**ABSTRACT**

**“SMAP, Searching for Moisture”**

(A study conducted using the GLOBE SMAP method to analyze soil moisture in fertilized and unfertilized soil during the morning and evening)

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This was an investigation comparing moisture levels in soil fertilized with poultry litter and non-fertilized soil, in the morning and evening. It is predicted that the fertilized soil samples in the evening will have the highest moisture levels.

The GLOBE SMAP Soil Moisture Protocol was used. Volume and weight of soil collection canisters was calculated. Then, in the morning and evening on the fertilized soil and unfertilized soil, samples were collected and dried in a soil oven. Wet soil weight, dry soil weight, water weight, gravimetric soil moisture, volumetric soil moisture, sample bulk density were calculated by entering the information into the GLOBE SMAP Soil Moisture website and analyzed with a statistics t-Test.

Fertilized morning samples: wet soil=333.0g, dry soil=255.6g, water weight=77.4g, gravimetric soil moisture=0.32g/g, volumetric soil moisture=0.31ml/ml, bulk density=0.93g/ml. Fertilized evening samples: wet soil=369.3g, dry soil=283.6g, water weight=85.6g, gravimetric soil moisture=0.33g/g, volumetric soil moisture=0.35ml/ml, bulk density=1.04g/ml. Unfertilized morning samples: wet soil=376.1g, dry soil=293.1g, water weight=48.9g, gravimetric soil moisture=0.31g/g, volumetric soil moisture=0.34ml/ml, bulk density=1.08g/ml. Unfertilized evening samples: wet soil=376.6g, dry soil=313.2g, water weight=63.4g, gravimetric soil moisture=0.22g/g, volumetric soil moisture=0.25ml/ml, bulk density=1.16g/ml.

The hypothesis was supported by the data. Fertilized samples averaged 45% more water weight, 22% higher gravimetric soil moisture, 10% higher volumetric soil moisture, and was 12% less dense. Morning samples averages 15% less water weight, had a 14% higher gravimetric soil moisture reading, a 10% higher volumetric soil moisture reading, and was 10% less dense than the evening samples. Evening fertilized samples had the best results.

**“SMAP”SMAP:** **S**oil **M**oisture **A**ctive **P**assive satellite soil analysis program.

**Searching for Moisture**

A study conducted using the GLOBE SMAP method to analyze soil

moisture in fertilized and unfertilized soil during the morning and evening.

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**March 12th 2020**

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**INTRODUCTION & RESEARCH QUESTION**

Soil moisture is important for climate, land, animals, plants, and water conservation.  In addition, it is essential to weather patterns. As the moisture evaporates from the soil it creates humidity in the atmosphere.  This can help with the formation of clouds. Farmers depend on soil moisture for production of grass. The researcher lives on a farm and wanted to do this project to if fertilized soil has more moisture than unfertilized soil. The researcher is curious because he helps with cattle and hay. The researcher wonders how the soil moisture compared to fertilized and unfertilized soil samples.  This information can help farmers determine if fertilizing the soil is beneficial for vegetation. The researcher had to study and learn some new terminology in order to better understand the testing. ***Gravimetric soil moisture*** represents the mass of water per mass of dry soil. ***Volumetric soil moisture*** represents the volume of water per volume of dry soil. The ***sample bulk density*** reading represents how compacted the soil is the weight of the soil in a given volume. Soils with a sample bulk density greater than 1.6g/ml can begin to restrict root growth.

This project is the result of an investigation comparing the moisture of soil that has been fertilized with poultry liter to soil that has not been fertilized, using the GLOBE SMAP protocols for analyzing soil moisture. The second objective for the investigation will be to compare the soil moisture amounts collected in the morning to the evening samples.

**HYPOTHESIS**

It is predicted that soil samples collected for the fertilized soil will average more moisture than the samples taken from the unfertilized soil, because the grass in that area will insulate the ground and help prevent evaporation.  It is also predicted that the soil moisture levels will be higher in the evening samples than in the morning samples, unless it rains during the day.

**GLOBE Protocol Used**

SMAP for Soil Moisture, Cloud Coverage, & Surface Temperature

**RESEARCH METHODS**

The soil sampling procedures outlined in the GLOBE SMAP Soil Moisture Protocol were used to analyze the soil samples. Soil sample canisters were weighed using a digital balance scale in the school science lab. The volume for the containers was calculated by observing the amount of water it takes to fill them up. Soil samples from each location was taken in the morning and again in the evening on at 5 different days. Soil from 5cm deep was used to fill the canisters. The filled soil canisters were weighed on the digital balance scale and recorded. Then, the filled canisters were placed in a soil oven set at 95˚C. The canisters were weighed after 12 hours, and then again at regular intervals afterward until the weight stabilized and did not change. Then, the weight of the dried soil canisters was recorded and the amount of water that evaporated from the soil was calculated using the GLOBE SMAP data collection sheet. The latitude, longitude, and elevation for the soil sample locations was charted and set-up in the GLOBE data base. The results of the soil moisture samples were uploaded into the GLOBE data base following the SMAP soil moisture protocol. Each time soil samples were collected, the GLOBE protocol for Surface Temperature was also used to collect the surface temperature and to record the surface and cloud conditions, as well as documenting the air temperature, barometric pressure and humidity. Cloud Conditions were also observed, following the GLOBE protocols for both, and then the data was recorded and sent in to the GLOBE database.

**Risk and Safety:** The only risk involved in this investigation is using the soil oven which was set at approximately 95°C (203°F). The researcher was trained in proper safety procedures by a designated supervisor in using the soil oven. The researcher was also supervised while putting samples in and taking them out of the soil oven.

**Data Analysis:** Once all the data was collected, charts and graphs were used to analyze it further.

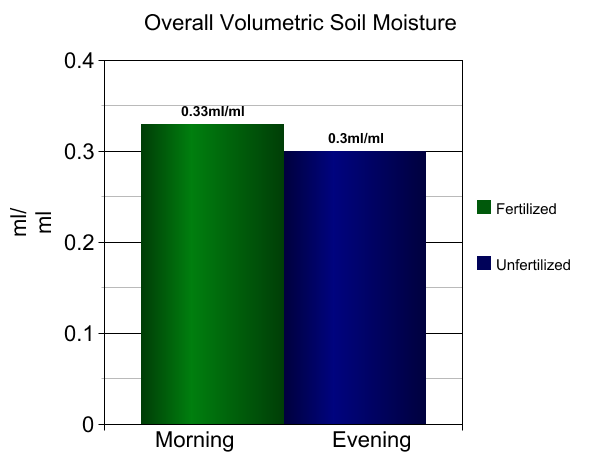
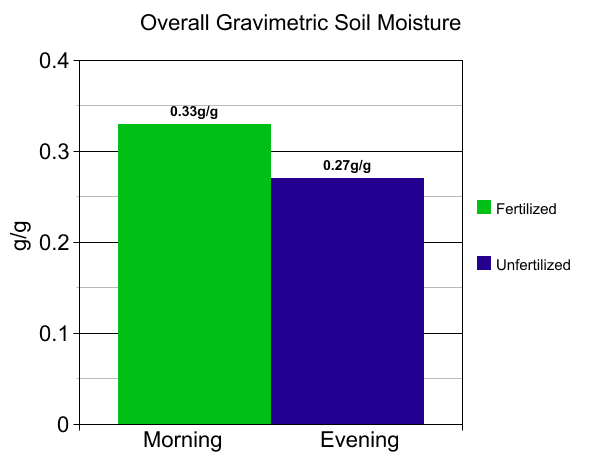
**MATERIALS**

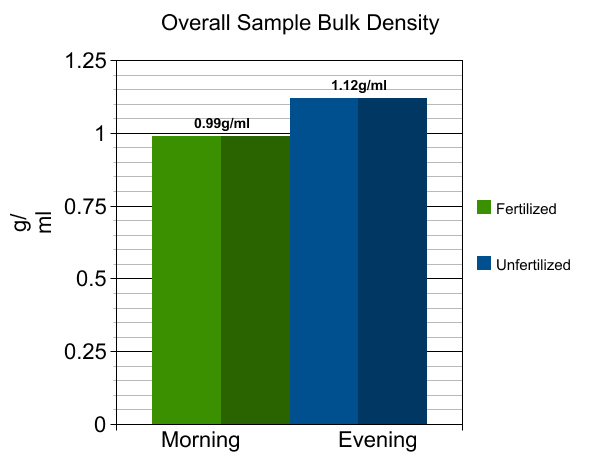
Barometer, Anemometer, Hygrometer, Digital Scale, iPhone app for GPS (latitude, longitude, elevation), iPad, Digital Infrared Thermometer, Soil Oven, Tin Canisters, Oven Mitts, and Beakers.

**DATA SUMMARY**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMAP Soil Moisture Overall Averages** | | | | | | | | |
| **Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  (g) | **Dry Soil**  **Weight**  (g) | **Water Weight**  (g) | **Gravimetric Soil Moisture**  (g/g) | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **Morning Samples** | |  |  |  |  |  |  |  |
| **Morning-F** | **333.0**g | **255.6**g | **28.5**g | **232.4**g | **77.4**g | **0.32**(g/g) | **0.31**ml/ml | **0.93**g/ml |
| **Morning-UF** | **376.1**g | **293.1**g | **28.6**g | **264.5**g | **48.9**g | **0.31**(g/g) | **0.34**ml/ml | **1.08**g/ml |
| **Overall Morning** | **354.6**g | **274.4**g | **28.6**g | **248.5**g | **63.2**g | **0.32**(g/g) | **0.33**ml/ml | **1.01**g/ml |
| **Evening Samples** | |  |  |  |  |  |  |  |
| **Evening-F** | **369.3**g | **283.6**g | **28.6**g | **255.0**g | **85.6**g | **0.33**(g/g) | **0.35**ml/ml | **1.04**g/ml |
| **Evening-UF** | **376.6**g | **313.2**g | **28.6**g | **284.6**g | **63.4**g | **0.22**(g/g) | **0.25**ml/ml | **1.16**g/ml |
| **Overall Evening** | **373.0**g | **298.5**g | **28.6**g | **269.8**g | **74.5**g | **0.28**(g/g) | **0.30**ml/ml | **1.11**g/ml |
|  |  |  |  |  |  |  |  |  |
| **Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  (g) | **Dry Soil**  **Weight**  (g) | **Water Weight**  (g) | **Gravimetric Soil Moisture**  (g/g) | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **Fertilized Samples** | |  |  |  |  |  |  |  |
| **Morning-F** | **333.0**g | **255.6**g | **28.5**g | **232.4**g | **77.4**g | **0.32**(g/g) | **0.31**ml/ml | **0.93**g/ml |
| **Evening-F** | **369.3**g | **283.6**g | **28.6**g | **255.0**g | **85.6**g | **0.33**(g/g) | **0.35**ml/ml | **1.04**g/ml |
| **Overall Fertilized** | **351.2g** | **269.6g** | **28.6g** | **243.7g** | **81.5g** | **0.33(g/g)** | **0.33ml/ml** | **0.99g/ml** |
| **Unfertilized Samples** | |  |  |  |  |  |  |  |
| **Morning-UF** | **376.1**g | **293.1**g | **28.6**g | **264.5**g | **48.9**g | **0.31**(g/g) | **0.34**ml/ml | **1.08**g/ml |
| **Evening-UF** | **376.6**g | **313.2**g | **28.6**g | **284.6**g | **63.4**g | **0.22**(g/g) | **0.25**ml/ml | **1.16**g/ml |
| **Overall Unfertilized** | **376.4g** | **303.2g** | **28.6g** | **274.6g** | **56.2g** | **0.27(g/g)** | **0.30ml/ml** | **1.12g/ml** |

**DATA SUMMARY (continued)**





**ANALYSIS AND RESULTS**

**Averages for the morning samples of the fertilized soil:** Weight measurements: wet soil=333.0g, dry soil=255.6g, water weight=77.4g, gravimetric soil moisture=0.32g/g, volumetric soil moisture=0.31ml/ml, sample bulk density=0.93g/ml.

**Averages for the morning samples of the unfertilized soil:** Weight measurements: wet soil=376.1g, dry soil=293.1g, water weight=48.9g, gravimetric soil moisture=0.31g/g, volumetric soil moisture=0.34ml/ml, sample bulk density=1.08g/ml.

**Averages for the evening samples of the fertilized soil:** Weight measurements: wet soil=369.3g, dry soil=283.6g, water weight=85.6g, gravimetric soil moisture=0.33g/g, volumetric soil moisture=0.35ml/ml, sample bulk density=1.04g/ml.

**Averages for the evening samples of the unfertilized soil:** Weight measurements: wet soil=376.6g, dry soil=313.2g, water weight=63.4g, gravimetric soil moisture=0.22g/g, volumetric soil moisture=0.25ml/ml, sample bulk density=1.16g/ml.

**OVERALL averages for fertilized soil:** Weight measurements: wet soil=351.2g, dry soil=269.6g, water weight=81.5g, gravimetric soil moisture=0.33g/g, volumetric soil moisture=0.33ml/ml, sample bulk density=0.99g/ml.

**OVERALL averages for unfertilized soil:** Weight measurements: wet soil=376.4g, dry soil=303.2g, water weight=56.2g, gravimetric soil moisture=0.27g/g, volumetric soil moisture=0.30ml/ml, sample bulk density=1.12g/ml.

**OVERALL averages for morning samples:** Weight measurements: wet soil=354.6g, dry soil=274.4g, water weight=63.2g, gravimetric soil moisture=0.32g/g, volumetric soil moisture=0.33ml/ml, sample bulk density=1.01g/ml.

**OVERALL averages for evening samples:** Weight measurements: wet soil=373.0g, dry soil=298.5g, water weight=74.5g, gravimetric soil moisture=0.28g/g, volumetric soil moisture=0.30ml/ml, sample bulk density=1.11g/ml.

**CONCLUSION**

The hypothesis was supported by the data. When comparing the **overall fertilized samples to the overall unfertilized samples**: the fertilized samples averaged 45% more water weight per sample, 22% higher gravimetric soil moisture, 10% higher volumetric soil moisture, and was 12% less dense. When comparing the **overall morning samples to the overall evening samples:** the morning samples averages 15% less water weight per sample, had a 14% higher gravimetric soil moisture reading, a 10% higher volumetric soil moisture reading, and was 10% less dense than the evening samples. The samples that averaged the **best readings was the evening fertilized samples**. They had the highest gravimetric soil moisture reading of 0.33g/g, highest volumetric soil moisture reading of 0.35ml/ml, and next to the lowest average density of 1.04g/ml. All of the soil samples had an average bulk density reading less than 1.6g/ml.

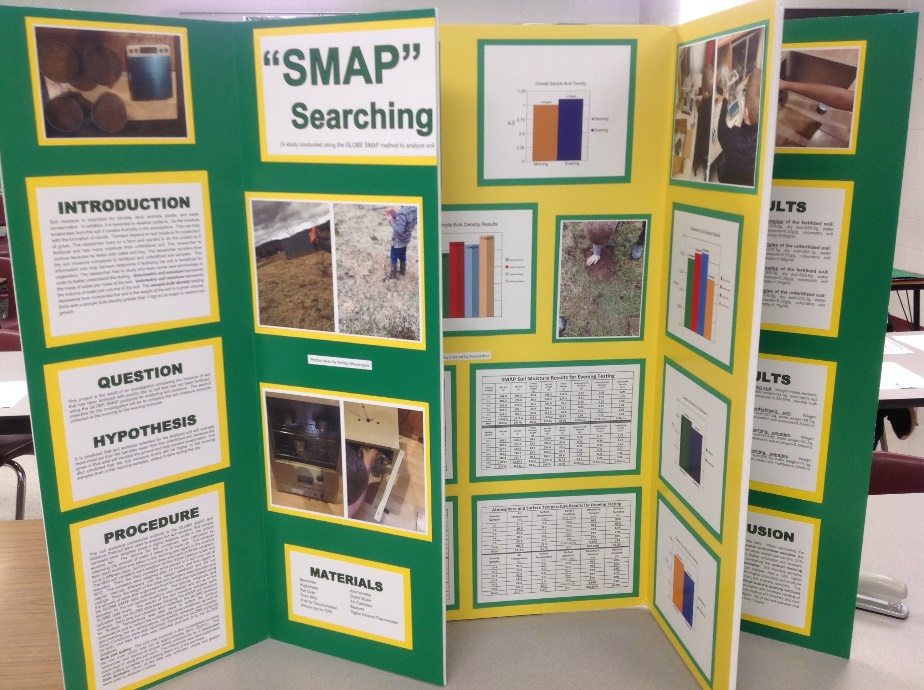
**DISCUSSION**

Soil moisture is very important in order to grow crops and hay for cattle. I the future, I would like to try and apply fertilizer below the surface of the soil, close to the roots of the plants, in order to maybe help the grass, grow better. I think that as the grass grows, it will absorb moisture from the soil, but at the same time, the grass above the ground will shade and insulate the soil, keeping if from drying out as fast as ground that does not have a good grass cover over it. In the future, I will also collect sol temperature data at 5cm and 10cm deep into the soil while I am collecting the soil samples for moisture analysis. It would also be interesting to try the test on different types of grass coverage and different types of soil.

**ACKNOLWEDGEMENTS**

I would like to thank my mom and dad for helping me with my project. My dad teaches me about farming and the importance of using fertilizer to grow hay to feed our cattle. My mom is great in helping me with the data collection and analysis of the data. My science teacher taught me about the GLOBE program and how to do the testing and enter the data into the GKLOBE database.







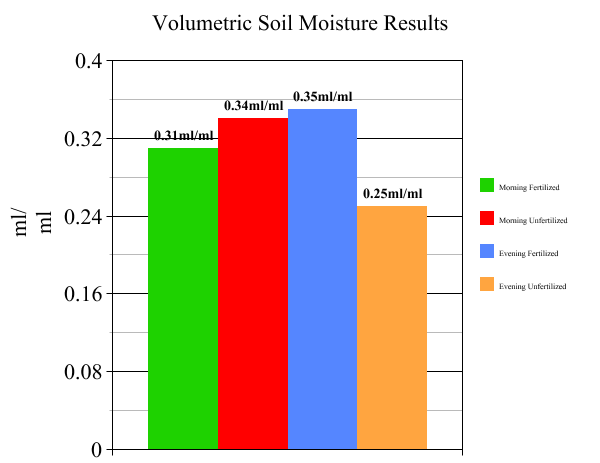
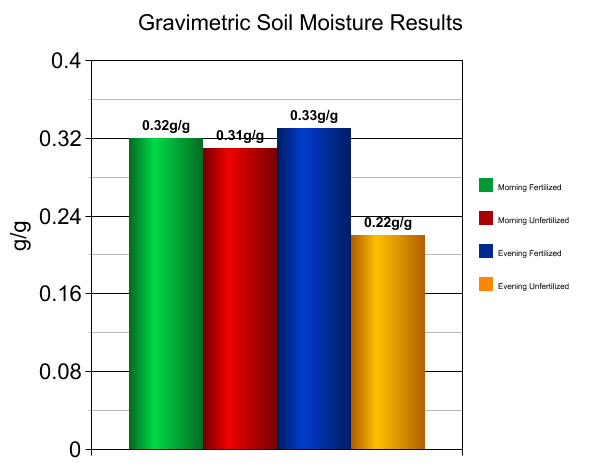
**ADDITIONAL DATA CHARTS & GRAPHS**

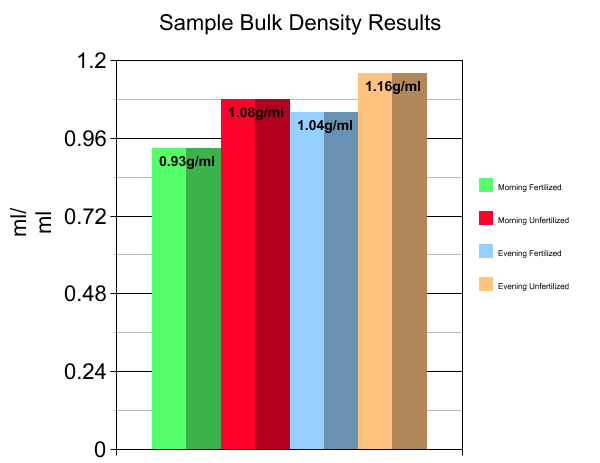
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMAP Soil Moisture Results for Morning Testing** | | | | | | | | |
| **Morning Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  **(g)** | **Dry Soil**  **Weight**  **(g)** | **Water Weight**  (g) | **Gravimetric Soil Moisture**  (g/g) | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **F-1** | **364.5** | **258.9** | **28.6** | **230.3** | **105.6** | **0.46** | **0.43** | **0.94** |
| **F-2** | **414.7** | **290.1** | **28.5** | **261.6** | **124.6** | **0.48** | **0.51** | **1.07** |
| **F-3** | **213.9** | **204.4** | **28.7** | **175.7** | **9.5** | **0.05** | **0.04** | **0.72** |
| **F-4** | **333.5** | **264.9** | **28.4** | **263.5** | **68.6** | **0.29** | **0.28** | **0.97** |
| **F-5** | **338.2** | **259.6** | **28.5** | **231.1** | **78.6** | **0.34** | **0.32** | **0.95** |
| **Total** | **1,664.8** | **1,277.9** | **142.7** | **1,162.2** | **386.9** | **1.62** | **1.58** | **4.65** |
| **Mean** | **333.0**g | **255.6**g | **28.5**g | **232.4**g | **77.4**g | **0.32**(g/g) | **0.31**ml/ml | **0.93**g/ml |
|  |  |  |  |  |  |  |  |  |
| **Morning Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  **(g)** | **Dry Soil**  **Weight**  **(g)** | **Water Weight**  (g) | **Gravimetric Soil Moisture**  **(g/)** | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **UF-1** | **349.7** | **301.3** | **28.8** | **272.5** | **48.4** | **0.18** | **0.20** | **1.12** |
| **UF-2** | **414.5** | **310.3** | **28.7** | **281.6** | **104.2** | **0.37** | **0.43** | **1.15** |
| **UF-3** | **454.8** | **284.6** | **28.6** | **256.0** | **170.2** | **0.66** | **0.70** | **1.05** |
| **UF-4** | **331.9** | **268.4** | **28.7** | **239.7** | **63.5** | **0.26** | **0.26** | **0.98** |
| **UF-5** | **329.8** | **301.3** | **28.6** | **272.7** | **28.6** | **0.10** | **0.12** | **1.12** |
| **Total** | **1,880.7** | **1,465.9** | **143.4** | **1,322.5** | **244.7** | **1.57** | **1.71** | **5.42** |
| **Mean** | **376.1**g | **293.1**g | **28.6**g | **264.5**g | **48.9**g | **0.31**(g/g) | **0.34**ml/ml | **1.08**g/ml |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SMAP Soil Moisture Results for Evening Testing** | | | | | | | | |
| **Evening Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  **(g)** | **Dry Soil**  **Weight**  **(g)** | **Water Weight**  (g) | **Gravimetric Soil Moisture**  **(g/)** | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **F-1** | **408.0** | **295.5** | **28.8** | **266.7** | **112.5** | **0.42** | **0.46** | **1.09** |
| **F-2** | **406.2** | **278.8** | **28.6** | **250.2** | **127.4** | **0.51** | **0.52** | **1.03** |
| **F-3** | **342.6** | **272.3** | **28.5** | **243.8** | **70.3** | **0.29** | **0.29** | **1.00** |
| **F-4** | **342.4** | **291.1** | **28.4** | **262.6** | **51.4** | **0.20** | **0.21** | **1.08** |
| **F-5** | **347.3** | **280.7** | **28.8** | **251.9** | **66.6** | **0.26** | **0.27** | **1.03** |
| **Total** | **1,846.5** | **1,418.4** | **143.1** | **1,275.2** | **428.2** | **1.68** | **1.75** | **5.23** |
| **Mean** | **369.3**g | **283.6**g | **28.6**g | **255.0**g | **85.6**g | **0.33**(g/g) | **0.35**ml/ml | **1.04**g/ml |
|  |  |  |  |  |  |  |  |  |
| **Evening Samples** | **Wet Soil**  (g) | **Dry Soil**  (g) | **Empty Container**  **Weight**  **(g)** | **Dry Soil**  **Weight**  **(g)** | **Water Weight**  (g) | **Gravimetric Soil Moisture**  **(g/)** | **Volumetric Soil Moisture**  (ml/ml) | **Sample Bulk**  **Density**  (g/ml) |
| **UF-1** | **358.2** | **328.7** | **28.7** | **300.0** | **29.5** | **0.10** | **0.12** | **1.23** |
| **UF-2** | **448.4** | **352.8** | **28.6** | **324.2** | **95.6** | **0.29** | **0.39** | **1.33** |
| **UF-3** | **347.7** | **283.6** | **28.7** | **254.9** | **64.1** | **0.25** | **0.26** | **1.04** |
| **UF-4** | **352.2** | **288.9** | **28.7** | **260.2** | **63.3** | **0.24** | **0.26** | **1.07** |
| **UF-5** | **376.8** | **312.2** | **28.5** | **283.7** | **64.6** | **0.23** | **0.26** | **1.16** |
| **Total** | **1,883.3** | **1,566.2** | **143.2** | **1,423.0** | **317.1** | **1.11** | **1.29** | **5.83** |
| **Mean** | **376.6**g | **313.2**g | **28.6**g | **284.6**g | **63.4**g | **0.22**(g/g) | **0.25**ml/ml | **1.16**g/ml |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Atmosphere and Surface Temperature Results for Morning Testing** | | | | | |
| **Morning Samples** | **Air**  **Temperature**  (°C) | **Surface Temperature**  (°C) | **Surface**  **Condition**  (Wet – Dry) | **Barometric Pressure**  (mb) | **Relative**  **Humidity**  (%) |
| **F-1** | **19.7** | **13.3** | Wet | **970** | **70%** |
| **F-2** | **19.7** | **14.5** | Wet | **964** | **95%** |
| **F-3** | **18.4** | **-1.5** | Wet | **970** | **80%** |
| **F-4** | **15.2** | **4.3** | Wet | **975** | **95%** |
| **F-5** | **18.2** | **-3.3** | Wet | **973** | **60%** |
| **Total** | **91.2** | **27.3** | 5-Wet | **4,852** | **400** |
| **Mean** | **18.2°C** | **5.5°C** | Wet | **970.4mb** | **80%** |
|  |  |  |  |  |  |
| **Morning Samples** | **Air**  **Temperature**  (°C) | **Surface Temperature**  (°C) | **Surface**  **Condition**  (Wet – Dry) | **Barometric Pressure**  (mb) | **Relative**  **Humidity**  (%) |
| **UF-1** | **19.7** | **13.1** | Wet | **970** | **70%** |
| **UF-2** | **19.7** | **14.4** | Wet | **964** | **95%** |
| **UF-3** | **18.4** | **-2.5** | Wet | **970** | **80%** |
| **UF-4** | **15.2** | **5.5** | Wet | **975** | **95%** |
| **UF-5** | **18.2** | **-3.2** | Dry | **973** | **60%** |
| **Total** | **91.2** | **27.3** | 4-Wet/1-Dry | **4,852** | **400** |
| **Mean** | **18.2°C** | **5.5°C** | Wet | **970.4mb** | **80%** |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Atmosphere and Surface Temperature Results for Evening Testing** | | | | | |
| **Evening**  **Samples** | **Air**  **Temperature**  (°C) | **Surface Temperature**  (°C) | **Surface**  **Condition**  (Wet – Dry) | **Barometric Pressure**  (mb) | **Relative**  **Humidity**  (%) |
| **F-1** | **21.7** | **7.3** | Wet | **961** | **88%** |
| **F-2** | **19.9** | **8.3** | Wet | **964** | **96%** |
| **F-3** | **22.6** | **1.1** | Wet | **973** | **63%** |
| **F-4** | **18.5** | **2.1** | Wet | **977** | **37%** |
| **F-5** | **24.0** | **4.7** | Dry | **973** | **50%** |
| **Total** | **106.7** | **23.5** | 4-Wet/1-Dry | **4,848** | **334** |
| **Mean** | **21.3°C** | **4.7°C** | Wet | **969.6mb** | **66.8%** |
|  |  |  |  |  |  |
| **Evening**  **Samples** | **Air**  **Temperature**  (°C) | **Surface Temperature**  (°C) | **Surface**  **Condition**  (Wet – Dry) | **Barometric Pressure**  (mb) | **Relative**  **Humidity**  (%) |
| **UF-1** | **21.7** | **7.5** | Wet | **961** | **88%** |
| **UF-2** | **19.9** | **8.3** | Wet | **964** | **96%** |
| **UF-3** | **22.6** | **0.5** | Wet | **973** | **63%** |
| **UF-4** | **18.5** | **3.2** | Wet | **977** | **37%** |
| **UF-5** | **24.0** | **5.5** | Dry | **973** | **50%** |
| **Total** | **106.7** | **25.0** | 4-Wet/1-Dry | **4,848** | **334** |
| **Mean** | **21.3°C** | **5.0°C** | Wet | **969.6mb** | **66.8%** |





**BIBLIOGRAPHY**

Baker, J. M., and R. R. Allmaras. "System for automating and multiplexing soil moisture measurement by time‐domain reflectometry." *Soil Science Society of America Journal* 54.1 (1990): 1-6.

Blake, G. Rꎬ, and K. H. Hartge. "Bulk density." *Methods of soil analysis: Part 1 Physical and mineralogical methods* 5 (1986): 363-375.

Board, Ocean Studies, and National Research Council. *Climate intervention: Reflecting sunlight to cool earth*. National Academies Press, 2015.

Butler, Dixon M., and Ian D. MacGregor. "GLOBE: Science and education." *Journal of Geoscience Education* 51.1 (2003): 9-20.

Entekhabi, Dara, et al. "The soil moisture active passive (SMAP) mission." *Proceedings of the IEEE* 98.5 (2010): 704-716.

Herkelrath, W. N., S. P. Hamburg, and Fred Murphy. "Automatic, real‐time monitoring of soil moisture in a remote field area with time domain reflectometry." *Water Resources Research* 27.5 (1991): 857-864.

Heuscher, Sonja A., Craig C. Brandt, and Philip M. Jardine. "Using soil physical and chemical properties to estimate bulk density." *Soil Science Society of America Journal* 69.1 (2005): 51-56.

Manrique, L. A., and C. A. Jones. "Bulk density of soils in relation to soil physical and chemical properties." *Soil Science Society of America Journal* 55.2 (1991): 476-481.

Reynolds, S. G. "The gravimetric method of soil moisture determination Part IA study of equipment, and methodological problems." *Journal of Hydrology* 11.3 (1970): 258-273.

Richards, L. A. "Methods of measuring soil moisture tension." *Soil Science* 68.1 (1949): 95.

Shinn, James D., et al. "Development of a CPT deployed probe for in situ measurement of volumetric soil moisture content and electrical resistivity." *Field Analytical Chemistry & Technology* 2.2 (1998): 103-109.

Wagner, Wolfgang, Guido Lemoine, and Helmut Rott. "A method for estimating soil moisture from ERS scatterometer and soil data." *Remote sensing of environment* 70.2 (1999): 191-207.