STAT-530
Biochar and their effects on plant growth

Kaniz Fatema

Gordon Harrison

Megha Singh

Introduction/Objectives

- Biochar can be used to release extra needed nutrients or minerals into soil to promote plant growth
- Combustion process of Pyrolysis is used to degrade biochar Precursors into base elements which can then be absorbed by plants
- Similar to the idea of fertilizer or manure

https://www.google.com/search?sca_esv=1e618ffcd8ec6d84&rlz=1C1ONGR_en&sxsrf=AHTn8zrTeqGT_Qr7dY7VUtrl_jael_l0QA:1745862650112&q=biochar&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWp5u5rQsC2YJafWTbyNSy6G3Vsi155b_IyTtSTnvQaXi8pqHe_O2hfOzwUB6ozx76JUREYUpcyM78Ln-gOjNjNCk4dms4om5gZlsxkTulLkqrAuQLMLdbTho7KccoLe6Vs6CB3sJf5it-MMCLHZAQkoF550afkai_OQv5vhB-Q1kxCznBzZZNGLi0mrXKqIz6vghQZYQ&sa=X&sqi=2&ved=2ahUKEwjIr9iYpfuMAxWhTDABHbCuOO0QtKgLegQIGBAB&biw=1280&bih=585&dpr=1.5#vhid=PDbpueK6-qrMnM&vssid=mosaic

Introduction/Objectives

- Our Primary objective is to see which Biochar precursor will yield the most elements and at which pyrolysis temperature is ideal
  - Temperature
    - 350C
    - 500C
    - 700C
  - Biochars
    - Pine chips (PC)
    - Poultry litter (PL)
    - Swine solids (SS)
    - Switchgrass (SG)
    - 50/50 PC-SG
    - 80/20 PC-SG

Introduction/Objectives

- Our second Objective is to see which biochar precursor induces the most growth in 4 plant types

  Plant types:

  - § Carrots
  - § Corn
  - § Lettuce
  - § Soybean

Data and Cleaning Process

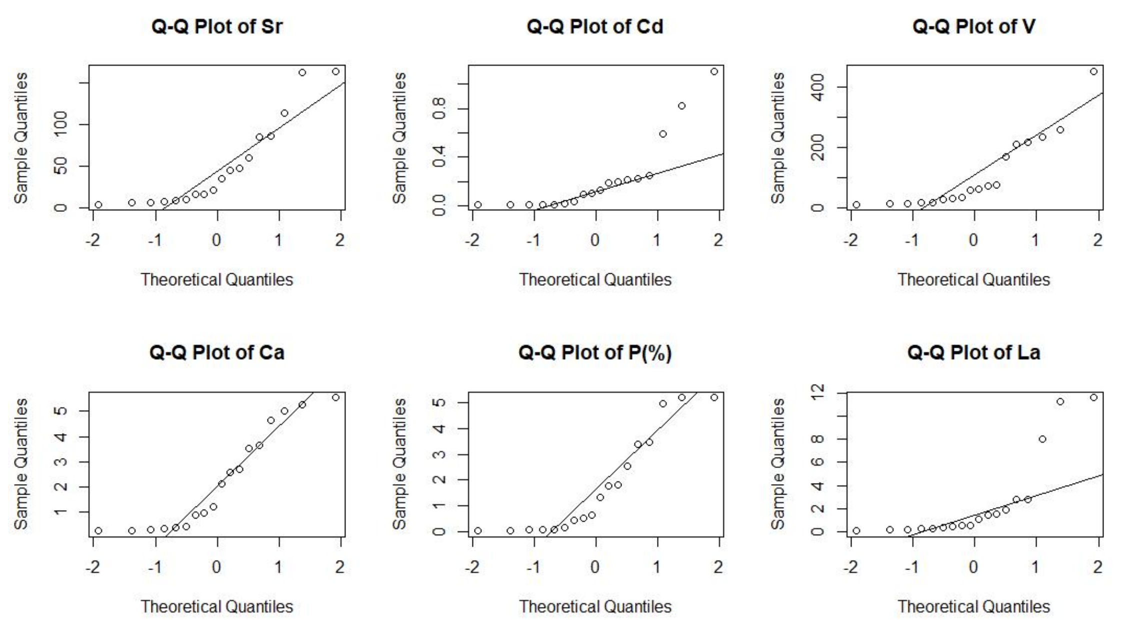
- For this project, 2 sets of related data were used
  - Sheet One: Biochar Chemical Analysis SH Unit Change 012920
    - Breakdown of the biochar's and the testing conditions that would be used along with concentrations of elements released(Used for K-means and PCA)
  - Sheet Two: Carrot SH Revised 012920, Corn SH Revised 012920, Lettuce SH 012920, Soybean SH Revised 012920
    - These four sheets breakdown the amount of each element that was found in each of the plants corresponding to the test soil and the biochar that was used, included the weight change of the shoot and leaves of plants(Used for ANOVA)

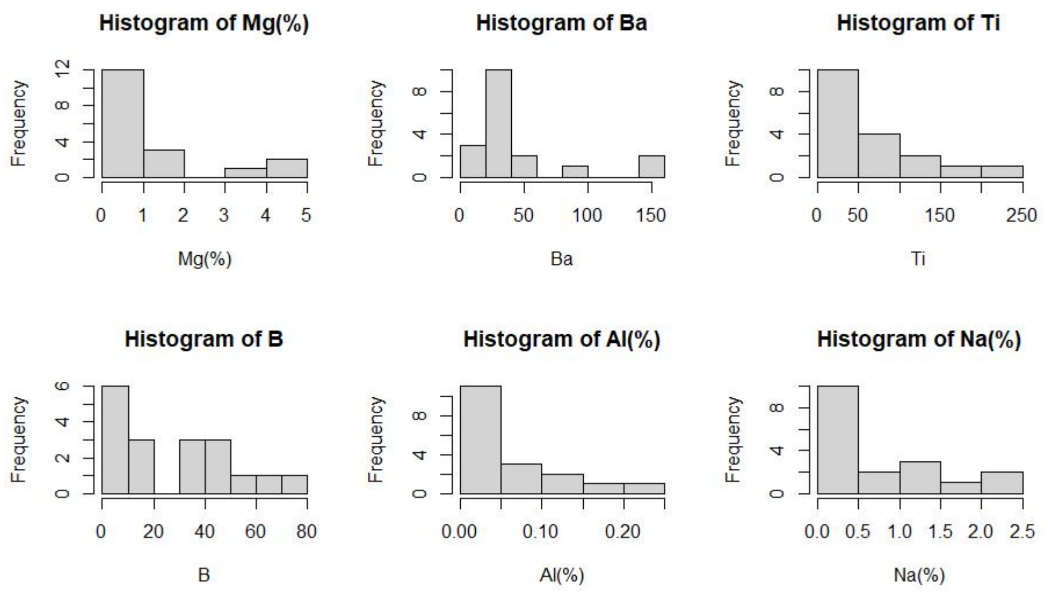
Data and Cleaning Process

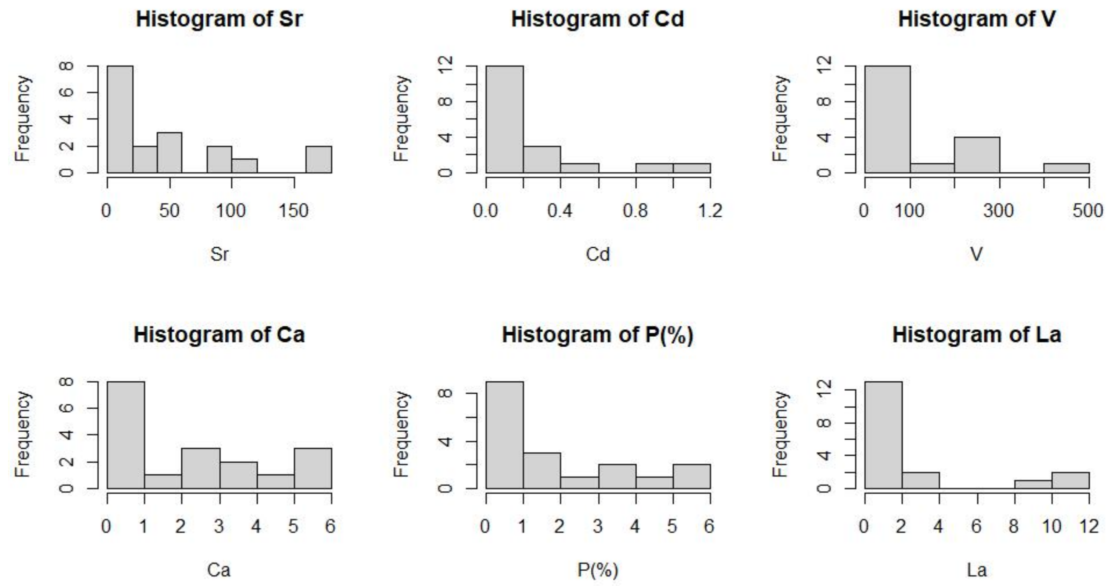
- The original Biochar Chemical Analysis SH Unit Change 012920 sheet contains the following columns:
  - *Sample, Feedstock, Temperature, Type, Molybdenum (PPM), Copper (PPM), Copper (mg/kg (DO)), Lead(PPM), Zinc(PPM), Zinc(mg/kg(DO)), Argon(PPB), Nickle(PPM), Cobalt(PPM), Manganese(PPM), Manganese(mg/kg(DO)), Iron(%), Iron(g/kg(DO)), Arsenic(PPM), Uranium(PPM), Gold(PPM), Thorium(PPM), Strontium(PPM), Cadmium(PPM), Antimony(PPM), Bismuth(PPM), Vanadium(PPM), Calcium(%), Calcium(g/kg(DO)), Phosphorus(%), Phosphorus(g/kg(DO)), Lanthanum(PPM), Chromium(PPM), Magnesium(%), Magnesium(g/kg(DO)), Barium(PPM), Titanium(PPM), Boron(PPM), Aluminum(%), Aluminum(g/kg(DO)), Sodium(%), Potassium(%), Potassium(g/kg(DO)), Tungsten(PPM), Scandium(PPM), Thallium(Tl), Sulfur(%), Sulfur(g/kg(DO)), Mercury(PPB), Selenium(PPM), Tellurium(PPM), Gallium(PPM).”*
- The cleaned sheet removed some of the undesirable variables that we were not interested in and contains the following columns:
  - *“Sample, Feedstock, Temperature, Type, Mo, Cu, , Pb, Zn, Zn(DO), Ni, Co, Mn, Mn(DO), Fe, Fe(DO), Th, Sr, Cd, V, Ca, Ca(DO), P(%), P(DO), La, Cr, Mg(%), Mg(DO), Ba, Ti, B, Al(%), Al(DO), Na(%), K(%), K(DO), W”*

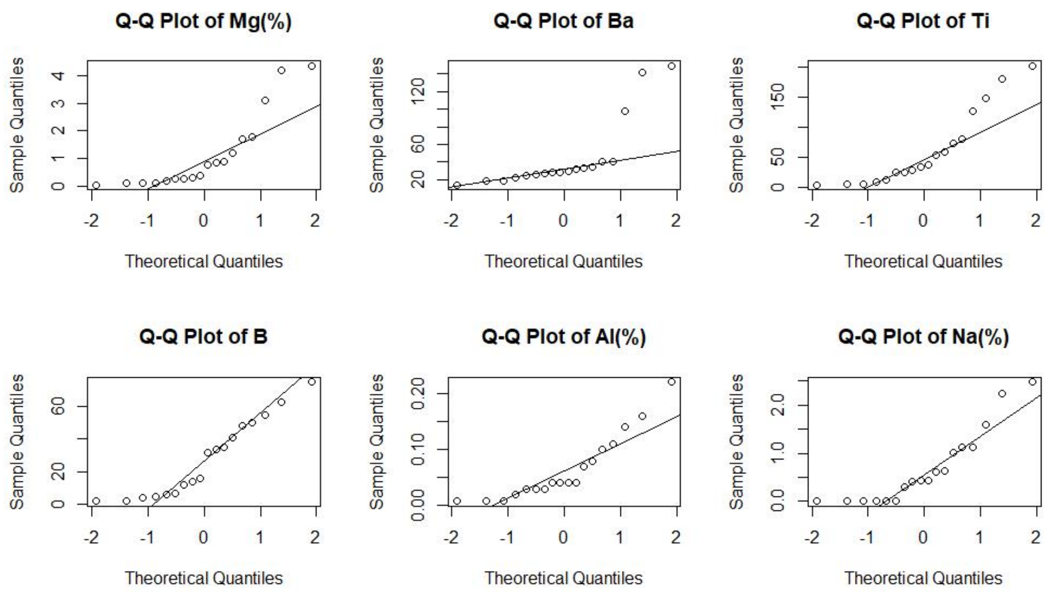
Data and Cleaning Process

- The four plant measurement sheets contain the following columns:
  - *“crop, stakeno, Color, soil, Treatment, feedstock, temperature, trtno, repno, species, tcn, tcngkg, log10tcngkg, arctcn, oc, arcoc, C/N ratio, leafaluminum, leaflog10aluminum, leafboron, leaflog10boron, leafcalcium, leaflog10calcium, leafcopper, leaflog10copper, leafiron, leaflog10iron, leafpotassium, leaflog10potassium, leafmagnesium, leaflog10magnesium, leafmanganese, leaflog10manganese, leafmolybenum, leaflog10molybdenum, leafsodium, leaflog10sodium, leafphosphorus, leaflog10phosphorus, leafsulfur, leaflog10sulphur, leafzinc, leaflog10zinc, revtrdw, revtrdw, revdrdw, log10revdiffrootdw, revisedrootdw, log10totrootdw, ratiotapdiff, arsintapdiff, shdw, logshootdw, shoot/total root ratio, arsinshoottotal, Ngshoot, log10Ngshoot, Alshoot, log10Algshoot, Bshoot, log10Bgshoot, Cashoot, log10Cashoot, Cushoot, log10Cushoot, Feshoot, log10Feshoot, Kshoot, log10Kgshoot, Mgshoot, log10Mgshoot, Mnshoot, log10Mnshoot, Moshoot, log10Moshoot, Nashoot, log10Nashoot, Pshoot, log10Pshoot, Sshoot, log10Sshoot, Znshoot, log10Znshoot, taprootlaboratory, traluminum, trlog10aluminum, trboron, trlog10boron, trcalcium, trlog10calcium, triron, trlog10iron, trlog10iron2, trpotassium, trlog10potassium, trpotassiummgg, trlog10potassiummgg, trmagnesium, trlog10magnesium, trmanagese, trlog10manganese, trmolybdenum, trlog10molybdenum, trsodium, trlog10sodium, trphosphorus, trlog10phosphorus, trsulphur, trlog10sulphur, trzinc, trlog10zinc, gKtaproot, log10gKtaproot, gPtaproot, log10gPtaproot, gCataproot, log10gCataproot, Mggtaproot, log10Mgtaproot, Fegtaproot, log10Fegtaproot, Mngtaproot, log10Mngtaproot, Zngtaproot, log10Zngtaproot”*
- The cleaned sheet removed some of the undesirable variables that we were not interested in along with filling in some 0 values with close to 0 values and contains the following columns:
  - *“Root Dry weight (g), Shoot Dry weight (g), Total Dry weight (g), crop, stakeno, soil, feedstock, temperature, Total combustible nitrogen in % , total organic in %, % C/% N ratio, Aluminum concentration in µg/g, Calcium concentration in µg/g, Iron concentration in µg/g, Potassium concentration in µg/g, Magnesium concentration in µg/g, Manganese concentration in µg/g, Sodium concentration in µg/g, Phosphorus concentration in µg/g, Zinc concentration in µg/g + 0.1 because of 0's.”*


Q-Q Plot of Sr
Q-Q Plot of Cd
Q-Q Plot of V
Q-Q Plot of Ca
Q-Q Plot of P(%)
Q-Q Plot of La
Sample Quantiles
Theoretical Quantiles


Histogram of Mg(%)
Histogram of Ba
Histogram of Ti
Histogram of B
Histogram of Al(%)
Histogram of Na(%)
Frequency
Mg(%)
Ba
Ti
B
Al(%)
Na(%)


Histogram of Sr
Histogram of Cd
Histogram of V
Histogram of Ca
Histogram of P(%)
Histogram of La
Frequency
Sr
Cd
V
Ca
P(%)
La

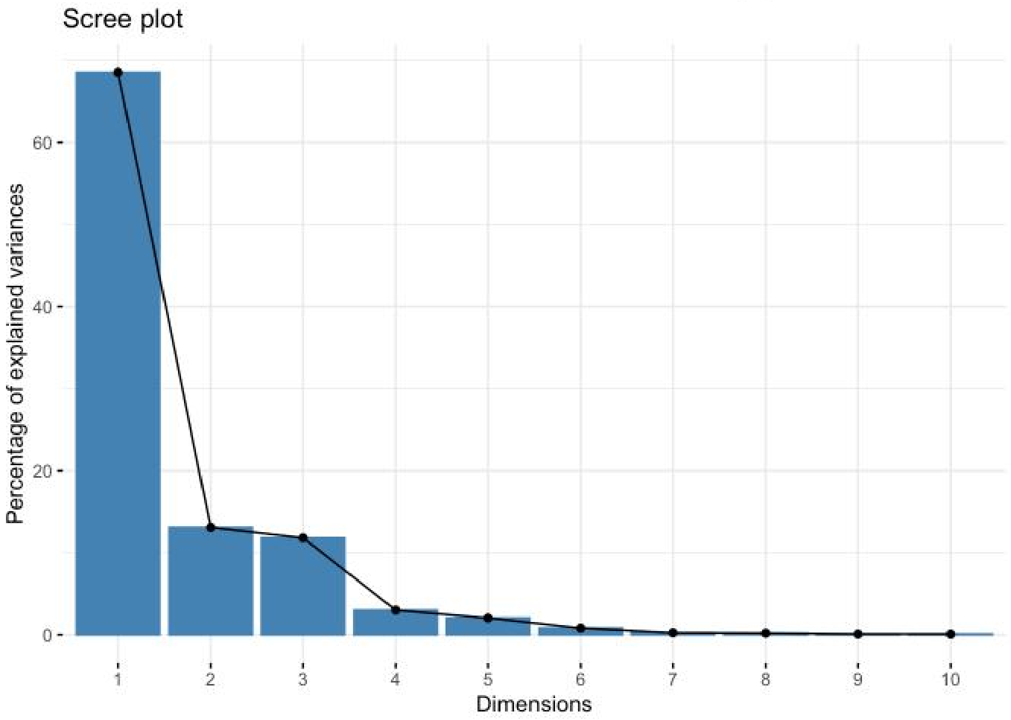

Q-Q Plot of Mg(%)
Q-Q Plot of Ba
Q-Q Plot of Ti
Q-Q Plot of B
Q-Q Plot of Al(%)
Q-Q Plot of Na(%)
Sample Quantiles
Theoretical Quantiles

Samples for K Means Clustering and PCA

Sample	Feedstock	Temperature
1	Pine chips	350
2	Pine chips	500
3	Pine chips	700
4	Poultry Liter	350
5	Poultry Liter	500
6	Poultry Liter	700
7	Swine Solids	350
8	Swine Solids	500
9	Swine Solids	700
10	Switchgrass	350
11	Switchgrass	500
12	Switchgrass	700
13	50/50 Pine Chip/Switchgrass	350
14	50/50 Pine Chip/Switchgrass	500
15	50/50 Pine Chip/Switchgrass	700
16	80/20 Pine Chip/Switchgrass	350
17	80/20 Pine Chip/Switchgrass	500
18	80/20 Pine Chip/Switchgrass	700

Scree Plot for PCA

4/27/25, 2:24 PM project530




```
fviz_pca_ind(pca)
```

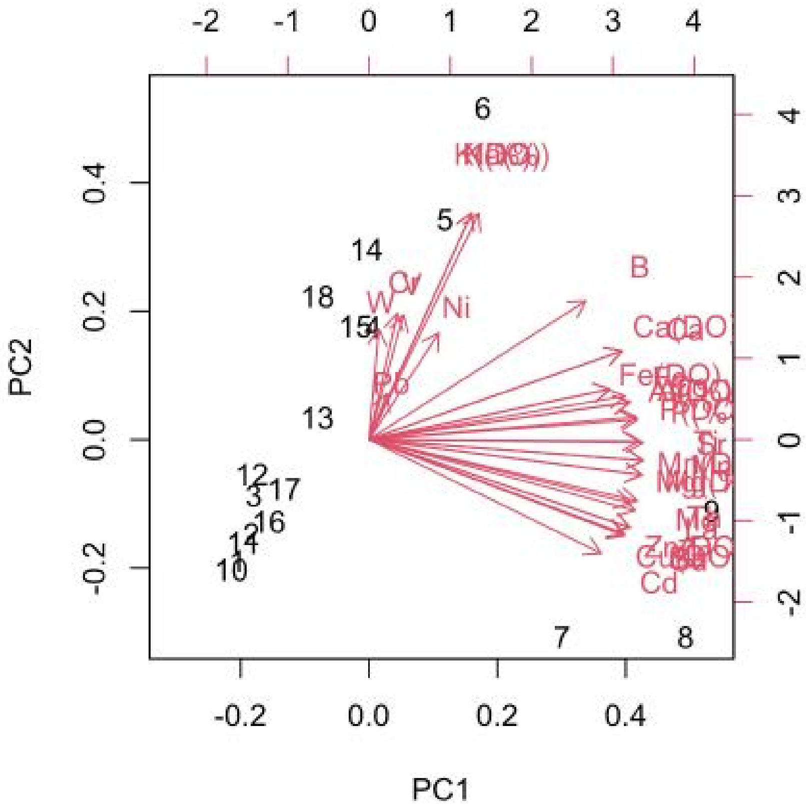
PCA Results

```
## Rotation (n x k) = (33 x 18):
##               PC1          PC2          PC3          PC4          PC5
## Mo     0.199692758 -0.110927764 -0.049314321 -0.008015986 -0.030380647
## Cu     0.194810446 -0.167211045 -0.065867488 -0.021503692 -0.009084561
## Cu(DO) 0.194810446 -0.167211045 -0.065867488 -0.021503692 -0.009084561
## Pb     0.013627019  0.079705170  0.120293961 -0.934425826 -0.236951545
## Zn     0.198937662 -0.153749027 -0.021201151  0.007920075 -0.016126965
## Zn(DO) 0.198937662 -0.153749027 -0.021201151  0.007920075 -0.016126965
## Ni     0.053196609  0.185761881 -0.442601999 -0.020761704  0.135717305
## Co     0.195270280  0.075769692 -0.158141552  0.029359183 -0.050709030
## Mn     0.209056380 -0.036587167  0.027185626  0.005526496 -0.009624874
## Mn(DO) 0.209056380 -0.036587167  0.027185626  0.005526496 -0.009624874
## Fe     0.183511870  0.087806378 -0.205022385 -0.031916791  0.151710479
## Fe(DO) 0.183511870  0.087806378 -0.205022385 -0.031916791  0.151710479
## Th     0.204503870 -0.107028814 -0.018761995 -0.020158116 -0.020038904
## Sr     0.208840201 -0.005551852  0.051837179  0.012490637 -0.010571104
## Cd     0.176900645 -0.198524673  0.064484705  0.150221916 -0.110767071
## V      0.026195825  0.217459854 -0.441537679 -0.073225615  0.121299414
## Ca     0.192830057  0.154612309  0.116445988  0.032262232  0.005929032
## Ca(DO) 0.192830057  0.154612309  0.116445988  0.032262232  0.005929032
## P(%)   0.204588577  0.034631646  0.084721634  0.035375727 -0.030005645
## P(DO)  0.203705316  0.039223166  0.088508175  0.037655767 -0.031591959
## La     0.202811489 -0.123952220 -0.015258956 -0.011750938 -0.014382496
## Cr     0.021553510  0.220312911 -0.441962072 -0.075740933  0.110319453
## Mg(%)  0.207968191 -0.061839310  0.023945963  0.014912906 -0.008617777
## Mg(DO) 0.207968191 -0.061839310  0.023945963  0.014912906 -0.008617777
## Ba     0.194456146 -0.164338941 -0.041463588 -0.038016974  0.012177760
## Ti     0.205746008 -0.002921576  0.019081211 -0.084044340 -0.041482386
## B      0.165242854  0.241891748  0.173582774  0.084129981  0.024958039
```

Method One: Principal Choice Analysis(PCA)

- PCA was done on the first dataset as well and yielded 2 major principal components. PC1 represents the presence of nutrients produced from the biochar's. PC2 is the presence of soluble elements, reflecting the salinity that will be produced from the bio chars.
- A high score in PC1 represents a high concentration of plant needed nutrients, while a low score will indicate a lack of these nutrients
- A high score in PC2 represents a high salt content produced from the biochar, while a low score will indicate a lack of salt

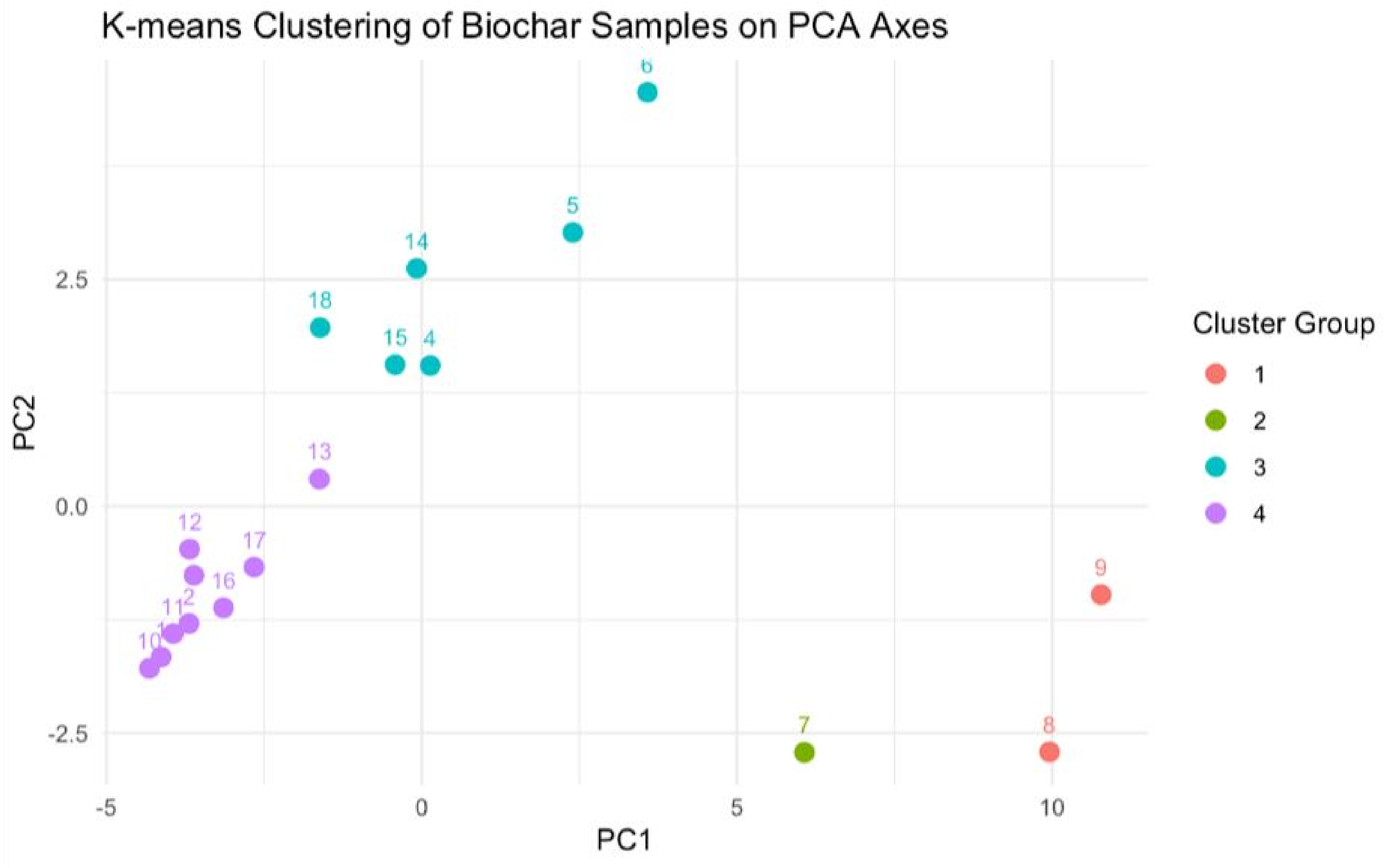
Bi Plot For PCA



Method Two: K Means Clustering

- K-means clustering was done on the first set of data to determine what each biochar could bring to the table, 4 main clusters were formed during this process:
  - Cluster One: Very high nutrient concentration with low salt content
    - § Contains Sample 8,9 ideal conditions for plant growth. Contains samples 4,13,14,15,18 decent nutrients allow for growth however higher salt will counteract water availability in plants, making accelerated growth harder
  - Cluster Two: High nutrient concentration with low salt content
    - § Contains Sample 7 while not as good as cluster one conditions for growth are still good
  - Cluster Three: Moderate nutrient concentration with high salt content
    - Contains samples 4,5,6,14,15,18 decent nutrients allow for growth however higher salt will counteract water availability in plants, making accelerated growth harder
  - Cluster Four: Low nutrient concentration with low salt content
    - Contains samples 1,2,3,10,11,12,13,16,17 like Cluster Three however the lack of nutrients will slow the rate of growth even more.

K Means Clustering



Method Three: ANOVA Analysis

- From the ANOVA analysis we found that the feedstock was significant for all plant types

```
carrot$soil <- as.factor(carrot$soil)
carrot$feedstock <- as.factor(carrot$feedstock)
carrot$temperature <- as.factor(carrot$temperature)
anova_model_carrot <- aov(total_dry ~ soil + feedstock + temperature, data = carrot)
summary(anova_model_carrot)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)
## soil          1   7.75   7.750   16.70 6.21e-05 ***
## feedstock     6  52.80   8.800   18.96  < 2e-16 ***
## temperature   2   2.47   1.234    2.66   0.0723 .
## Residuals   212  98.39   0.464
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 6 observations deleted due to missingness
```

```
soybean$soil <- as.factor(soybean$soil)
soybean$feedstock <- as.factor(soybean$feedstock)
soybean$temperature <- as.factor(soybean$temperature)
anova_model_soy <- aov(total_dry ~ soil + feedstock + temperature, data = soybean)
summary(anova_model_soy)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## soil          1 157.56  157.56 245.127 <2e-16 ***
## feedstock     6 107.02   17.84  27.751 <2e-16 ***
## temperature   2   4.06    2.03   3.155 0.0446 *
## Residuals   218 140.12    0.64
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
lettuce$soil <- as.factor(lettuce$soil)
lettuce$feedstock <- as.factor(lettuce$feedstock)
lettuce$temperature <- as.factor(lettuce$temperature)
anova_model_lettuce <- aov(total_dry ~ soil + feedstock + temperature, data = lettuce)
summary(anova_model_lettuce)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## soil          1   1.25   1.254   1.530  0.217
## feedstock     6 143.79  23.965  29.241 <2e-16 ***
## temperature   3   1.10   0.368   0.449  0.718
## Residuals   217 177.85   0.820
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
corn$soil <- as.factor(corn$soil)
corn$feedstock <- as.factor(corn$feedstock)
corn$temperature <- as.factor(corn$temperature)
anova_model_corn <- aov(total_dry ~ soil + feedstock + temperature, data = corn)
summary(anova_model_corn)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)
## soil          1 2166.4  2166.4  567.38  < 2e-16 ***
## feedstock     8  669.9    83.7   21.93  < 2e-16 ***
## temperature   2  106.2    53.1   13.91 2.07e-06 ***
## Residuals   216  824.7     3.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Results

- From both K means and PCA, it can be seen that samples 7,8,9 are some of the top contenders for plant growth. As the conditions they produce through pyrolysis leads to more ideal growth conditions: High nutrient concentrations along with lower salt content
- ANOVA analysis gave us more of an insight into this as it can be observed that most of the plant growth happened when the plants had Swine Solids used as the biochar precursor.
- The results from these approaches lead us to the conclusion that Swine Solids combusted and any temperature will contribute the most to plant growth and the highest presences of nutrients

Challenges

- One challenge that was faced was missing data and the lack of large amounts of data, missing data in dataset two would have caused many of the records to not be useable, due to the presence of 0 values, therefore we had to integrate nonzero zero values(very small numbers)
- Another challenge was a lack of a response variable in dataset one, which caused the need for dataset two for a regression or ANOVA to be done.

Conclusions

- Swine Solids are the top contender for plant growth and nutrient release at any of the listed temperature(350,500,700)
- Ramifications of this finding can lead to a larger use of waste material from the meat/pork industry allowing a larger amount of waste to be reused in a beneficial way
- Use of Swine Solids as biochar precursor can lead to increased plant growth and the presence of more desirable elements in soil that can be used during other crop growth

Sources

- Olszyk, D., Shiroyama, T., Novak, J., Cantrell, K., Sigua, G., Watts, D., & Johnson, M. G. (2020). *Biochar affects growth and shoot nitrogen in four crops for two soils*. Agrosystems, Geosciences & Environment, 3(1). https://doi.org/10.1002/agg2.20067
- Olszyk, D. M., Shiroyama, T., Novak, J. M., Cantrell, K. B., Sigua, G., Watts, D. W., & Johnson, M. G. (2020). *Biochar Affects Essential Nutrients of Carrot Taproots and Lettuce Leaves*. HortScience horts, 55(2), 261-271. Retrieved Apr 28, 2025, from https://doi.org/10.21273/HORTSCI14421-19
- *Essential Plant Nutrients*. Alabama Cooperative Extension System. (2024, December 9). https://www.aces.edu/blog/topics/farming/essential-plant-elements/