C      F      17
## 121         V15   No-till  R1  A      C       8
## 122         V15   No-till  R1  B      C      14
## 123         V15   No-till  R1  C      C       7
## 124         V15   No-till  R1  A      F      15
## 125         V15   No-till  R1  B      F      11
## 126         V15   No-till  R1  C      F      19
## 127         V15   No-till  R2  A      C      15
## 128         V15   No-till  R2  B      C      13
## 129         V15   No-till  R2  C      C      16
## 130         V15   No-till  R2  A      F      20
## 131         V15   No-till  R2  B      F      32
## 132         V15   No-till  R2  C      F      31
## 133         V15   No-till  R5  A      C      25
## 134         V15   No-till  R5  B      C      18
## 135         V15   No-till  R5  C      C      20
## 136         V15   No-till  R5  A      F      33
## 137         V15   No-till  R5  B      F      33
## 138         V15   No-till  R5  C      F      14
## 139         V15   No-till  R6  A      C      12
## 140         V15   No-till  R6  B      C      22
## 141         V15   No-till  R6  C      C      21
## 142         V15   No-till  R6  A      F      36
## 143         V15   No-till  R6  B      F      18
```

```
## 144         V15  No-till  R6  C  F  29
## 145         R4   Conv.    R1  A  C  21
## 146         R4   Conv.    R1  B  C  12
## 147         R3   Conv.    R1  A  C  15
## 148         R6   Conv.    R1  A  C  22
## 149         R3   Conv.    R1  B  C  18
## 150         R6   Conv.    R1  B  C  20
## 151         R3   Conv.    R1  C  C  18
## 152         R6   Conv.    R1  C  C  21
## 153         R4   Conv.    R1  C  C  19
## 154         R3   Conv.    R1  A  F  15
## 155         R4   Conv.    R1  A  F  11
## 156         R6   Conv.    R1  A  F  10
## 157         R3   Conv.    R1  B  F  10
## 158         R4   Conv.    R1  B  F   7
## 159         R6   Conv.    R1  B  F   6
## 160         R3   Conv.    R1  C  F  16
## 161         R4   Conv.    R1  C  F  16
## 162         R6   Conv.    R1  C  F  15
## 163         R3   Conv.    R2  A  C   7
## 164         R4   Conv.    R2  A  C  28
## 165         R6   Conv.    R2  A  C  22
## 166         R3   Conv.    R2  B  C   9
## 167         R4   Conv.    R2  B  C  19
## 168         R6   Conv.    R2  B  C  15
## 169         R3   Conv.    R2  C  C  14
## 170         R4   Conv.    R2  C  C  21
## 171         R6   Conv.    R2  C  C  18
## 172         R3   Conv.    R2  A  F  13
## 173         R4   Conv.    R2  A  F  11
## 174         R6   Conv.    R2  A  F  12
## 175         R3   Conv.    R2  B  F  12
## 176         R4   Conv.    R2  B  F   8
## 177         R6   Conv.    R2  B  F   4
## 178         R3   Conv.    R2  C  F  15
## 179         R4   Conv.    R2  C  F   8
## 180         R6   Conv.    R2  C  F  10
## 181         R3   Conv.    R5  A  C  25
## 182         R4   Conv.    R5  A  C  18
## 183         R6   Conv.    R5  A  C  23
## 184         R3   Conv.    R5  B  C  18
## 185         R4   Conv.    R5  B  C  16
## 186         R6   Conv.    R5  B  C  22
## 187         R3   Conv.    R5  C  C  19
## 188         R4   Conv.    R5  C  C  14
## 189         R6   Conv.    R5  C  C  17
## 190         R3   Conv.    R5  A  F  22
## 191         R4   Conv.    R5  A  F   9
## 192         R6   Conv.    R5  A  F   7
## 193         R3   Conv.    R5  B  F  13
## 194         R4   Conv.    R5  B  F  14
## 195         R6   Conv.    R5  B  F   9
## 196         R3   Conv.    R5  C  F  23
## 197         R4   Conv.    R5  C  F   9
```

```
## 198     R6   Conv.    R5   C        F          6
## 199     R3   Conv.    R6   A        C         25
## 200     R4   Conv.    R6   A        C         22
## 201     R6   Conv.    R6   A        C         20
## 202     R3   Conv.    R6   B        C         27
## 203     R4   Conv.    R6   B        C         19
## 204     R6   Conv.    R6   B        C         15
## 205     R3   Conv.    R6   C        C         23
## 206     R4   Conv.    R6   C        C         22
## 207     R6   Conv.    R6   C        C         13
## 208     R3   Conv.    R6   A        F         18
## 209     R4   Conv.    R6   A        F         13
## 210     R6   Conv.    R6   A        F         17
## 211     R3   Conv.    R6   B        F         19
## 212     R4   Conv.    R6   B        F         10
## 213     R6   Conv.    R6   B        F         11
## 214     R3   Conv.    R6   C        F         17
## 215     R4   Conv.    R6   C        F          5
## 216     R6   Conv.    R6   C        F         16
## 217     R3   No-till  R1   A        C         20
## 218     R4   No-till  R1   A        C         25
## 219     R6   No-till  R1   A        C         18
## 220     R3   No-till  R1   B        C         21
## 221     R4   No-till  R1   B        C         17
## 222     R6   No-till  R1   B        C         15
## 223     R3   No-till  R1   C        C         22
## 224     R4   No-till  R1   C        C         27
## 225     R6   No-till  R1   C        C         20
## 226     R3   No-till  R1   A        F         25
## 227     R4   No-till  R1   A        F         11
## 228     R6   No-till  R1   A        F         12
## 229     R3   No-till  R1   B        F         39
## 230     R4   No-till  R1   B        F         12
## 231     R6   No-till  R1   B        F          9
## 232     R3   No-till  R1   C        F         19
## 233     R4   No-till  R1   C        F          7
## 234     R3   No-till  R2   A        C         18
## 235     R4   No-till  R2   A        C         24
## 236     R6   No-till  R2   A        C         16
## 237     R3   No-till  R2   B        C         18
## 238     R4   No-till  R2   B        C         17
## 239     R6   No-till  R2   B        C         16
## 240     R3   No-till  R2   C        C         14
## 241     R4   No-till  R2   C        C         22
## 242     R6   No-till  R2   C        C         25
## 243     R3   No-till  R2   A        F         22
## 244     R4   No-till  R2   A        F         10
## 245     R6   No-till  R2   A        F         13
## 246     R3   No-till  R2   B        F         13
## 247     R4   No-till  R2   B        F          8
## 248     R6   No-till  R2   B        F         13
## 249     R3   No-till  R2   C        F         15
## 250     R4   No-till  R2   C        F         10
## 251     R6   No-till  R2   C        F         10
```

```
## 252          R3    No-till  R5      A       C       25
## 253          R4    No-till  R5      A       C       19
## 254          R6    No-till  R5      A       C       17
## 255          R3    No-till  R5      B       C       13
## 256          R4    No-till  R5      B       C       16
## 257          R6    No-till  R5      B       C       19
## 258          R3    No-till  R5      C       C       15
## 259          R4    No-till  R5      C       C        9
## 260          R6    No-till  R5      C       C       19
## 261          R3    No-till  R5      A       F       15
## 262          R4    No-till  R5      A       F        5
## 263          R6    No-till  R5      A       F       12
## 264          R3    No-till  R5      B       F       14
## 265          R4    No-till  R5      B       F        5
## 266          R6    No-till  R5      B       F       17
## 267          R3    No-till  R5      C       F       11
## 268          R4    No-till  R5      C       F        6
## 269          R6    No-till  R5      C       F       28
## 270          R3    No-till  R6      A       C       18
## 271          R4    No-till  R6      A       C       15
## 272          R6    No-till  R6      A       C       19
## 273          R3    No-till  R6      B       C       15
## 274          R4    No-till  R6      B       C       14
## 275          R6    No-till  R6      B       C       20
## 276          R3    No-till  R6      C       C       14
## 277          R4    No-till  R6      C       C       23
## 278          R6    No-till  R6      C       C       24
## 279          R3    No-till  R6      A       F       11
## 280          R4    No-till  R6      A       F        8
## 281          R6    No-till  R6      A       F        7
## 282          R3    No-till  R6      B       F       11
## 283          R4    No-till  R6      B       F        7
## 284          R6    No-till  R6      B       F       14
## 285          R3    No-till  R6      C       F       21
## 286          R4    No-till  R6      C       F        9
## 287          R6    No-till  R6      C       F       14
```

```r
microbiome.fungi %>% # Note: A syntax allowing the combination of an output to an input
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  filter(Treatment == "Conv.") %>% # subsetting to only include the conventional treatment
  mutate(logRich = log(richness)) %>% # creating a new column of the log richness
  head() # displaying the first six rows
```

```
##                                    SampleID Crop Compartment DateSampled
## 1 Corn2017LeafObjective2Collection1T1R1CAH2 Corn        Leaf     6/26/17
## 2 Corn2017LeafObjective2Collection1T1R1CBA3 Corn        Leaf     6/26/17
## 3 Corn2017LeafObjective2Collection1T1R1CCB3 Corn        Leaf     6/26/17
## 4 Corn2017LeafObjective2Collection1T1R1FAC3 Corn        Leaf     6/26/17
## 5 Corn2017LeafObjective2Collection1T1R1FBD3 Corn        Leaf     6/26/17
## 6 Corn2017LeafObjective2Collection1T1R1FCE3 Corn        Leaf     6/26/17
##   GrowthStage Treatment Rep Sample Fungicide richness   logRich
## 1          V6     Conv.  R1      A         C        9 2.1972246
## 2          V6     Conv.  R1      B         C        6 1.7917595
## 3          V6     Conv.  R1      C         C        5 1.6094379
```

```
## 4             V6      Conv.  R1       A         F         7 1.9459101
## 5             V6      Conv.  R1       B         F         4 1.3862944
## 6             V6      Conv.  R1       C         F         2 0.6931472
```

summarise() We can use the `summarise()` function to find things like means and standard deviations/errors.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  filter(Treatment == "Conv.") %>% # subsetting to only include the conventional treatment
  mutate(logRich = log(richness)) %>% # creating a new column of the log richness
  summarise(Mean.rich = mean(logRich)) # calculating overall mean log richness within the conventionally
```

```
##   Mean.rich
## 1  2.304395
```

We can also connect multiple summary statistics here. More powerful.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  filter(Treatment == "Conv.") %>% # subsetting to only include the conventional treatment
  mutate(logRich = log(richness)) %>% # creating a new column of the log richness
  summarise(Mean.rich = mean(logRich), # calculating the mean richness, stdeviation, and standard error
            n = n(),
            sd.dev = sd(logRich)) %>%
  mutate(std.err = sd.dev/sqrt(n))
```

```
##   Mean.rich   n    sd.dev    std.err
## 1  2.304395 144 0.7024667 0.0585389
```

This is useful, but maybe we want to have summary statistics by group! We can also do this very easily using the `group_by()` function.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  mutate(logRich = log(richness)) %>% # creating a new column of the log richness
  summarise(Mean.rich = mean(logRich), # calculating the mean richness, stdeviation, and standard error
            n = n(),
            sd.dev = sd(logRich)) %>%
  mutate(std.err = sd.dev/sqrt(n))
```

```
## `summarise()` has grouped output by 'Treatment'. You can override using the
## `.groups` argument.
```

```
## # A tibble: 4 x 6
## # Groups:   Treatment [2]
##   Treatment Fungicide Mean.rich     n sd.dev std.err
##   <chr>     <chr>         <dbl> <int>  <dbl>   <dbl>
## 1 Conv.     C              2.53    72  0.635  0.0748
## 2 Conv.     F              2.07    72  0.696  0.0820
## 3 No-till   C              2.63    72  0.513  0.0604
## 4 No-till   F              2.36    71  0.680  0.0807
```

16

Connecting to plotting These groups of functions and packages also all work together very nicely. For example, direct input into ggplot is possible. In which case you would not have to enter the data statement, you just need to start inputing your aesthetics.

```
plot1 <- microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  mutate(logRich = log(richness)) %>% # creating a new column of the log richness
  summarise(Mean.rich = mean(logRich), # calculating the mean richness, stdeviation, and standard error
            n = n(),
            sd.dev = sd(logRich)) %>%
  mutate(std.err = sd.dev/sqrt(n)) %>%
  ggplot(aes(x = Fungicide, y = Mean.rich)) + # adding in a ggplot
  geom_bar(stat="identity") +
  geom_errorbar( aes(x=Fungicide, ymin=Mean.rich-std.err, ymax=Mean.rich+std.err), width=0.4) +
  theme_minimal() +
  xlab("") +
  ylab("Log Richness") +
  facet_wrap(~Treatment)
```

```
## `summarise()` has grouped output by 'Treatment'. You can override using the
## `.groups` argument.
```

```
plot1
```
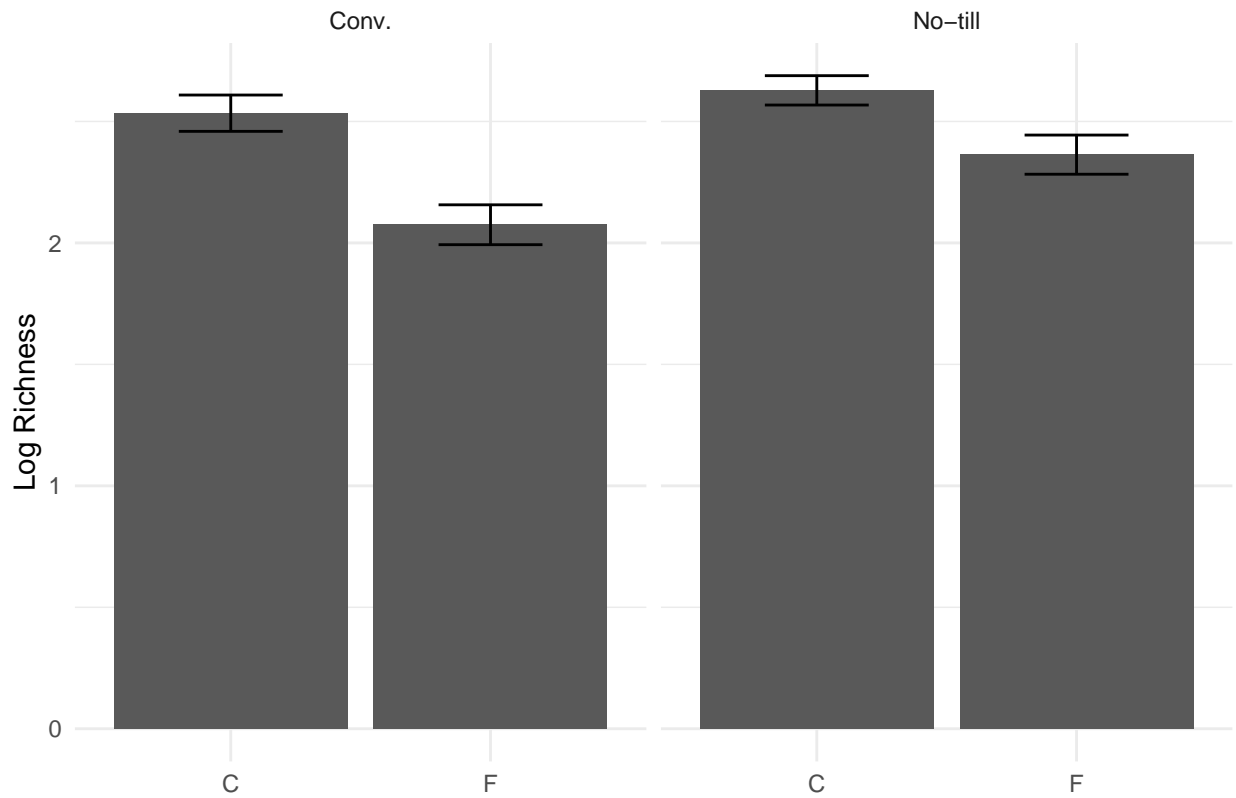
Joining The join group of functions are super useful. Have you ever tried to match up data by rows based on some criteria? Its almost impossible without messing up over 10-15 rows of data. Note: Allow the joining of multiple datasets based on a common column variable. For example, joining datasets back to a metadata file.

More info can be found here: https://dplyr.tidyverse.org/reference/mutate-joins.html

But we can easily do this with the joining functions. They include:

-left_join() - Keep all rows of X and add matching rows from Y. Any rows in Y that don't match X are excluded. -right_join() - reverse of left_join() -inner_join() - only keep rows that are common to both X AND Y, remove everything else. -full_join() - Keep any columns that are in either X or Y

To try these out lets split our data into separate sets including taxonomy and metadata.

Here we are also sampling 100 random rows of our dataset using the `sample_n()` function

```
# selecting just the richness and sample ID
richness <- microbiome.fungi %>%
  select(SampleID, richness)

# selecting columns that don't include the richness
metadata <- microbiome.fungi %>%
  select(SampleID, Fungicide, Crop, Compartment, GrowthStage, Treatment, Rep, Sample)

head(metadata)
```

```
##                                       SampleID Fungicide Crop Compartment
## 1 Corn2017LeafObjective2Collection1T1R1CAH2           C Corn        Leaf
## 2 Corn2017LeafObjective2Collection1T1R1CBA3           C Corn        Leaf
## 3 Corn2017LeafObjective2Collection1T1R1CCB3           C Corn        Leaf
## 4 Corn2017LeafObjective2Collection1T1R1FAC3           F Corn        Leaf
## 5 Corn2017LeafObjective2Collection1T1R1FBD3           F Corn        Leaf
## 6 Corn2017LeafObjective2Collection1T1R1FCE3           F Corn        Leaf
##   GrowthStage Treatment Rep Sample
## 1          V6     Conv.  R1      A
## 2          V6     Conv.  R1      B
## 3          V6     Conv.  R1      C
## 4          V6     Conv.  R1      A
## 5          V6     Conv.  R1      B
## 6          V6     Conv.  R1      C
```

```
head(richness)
```

```
##                                       SampleID richness
## 1 Corn2017LeafObjective2Collection1T1R1CAH2        9
## 2 Corn2017LeafObjective2Collection1T1R1CBA3        6
## 3 Corn2017LeafObjective2Collection1T1R1CCB3        5
## 4 Corn2017LeafObjective2Collection1T1R1FAC3        7
## 5 Corn2017LeafObjective2Collection1T1R1FBD3        4
## 6 Corn2017LeafObjective2Collection1T1R1FCE3        2
```

```
head(left_join(metadata, richness, by = "SampleID")) # adding the richness data to the metadata based o
```

```
##                                       SampleID Fungicide Crop Compartment
```

```
## 1 Corn2017LeafObjective2Collection1T1R1CAH2          C Corn      Leaf
## 2 Corn2017LeafObjective2Collection1T1R1CBA3          C Corn      Leaf
## 3 Corn2017LeafObjective2Collection1T1R1CCB3          C Corn      Leaf
## 4 Corn2017LeafObjective2Collection1T1R1FAC3          F Corn      Leaf
## 5 Corn2017LeafObjective2Collection1T1R1FBD3          F Corn      Leaf
## 6 Corn2017LeafObjective2Collection1T1R1FCE3          F Corn      Leaf
##   GrowthStage Treatment Rep Sample richness
## 1          V6     Conv.  R1      A        9
## 2          V6     Conv.  R1      B        6
## 3          V6     Conv.  R1      C        5
## 4          V6     Conv.  R1      A        7
## 5          V6     Conv.  R1      B        4
## 6          V6     Conv.  R1      C        2
```

Now this is kind of a silly example because we already had the data set joined how we wanted it and split it apart. But you can imagine if you have two separate data sets with one column in common and you wanted to combine them into one, instead of taking days to do this by hand you could simply load into R and do it.

Pivoting   Pivoting is also useful for converting from wide to long format and back again. We can do this with `pivot_longer()` and `pivot_wider()`

More info can be found here: https://tidyr.tidyverse.org/reference/pivot_wider.html

I will demonstrate `pivot_wider()` assuming that most data is already formatted as long data. Lets explore turning our data set into a wide format, since its in long format.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>%
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  summarise(Mean = mean(richness)) # calculates the mean per Treatment and Fungicide
```

```
## 'summarise()' has grouped output by 'Treatment'. You can override using the
## '.groups' argument.
```

```
## # A tibble: 4 x 3
## # Groups:   Treatment [2]
##   Treatment Fungicide  Mean
##   <chr>     <chr>     <dbl>
## 1 Conv.     C         14.6
## 2 Conv.     F          9.75
## 3 No-till   C         15.4
## 4 No-till   F         13.1
```

Wide format - sets the values within the fungicide column into column names

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  summarise(Mean = mean(richness)) %>% # calculates the mean per Treatment and Fungicide
  pivot_wider(names_from = Fungicide, values_from = Mean) # pivot to wide format
```

```
## 'summarise()' has grouped output by 'Treatment'. You can override using the
## '.groups' argument.
```

```
## # A tibble: 2 x 3
## # Groups:   Treatment [2]
##   Treatment    C     F
##   <chr>     <dbl> <dbl>
## 1 Conv.      14.6  9.75
## 2 No-till    15.4 13.1
```

Easily can take the difference bewteen the fungicide and control now.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns  filter(Class == "Sor
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  summarise(Mean = mean(richness)) %>% # calculates the mean per Treatment and Fungicide
  pivot_wider(names_from = Fungicide, values_from = Mean) %>% # pivot to wide format
  mutate(diff.fungicide = C - F) # calculate the difference between the means.
```

```
## 'summarise()' has grouped output by 'Treatment'. You can override using the
## '.groups' argument.
```

```
## # A tibble: 2 x 4
## # Groups:   Treatment [2]
##   Treatment    C     F diff.fungicide
##   <chr>     <dbl> <dbl>          <dbl>
## 1 Conv.      14.6  9.75           4.89
## 2 No-till    15.4 13.1            2.32
```

Now we can easily calculate the difference between fungicide and control and plot it.

```
microbiome.fungi %>%
  select(SampleID, Crop, Compartment:Fungicide, richness) %>% # selecting columns  filter(Class == "Sor
  group_by(Treatment, Fungicide) %>% # grouping by treatment and fungicide to later calculate summary s
  summarise(Mean = mean(richness)) %>% # calculates the mean per Treatment and Fungicide
  pivot_wider(names_from = Fungicide, values_from = Mean) %>% # pivot to wide format
  mutate(diff.fungicide = C - F) %>%  # calculate the difference between the means.
  ggplot(aes(x = Treatment, y = diff.fungicide)) + # Plot it
  geom_col() +
  theme_minimal() +
  xlab("") +
  ylab("Difference in average species richness")
```

```
## 'summarise()' has grouped output by 'Treatment'. You can override using the
## '.groups' argument.
```