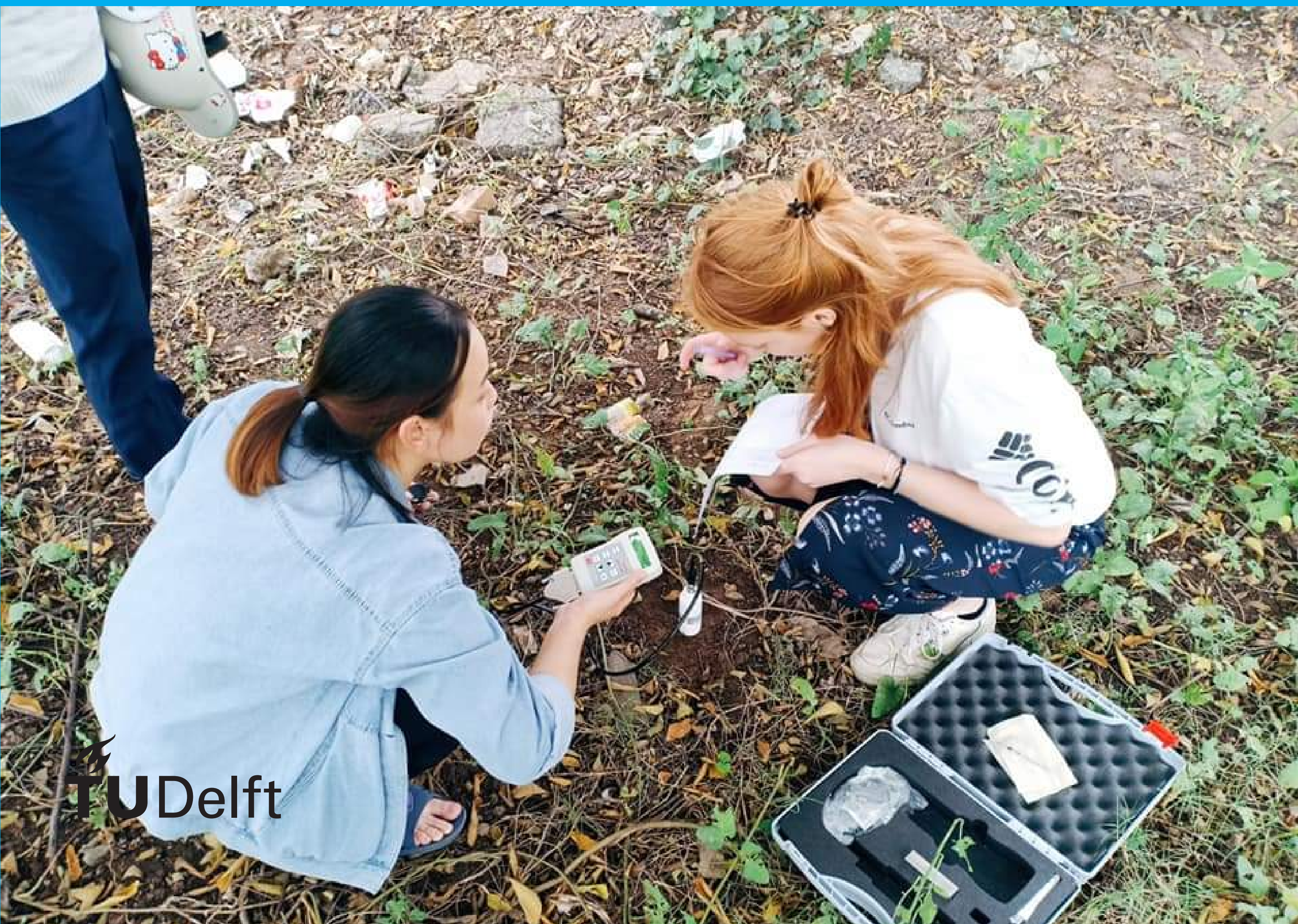
The Seasonal and Spatial Distribution of the Soil Moisture in Hanoi

Bachelor Thesis

Florine Speth

CTB3000
6 April 2020
Delft University of Technology



The Seasonal and Spatial Distribution of the Soil Moisture in Hanoi

Bachelor Thesis

by

Florine Speth

to obtain the degree of Bachelor of Science
at the Delft University of Technology,

Student number:	4584279	
Project duration:	February 10, 2020 – April 6, 2020	
Thesis committee:	Dr. T. A. Bogaard,	Delft University of Technology, supervisor
	Ir. J. L. F. Eulderink,	Delft University of Technology, supervisor
	Dr. Tạ Thị Thoảng,	Hanoi University of Natural Resources and Environment, local supervisor
	Msc. Trần Thùy Chi,	Hanoi University of Natural Resources and Environment, local supervisor

This thesis is confidential and cannot be made public until March 30 2020.

Disclaimer

This research was intended to be fully executed in Hanoi, the capitol of Vietnam at the Hanoi University of Natural Resources and Environment from February 10th until March 30th. During this complete research period, soil moisture would have been measured daily on different locations with both the ThetaProbe and the Decagon with the intention of ending up with a big dataset. This dataset of many values would subsequently be examined and used to answer the main research question. Additionally to these daily measurements, soil samples would have been taken of the field from the different measuring locations and investigated in the laboratory regarding the grain size, soil moisture and soil type.

However due to unforeseen circumstances, that is to say the worldwide outbreak of the COVID-19 virus, we (sadly) had to leave Hanoi prematurely and return to the Netherlands as soon as possible for our own safety. We left Hanoi on March 14th and the week prior to this HUNRE was closed due to the virus as well. This meant that more than three weeks of measurements could no longer be obtained. Therefore the initial methodology had to be adjusted to these circumstances in order to end up with more values. Thus a new experiment, which could be performed in The Netherlands, was added to the original methodology. In this research the newly adapted methodology has being described and performed. However, it would be a waste to neglect the initial methodology, therefore it has been briefly described in this section, with the hope that students (from HUNRE) can perform the initial research in the future.

Preface

This research operates as a Bachelor Thesis and is mandatory to obtain my bachelors degree in Civil Engineering at the Delft University of Technology. This research has partly taken place in Hanoi at the University of Natural Resources and Environment and partly in the Netherlands. It aims at creating a better understanding in the hydrological processes of soil moisture in Vietnam and additionally aims to support the collaborative project set up by the TU Delft and HUNRE 'Climate Proof Vietnam' OKP. During the research I have worked together with two other Dutch Bachelor students: Renske den Brave and Sterre Neumann, who were also performing their bachelor thesis at HUNRE as well as with some Vietnamese students of HUNRE. We have performed the measurements of all of our researches together, so we have been involved in each others researches as well.

I would like to thank my supervisors Thom Bogaard and Juliette Eulderink for guiding me, from a distance and nearby, in this final process of my Bachelor, as well as both my local supervisors Dr. Tạ Thị Thoảng and Msc. Trần Thùy Chi for taking me in at HUNRE and giving me local support. You have made us feel very welcome at your University, we have enjoyed our stay very much and were very sad that it had such an abrupt end. Finally I would like to thank Lindsey Schwidder for this opportunity to contribute to the Climate Proof Vietnam project.

Florine Speth
Delft, March 2020

Abstract

In this study the Volumetric Water Content (VWC) on an nearby the campus of the Hanoi University of Natural Resources and Environment (HUNRE) has been investigated. HUNRE is located in the Nam Từ Liêm district west of Hanoi's city centre. There are many farms and agricultural fields located in this area, but little information regarding the soil moisture is available about this area. Therefore this study will look into the spatial en seasonal distribution of the soil moisture on and around the campus of HUNRE. This location has been chosen, because this thesis has been performed in co-operation with students of HUNRE with the hope that more similar studies about local water quality and hydrological processes emerge.

The methodology of this research can be separated into three sections: Seasonal distribution, Spatial distribution and Consolidation experiment, respectively. To investigate the seasonal distribution and patterns of the soil moisture an existing dataset has been used to compare with a newly created dataset, which has been obtained in this research. The former dates from September to October 2019 and the latter dates from February to March, the wet and dry season respectively. In both datasets the soil moisture has been measured with the TM-5 Decagon. Secondly the spatial distribution of the soil moisture has been investigated by the use of a handheld soil moisture meter, the ML-3 ThetaProbe. In this part of the research soil moisture has been measured daily on three distinct locations, in order to map the soil moisture distribution. These locations consist of different soil types: a mixture of different soil types, a clay soil and a loam soil respectively. Lastly a small experiment regarding the relation between the soil moisture decrease and degree of consolidation has been performed in The Netherlands. In this research the soil moisture decrease of two different soil types, sand and loam, consisting of three different bulk densities has been monitored. Thus six different samples have been weighed daily, in order to monitor the volumetric water content decrease through time.

It could be concluded that in the wet season a higher average VWC has been measured, as well as a more unstable VWC throughout time, than in the dry season. Subsequently the average VWC on HUNRE turned out the lowest with the highest standard deviation, while the VWC at the agricultural field turned out the highest, with the lowest standard deviation. Lastly the results of the consolidation experiment have shown that the VWC of the sand samples decreases at a higher rate than that of the loam samples. From observing only the sand samples the results show that the lowest the bulk density had the lowest the evaporation rate, consequently the highest bulk density had the highest evaporation rate.

Contents

1 Introduction **6**

2 Locations **8**
2.1 Area description . . . 8
2.2 Mapping of locations . . . 8

3 Materials and Methods **10**
3.1 Materials . . . 10
3.2 Methodology . . . 10

4 Results **13**
4.1 Seasonal distribution . . . 13
4.2 Spatial distribution . . . 15
4.3 Soil consolidation . . . 17
4.4 Combined results . . . 19

5 Discussion **21**

6 Conclusion **23**

Bibliography **24**

A Appendix: Locations **25**

B Appendix: Methodology **27**

C Appendix: Results **28**

D Volumetric water content background **34**
D.1 Soil moisture . . . 34
D.2 Different VWC measuring methods . . . 34

1
Introduction

Soil moisture is a key hydrological variable since it controls the interactions between the atmosphere, biosphere and hydrosphere. It is responsible for the partitioning of precipitation into evaporation, transpiration, percolation and run-off. Soil Moisture monitoring is used to indicate droughts in vegetated areas and is an important parameter to early warning systems for flood. [Koliolios, 2020] The variability in soil moisture is not only controlled by temporal variability in atmospheric conditions but also spatial variability in land-surface conditions [Lawrence and Hornberger, 2007]. World wide many researches have been performed regarding soil moisture in order to gain a better understanding in how it reacts to different parameters.

This study has been carried out in Hanoi, the capital of Vietnam, to specific in the Nam Từ Liêm district, West of the city centre. The climate in Hanoi is monsoonal, with a hot, rainy season (May to September) and a warm, dry season (October to March). The relative humidity is around 84 percent throughout the year. There are seasonal divisions present, with temperatures fluctuating between 5°C in December and January up until more than 37°C in April [Hays, 2014]. This seasonal division can result in unsuspected flooding or droughts and may cause catastrophic consequences for the inhabitants. Monitoring the soil moisture can help in understanding and predicting the division of this rainfall throughout the year, so that the inhabitants, and especially the farmers, can anticipate in these fluctuations and prepare for these floods and droughts. In the Nam Từ Liêm district there are many farms and agricultural fields present on which many different crops are being cultivated. These farmers would benefit from gaining more knowledge about the soil moisture distribution on their land and throughout the year, to anticipate in these seaonal fluctuations. However there is not much information available regarding the soil moisture distribution in this district.

Therefore this research will be investigating the spatial and seasonal distribution of the soil moisture on and around the campus of the Hanoi University of Natural Resources and Environment (HUNRE) will be investigated. The only investigable soil present at the HUNRE campus is located in a small measuring garden. This garden is surrounded by asphalt and tall concrete buildings and is constructed for teaching purposes. In this research the soil moisture will be measured at this garden as well as other locations. These locations are surrounded by a natural environment, in contrast to the garden. Investigating the soil moisture on these different spots will create the possibility to compare the values of each measuring location to one another and investigate whether the soil moisture is depended on its location. Furthermore measurements at the garden will be compared to older data that consists of soil moisture monitoring values from September until November. This dataset was created by two Bachelor students from the Delft University of Technology and has been obtained during a different season, namely the wet season. Not only will their data be used and investigated in this research, this dataset will be complemented with new values and thus become more complete. Lastly a small experiment regarding the evaporation rate in time of different soil samples consisting of different bulk densities has been carried out, in order to gain more information on the volumetric water content decrease in different soil types and different degrees of consolidation.

The main research question of this research is:

What is the spatial and seasonal distribution of the soil moisture on and around the campus of HUNRE?

The sub questions, that will help answer the main research question are the following:

1. What are the area descriptions of the different locations, surrounding the measuring spots, and what is this soil made for (agriculture, forest, urban, etc.)?
2. What are the exact soil moisture values at the garden at HUNRE and at the other locations?
3. Is there a connection between the soil type and measured soil moisture values?
4. How does the Volumetric Water Content decrease through time and in different soil types?

The aim of this Bachelor Thesis is comparing soil moisture values on different locations and during different periods and of different soil types, in order to gain insight into the temporal and spatial distribution of the soil moisture. Next to this, this research can be used for future studies as a base of a new continuation research. The expanded dataset, which will be left behind after this research, will hopefully be used and perfected by other students, either from the TU Delft or from HUNRE. This research has been carried out in co-operation with students of HUNRE, to share knowledge and to enthusiasm them to continue these measurements after this study has finished.

The structure of this report is as follows: firstly an area description and an elaboration of the different measuring locations will be given. Secondly the methodology of the performed research will be described in detail, including a description of the different devices that have been used. Subsequently the results of the measurements are represented graphically and elaborated on. Thereafter these results will be interpreted and compared to results of similar studies in the Discussion and recommendation chapter, where in the end a recommendation is given. Finally a clear and concise conclusion can be found.

2 Locations

To investigate the spatial distribution, the soil moisture has been measured on multiple different locations. In this section first an area description will be given, subsequently the chosen locations will be elaborated and mapped.

2.1. Area description

The HUNRE campus is located in in the Nam Từ Liêm district in the West of Hanoi, see figure 2.1. Its dimensions are approximately 800 by 1200 m and the ground is mostly made up of asphalt and concrete. There are a few trees and bushes on the campus for aesthetic reason, which are positioned in specifically designed soil strokes. There are four tall buildings, that consist of 6 to 8 floors each. In the back of the campus, next to a building which is used for student housing, a small measuring garden is located. This garden can be described as a rectangle ‘tub’ filled with soil. Its dimensions are approximately 12 by 16 m and it is 30 cm deep. The soil in this measuring garden has been artificially placed and consists of many rocks, gravel and sand. This garden is not being taken care of, since there is quite some rubbish laying around and weeds are growing uncontrollably. The garden is used by professors of HUNRE to teach the students about different meteorological equipment, such as wind-, rain- and humidity meters, which are installed in this garden. Unfortunately this equipment does not work and no data is stored, they are there for teaching purposes only.

Not far up North from the campus, a large grass field is located. This field is divided into many smaller rectangular fields, which are almost all used for agricultural purposes. Various crops are being cultivated on these fields. Most of the soil is clayey and very moist, due to many irrigation canals which are positioned between these fields. The ground level of these fields is all similar to one another, thus there is no significant height difference present.

2.2. Mapping of locations

To obtain a diverse dataset the soil type on all locations should differ as much as possible. This will create the opportunity to investigate whether different soil types result in different soil moisture contents. With this in mind, three different measuring spots have been chosen. These are appointed and elaborated below.

The first measuring spot will be located at the HUNRE garden. In this location the soil is artificially placed and is surrounded by asphalt and concrete This can be seen in Appendix A figure A.1. This spot has been chosen in order to investigate whether it can be traced back to the soil moisture values that the soil has been placed artificially.

The second measuring spot is located approximately 350 meter North-Northeast of the HUNRE garden. This spot is located in the middle of a large agricultural field which is enclosed by small irrigation canals. These canals span approximately 50 cm and are a mere 10 cm deep. The soil in this spot is very dense and clayey. The soil texture therefore is different from the soil at the garden. In Appendix A figure A.3 an overview picture of this location is given and in figure A.4 a detailed picture of the soil on this location can be found.

The third spot was intended to be positioned on a higher ground level than de second spot. However, after surveying the ground levels in the area by walking around and observing from the roof of the university, it could be concluded that there were no significant elevation differences. Approximately 100 meter North-Northeast of location 2 and 450 meter North-Northeast from the HUNRE garden an open air plant shop is positioned. In this shop multiple different crops are being cultivated. This spot is chosen as a third measuring spot, because the soil density on this location is different from the soil density of the second measuring spot. The soil on this spot is more granular and less dense, which can be seen in Appendix A figure A.6. In figure A.5 an overview picture of this location is given.

In figure 2.1 a clear map of the three measuring locations is provided, they have been numbered 1 to 3[1].

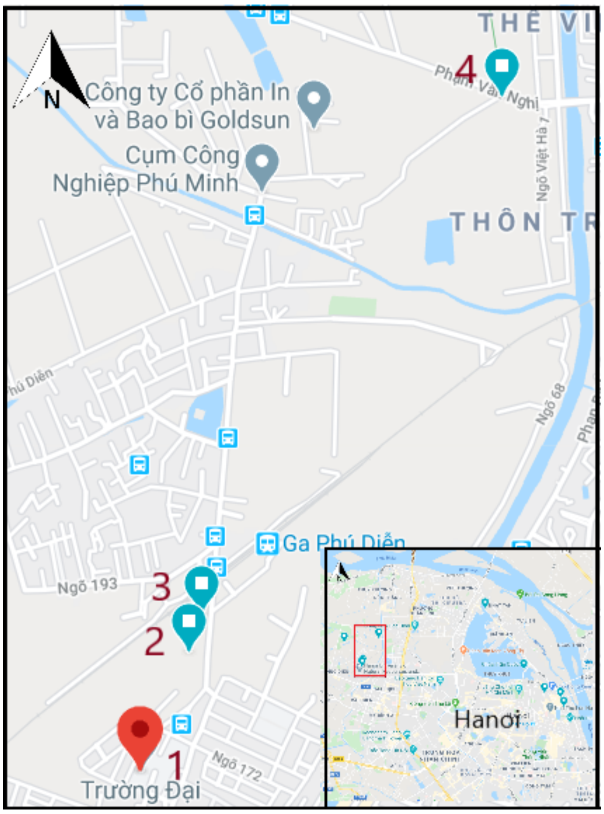


Figure 2.1: Map of the 3 measuring locations

[1]Initially a fourth location was also monitored. But due to too little measurements this location has been left out of the results. See chapter 5 for more information about this location.

3 Materials and Methods

In this chapter the equipment and methodology used to obtain the desired VWC will be provided and elaborated. To read more about the meaning of the VWC, see Appendix D.

3.1. Materials

To investigate the desired soil moisture values, two different devices have been used; that is to say the TM-5 Decagon and the ThetaProbe ML3. The first device has been chosen to use in this research, because former Bachelor students have already measured the soil moisture in the HUNRE garden in 2019 with this device. This means that their dataset is available and can be used for comparison with a newly to be obtained dataset. In order to make an accurate comparison between two datasets, it is of interest that the measuring methods resemble as much as possible. Therefore this device will be used in this research. The ThetaProbe will be used, as it is a handheld device, to obtain the spatial distribution of the soil moisture. Additionally this device was already present at HUNRE.

3.1.1. TM-5 Decagon

The TM-5 Decagon measures the water content as well as the temperature of soil. The 5TM sensor uses an electromagnetic field to measure the dielectric permittivity of the surrounding medium. The sensor supplies a 70 MHz oscillating wave to the sensor prongs that charges according to the dielectric of the material. The stored charge is proportional to soil dielectric and soil volumetric water content. The 5TM microprocessor measures the charge and outputs a value of dielectric permittivity from the sensor [Decagon Devices, 2017].

3.1.2. ThetaProbe ML3

The ML3 ThetaProbe measures soil moisture. It is a handheld device, which means it can easily be used on multiple different locations, to provide a spatial profile of the soil moisture. Its sealed plastic body is attached to four sensing rods which insert directly into the soil for taking readings. These rods are 60 mm long, and therefore soil moisture is measured at a depth of 60 mm. When power is applied to the ML3 it creates a 100MHz waveform(similar to FM radio). The wave form is applied to an array of stainless steel rods which transmit an electromagnetic field into the soil. The water content of the soil surrounding the rods dominates its permittivity. The permittivity of the soil has a strong influence on the applied field, which is detected by the ML3, resulting in a stable voltage output that acts as a simple, sensitive measure of soil moisture content [DevicesLtd, 2017].

3.2. Methodology

In order to answer the main research question, multiple measurements and experiments had to be executed. Therefore the methodology of this research can be divided into three sections: spatial distribution, seasonal distribution and consolidation experiment. All three types of measurements have been executed during a different period and they all have different durations. In table 3.1 a clear overview per measuring type can be found. These measurements have also been executed in different countries, which measurements have been performed where can also be found in the table. The reason for this, is that our time in Hanoi was sadly limited, thus an extra experiment in The Netherlands was necessary.

Type of measurement	Measuring duration	Exact dates	Country and city of execution
Seasonal distribution	4 weeks	Feb 24 - Mar 23	Vietnam, Hanoi
Spatial distribution	3 weeks	Feb 17 - Mar 5	Vietnam, Hanoi
Soil consolidation	1 week	Mar 20 - Mar 28	The Netherlands, Bilthoven

Table 3.1: Measuring duration and exact dates of the three types of measurements

3.2.1. Seasonal distribution

The TM-5 Decagon has been used to perform soil moisture measurements for this section. This device had already been installed in the garden, when measurements were performed during the wet season. It has been used again for measuring the soil moisture in the garden and did not have to be set up in a different way but could be used in its current placing. The device was setup as follows: four different sensors are positioned in two different locations at the garden, these locations can be seen in appendix A figure A.7 and are named respectively 'left' and 'right' location. Per location there are two sensors at two different depths installed: one at a depth of 10 cm and the other at 30 cm deep. This device is configured to measure the temperature and soil moisture at the four locations every 15 minutes. To obtain the data, a laptop should be connected to the Decagon and the data can be downloaded on the laptop. Hence all data has been downloaded at once at the end of the measuring period and subsequently has been put into a clear graph. The data from this device spans from February 24th until March 23rd.

3.2.2. Spatial distribution

Because the ThetaProbe is a handheld device as mentioned before, it has been used to obtain a spatial distribution of the soil moisture. The measurements were performed daily on Monday until Friday, thus with an exception of the weekends. This was because the university was closed during this time.

On every measuring spot the ThetaProbe has been inserted into the ground 4 to 5 times, approximately within a radius of 1 m from each other. These values eventually have all been put together in a table, with the intention of taking the average of these values in order to end up with one value per day per location. Additionally to the average, the standard deviation has been calculated, to gain a better understanding of the distribution of the different values and observe which measurements deviates the most. When the measurement period had passed, this data could be converted into clear, well-arranged graphs, which would allow comparison of the different locations.

3.2.3. Soil consolidation

Additionally to the research regarding the distribution of the soil moisture, a small experiment regarding different degrees of consolidation has been performed in The Netherlands. Because the investigated soil at the measuring locations in Hanoi were all made up of different degrees of consolidation it would be interesting to monitor the rate of decrease in VWC of soil samples with a different bulk density. Hence a third experiment has been carried out in The Netherlands.

In this experiment 12 small pots with a volume of 600 ml or 0.0006 m^3 have al been filled till the edge with soil, so that the soil volume equals the volume of the pot (which is 600 ml). These bottom of the pots have been sealed up, so that water can only escape through the soil surface. Additionally the insides of these pots have been covered with tinfoil. To limit the influence of the sun on the sides. In Appendix B figure B.2 a picture of one of the filled soil samples is given. Six of these pots were filled with sand and the remaining six with loam. Per soil type the six pots have been filled in pairs with three different degrees of consolidation and thus result in three different bulk densities per soil. The pots have all been numbered 1 to 12 and additionally a code has been given per pot. This code consists of a letter and a number. The letter shows the soil type, namely 'S' stands for sand and 'L' stands for loam. The number after the letter ranges from 1 to 3, 1 representing the lowest degree of consolidation and 3 the highest. Subsequently all pots have been filled with exactly 100 ml of water with the use of a plastic syringe. See Appendix B figure B.1 for a picture of the syringe used in this research.

The 12 soil samples have been put outside in the garden in The Netherlands. Starting from March 20th at 18:00 PM they have been weighed twice daily. That is to say every day at 10:00 AM as well as 18:00 PM. In figure 3.1 the placement of the prepared soil samples can be seen, with the corresponding code per soil sample. The samples were positioned in the middle of a grass field, which was surrounded by some tall trees.

Figure 3.1: The placement of the 12 soil samples, with their corresponding code.

After the experiment has been carried out, the weight difference per measurement could be converted into the VWC (θ_v) using the following formula (1) [Bilskie, 2001].

$$\theta_v = \frac{V_{water}}{V_{soil}} = \frac{\theta_g * \rho_{bulk}}{\rho_{water}} (1)$$

Where θ_g stands for the Gravimetric Water Content and can be calculated by dividing the mass of the water by the mass of the dry soil (2) and ρ_{bulk} represents the bulk density, which can be calculated by dividing the mass of the dry soil sample by the volume of the sample, namely 600 ml in this case (3) Bilskie [2001].

$$\theta_g = \frac{m_{water}}{m_{soil}} (2)$$

$$\rho_{bulk} = \frac{m_{soil}}{V_{soil}} (3)$$

Thence the VWC of the different soil types and bulk densities could be put into a clear graph, so that they can be compared to each other easily.

During this experiment several weather conditions have also been written down, in order to link them to the results of the measurements. These values have been obtained from the Dutch KNMI weather station located in De Bilt, which is approximately 6.7 km away from the location where the experiment is carried out [KNMI, 2020].

4 Results

In this chapter the results of the performed measurements end experiments are given and elaborated. The results are subdivided into three sections: Seasonal distribution, Spatial distribution and Soil consolidation. Lastly the results will be combined.

4.1. Seasonal distribution

As stated before, in a previous research [Alma, 2019] the soil moisture in the garden of HUNRE has been monitored during the period of September and October 2019. A graphic representation of the data of this previous research as well as the data of this current research can be found below respectively in figure 4.1 and 4.2. Per measuring depth the values of the two locations have been combined, that is to say the left and right location at 10 cm depth have been combined as well as both of 30 cm depth, in order to get a more simplified and clearer visual display of the values. Each graph shows the measured soil moisture values and the corresponding soil temperature at 10 cm and 30 cm depth.

4.1.1. Soil temperature

In both graphs there is a clear difference in the degree of oscillation of the soil temperature between 10 and 30 cm depth; the soil temperature at a depth of 10 cm fluctuates stronger than at 30 cm depth. This is a result of the air temperature that can more easily penetrate to a depth of 10 cm than 30 cm, and thus has more effect on the soil temperature at a lower depth.

Additionally a higher soil temperature has been measured in the period Sep-Oct 2019 (29.5 °C) than the period Feb-Mar 2020 (24.3°C). This can be the result of the higher average monthly air temperature in September and October compared to February and March as shown in table 4.1. In this table average values of various different weather conditions are given.

	Sep	Oct	Feb	Mar
Temperature [°C]	27.8	25.3	17.5	20.5
Relative humidity [%]	79	75	82	83
Precipitation [mm]	265.4	130.7	26.2	43.8
Sun hours [H]	5.4	5.3	1.6	1.4

Table 4.1: Average values of several weather conditions [cli, 2019]

Both graphs show that the soil temperature decreases right after a rain shower has occurred. This is the result of the cold rain water that infiltrates into the ground and influences the soil temperature.

4.1.2. Volumetric water content Decagon

The variance of the VWC values from the wet season is higher, in comparison to the variance of the VWC values obtained in this research period. During the wet season the VWC at 30 cm depth shifts approximately between 16 to 30%, while in the dry season the VWC varies approximately between 23 to 30%. The reason for this dispersion in the wet season is that multiple rain showers have occurred during this measuring period. In the graph these rain showers can be recognised by a sudden increase in VWC, whereafter it slowly decreases to a new, higher VWC. This can be explained by the fact that the precipitation infiltrates in the ground and subsequently is (partly) retained by the soil. This consequently causes a rise of VWC in the soil. In the first graph (4.1) it can be seen that this happens around four times, while in the second graph this only occurs once.

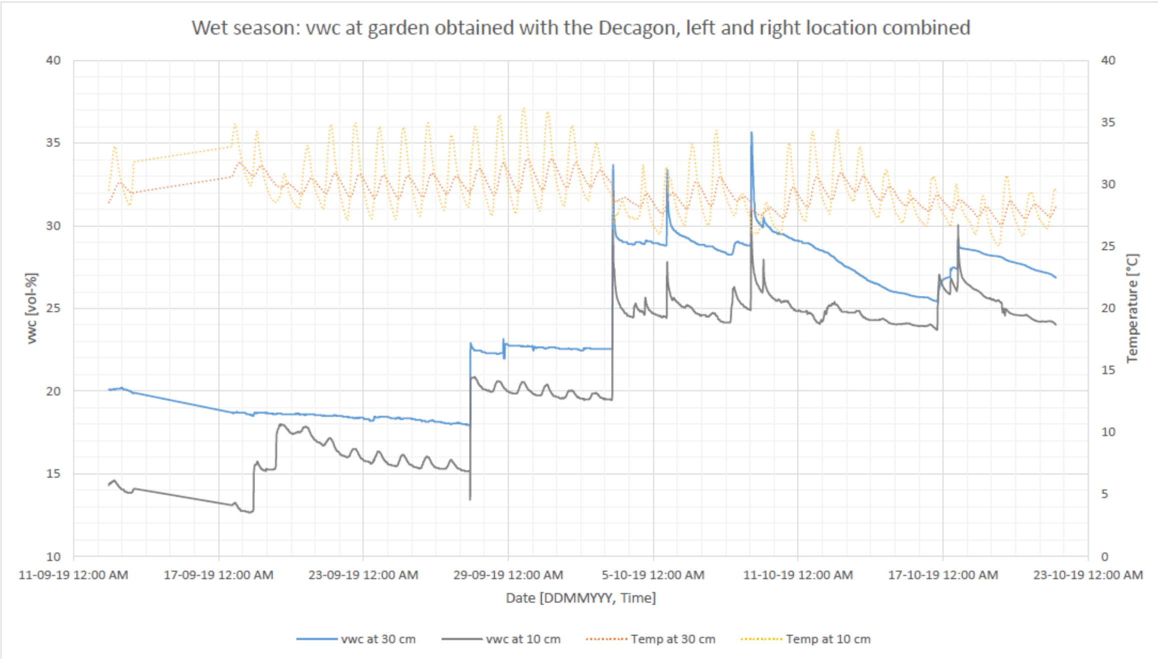


Figure 4.1: Values Decagon at 10 and 30 cm depth in the garden. Measuring period: 10/9/2019 - 23/10/2019 [Alma, 2019]

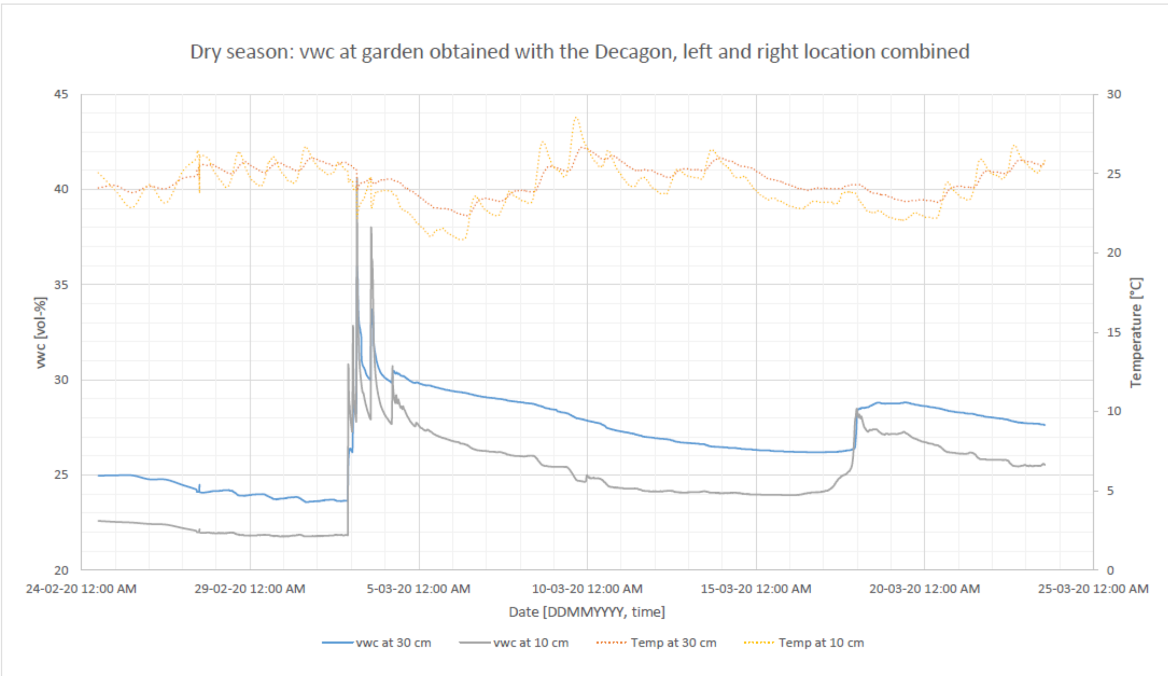


Figure 4.2: Values Decagon at 10 and 30 cm depth in the garden. Measuring period: 24/02/2020 - 23/03/2020

Despite the higher frequency of rain showers in the wet season, the average VWC of this dataset turned out lower than during the dry season. The average values of the VWC are namely 24.2% at 30 cm depth and 21.2% at 10 cm depth in the wet season and 27.3% at 30 cm depth and 25.1% at 10 cm depth in the dry season. The reason for this could be that the relative humidity in Hanoi is lower in Sep-Oct than in Feb-Mar as can be found in table 4.1. This lower relative humidity causes a higher evaporation rate [Urone and Hinrichs, 2019], hence more moist evaporates from the soil which consequently results in a lower VWC.

In Appendix C the uncombined results of the Decagon are given. In these graphs the results of the Decagon are divided into two similar graphs, each graph represents one measuring location in the garden, that is to say the left (figure C.5 and C.7) or right (fiure C.6 and C.8) location.

4.2. Spatial distribution

4.2.1. Weather conditions

Several weather conditions have been monitored during the research period of the spatial distribution (see table 3.1 for the dates of this measuring period). In Appendix C the values of the different weather conditions can be found, these are respectively the air temperature C.1, the relative humidity C.2 and the daily amount of precipitation C.3. In these graphs there is a clear view of stable weather conditions up until March 3rd. On this day and the day after, a lot of precipitation has been measured whereafter the air temperature has dropped immensely. This huge amount of precipitation subsequently caused a higher humidity on these days as well. In the graphs not only the daily average temperature and mean humidity are given, but also the temperature and humidity values from the exact time when the measurement were performed are given.

4.2.2. Volumetric water content ThetaProbe

In figure 4.3 a graphic representation of the soil moisture values obtained on the 3 different locations is given. The numerical values of these measurements are given in Appendix C table C.1. In this graph the measurements of the three locations are plotted in time and are represented by the dots. A line has been added between these dots, in order to get a more visual representation of the increase or decrease, thus the distribution, per location.

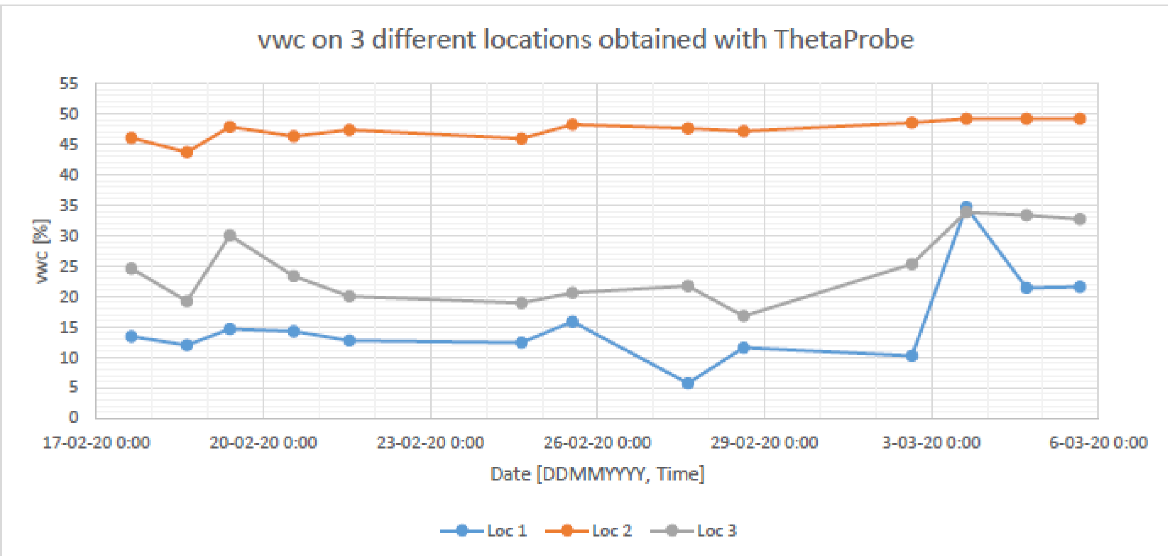


Figure 4.3: Results of the VWC obtained with the ThetaProbe at the 3 different locations

The graph shows that the soil at location 3 generally is less moist than that of location 2. This can be explained by the fact that the soil of location 3 is mainly made up of loam, while location 2 consists of mainly clay. In previous experiments it has been investigated that soil types consisting of fine soil texture have smaller pore sizes, but a higher porosity [Tarboton, 2003]. Subsequently soils with small pore sizes tend to have a higher water holding capacity [Voroney, 2018]. Loam grains are generally coarser than clay grains, therefore the soil at location 3 consists of larger pore sizes, but a lower porosity than location 2. Because of this larger pore size, the water infiltrates the soil faster and less water is being retained by the soil. This consequently causes a lower soil moisture. In other words: the infiltration rate of loam is higher than clay [Brouwer et al.].

Subsequently the graph shows that the VWC at location 1 is quite unsteady and fluctuates quite much between February 26th and March 3rd. Next to this temporal fluctuation, the daily measurements deviate quite much from each other. This can be seen in appendix C table C.2. The standard deviation of the daily group of measurements per location has been calculated and are shown in this table. A high std value means that the measurements differ a lot from each other. These high std values can support the fact that the soil in this garden has been artificially placed and that there is no uniform soil type present in this garden, a mixture of different soil types has been randomly filled this garden.

Another thing that stands out from the graph is that after the precipitation on March 3rd the soil moisture values of location 3 decreased very slowly, while at location 1 the VWC dropped quite rapidly the next day. This shows that the soil in location 3 has a higher capacity to hold water than location 1. On location 1 the water passes through the soil pores more rapidly and less water is being retained. This is most likely a result of the high porosity of the soil at location 1, because it consists of many different soils and many rocks are present as well.

The graph shows that location 2 has the most uniform VWC, as this line varies the least during the week. This is substantiated when looking at table C.2 in appendix C, because this shows a relatively small standard deviation for the daily measurements at location 2. This means that all VWC values at this location are close to each other and diverge not much from the average value. This could possibly be explained by the fact that this soil is almost always close to saturation. The saturated VWC of location 2 namely is reached on March 3rd, when a large rain shower occurred (figure C.3), because after this large amount of precipitation the water could not completely infiltrate into the ground. This resulted in a flooded area, where water was present above the ground level. A picture of this situation at location 2 can be found in appendix C figure C.4. Since the area was completely flooded, the VWC of this and the next couple of days could not be measured with the ThetaProbe, therefore an accurate assumption of this VWC had been made, making use of data from a previous research [Tarboton, 2003]. The soil type at this location has been assumed to be silty clay which results in a saturated moisture content of approximately 49.2%.

From the graph it can be observed that the gradient of the lines quite resemble each other. That is to say, that on many days the VWC on that same day of the three locations either all increases or all decreases. The only exception of this equal increase or decrease occurs on March 27th. On this day the VWC of location 1 decreases at a high rate, the VWC of location 2 decreases just a bit and the VWC of location 3 increases just a bit compared to the day before. This could be explained by the fact that there is no uniform soil type present at location 1, consequently different soil types result in different VWC. Thus unlogical changes may be present in the VWC distribution of this location.

4.3. Soil consolidation

The results of this experiment are graphically represented in the figures below, figure 4.4 is regarding the sand samples and figure 4.5 is regarding the loam samples. Both graphs show the VWC through time. In both these graphs it can be seen that two measurements per day have been done; one in the morning at 10:00 AM and one early in the evening at 18:00 PM. The oscillations in these graphs show a lower evaporation rate at night than during the day, this is a result of the lower temperature and the less sun hours at night. In table 4.2 the values of the different degrees of consolidation of the soil samples can be found. This is called the bulk density and is expressed in kg/m^3.

Sample	ρ_{bulk} $[kg/m^3]$
S1	1041.667
S2	1143.333
S3	1297.5
L1	374.1667
L2	453.333
L3	536.667

Table 4.2: Bulk densities of the different soil samples. S: sand, L:loam

Data regarding air temperature, relative humidity and sun hours have also been obtained from a nearby weather station [KNMI, 2020]. This data has been put into graphs and can be found in Appendix C figures C.9, C.10 and C.11. The graphs show that the weather has been very stable throughout the week and there has been no precipitation at all.

Both graphs show resemblance of an inverse exponential relationship between the VWC and the time. The VWC decreases at a higher rate in the first couple of days, whereafter the slope decreases and thus the rate of VWC decrease lowers. A possible reason for this inverse exponential shape is that the water present in the pores in the top layer of the soil samples will be reached more easily by the energy of the sun. This causes the moist in the top layer evaporate faster out of the soil. The more moist is evaporated, the deeper the residual moist is positioned in the sample. Consequently it takes more time to reach this deeper positioned water, which causes this water to evaporate at slower, and thus the evaporation rate slowly decreases. Additionally the moist will naturally sink deeper by the force of gravity, this also causes the water in the samples to sink and thus take longer to evaporate.

This experiment shows that a higher porosity results in a lower evaporation rate, because both in graph 4.4 and 4.5 the samples with the lowest degree of consolidation, respectively S1 and L1, have the lowest evaporation rate. A lower degree of consolidation causes a higher porosity. This conclusion can also be substantiated when comparing the two different soil types with one another. The VWC of loam decreases at a lower rate than sand, because the loam samples reach a VWC of zero somewhere on March 28th, while the sand samples already reach zero on March 27th. Loam generally has a higher porosity than loam [Tarboton, 2003], hence this experiment has proven that moist in soils with a lower bulk density, and thus a higher porosity, evaporates at a lower rate.

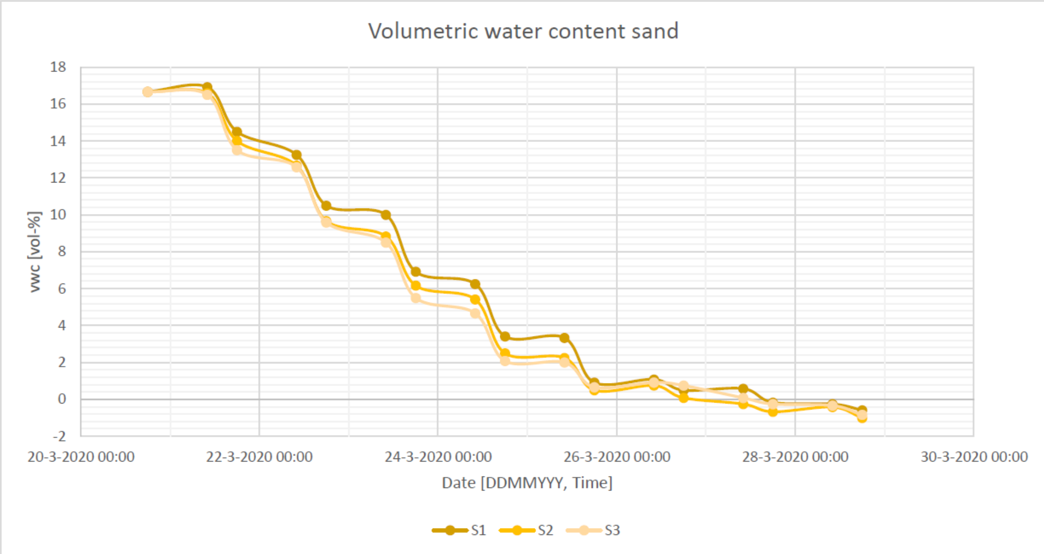


Figure 4.4: Volumetric water content in time of three sand samples

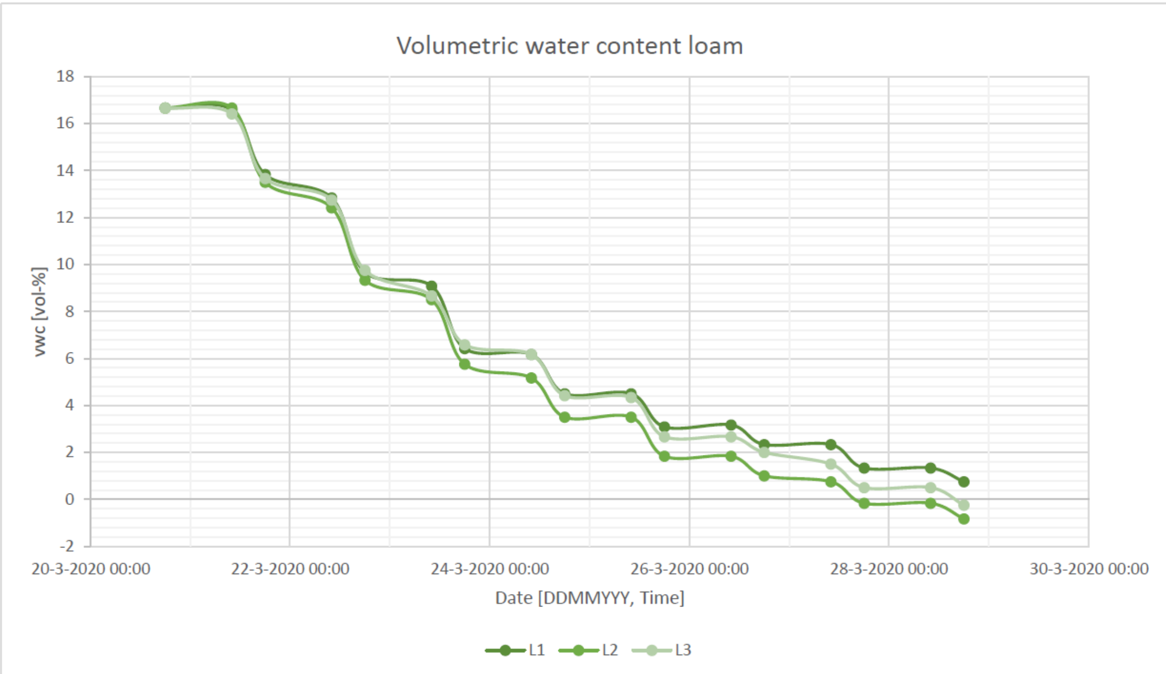


Figure 4.5: Volumetric water content in time of three loam samples

On March 25th several small cracks appeared on the soil surface of the soil samples 1.S1 and 2.S1. There were also smaller cracks present in sample 3.S2 but not as large as the ones on bot S1 samples. A picture of this is given below in figure 4.6. This might be a result of the temperature dropping below zero during that specific night. This may have caused the moist in the samples to freeze and thus the water to expand. When the samples were heated up again by the sun, soil from the top layer warmed up quickly and evaporated, while the soil at the lower soil might still have been frozen. This causes the soil at the surface to shrink, and consequently small cracks were formed.

Figure 4.6: Cracks on samples (from top left to bottom left) 1.S1, 2.S1 and 3. S2

4.4. Combined results

Looking at the dataset of the garden of HUNRE (figure 4.2, you can find one clear peak on March 3rd. On this day a large rain shower occurred (see Appendix C figure C.3), which has caused the VWC to increase. After this rainfall the VWC decreased, because the water present in the soil either evaporated into the air or infiltrated further into the ground to lower a level. A more detailed graph of this rainfall and the following couple of days are shown below in figure 4.7. This graph shows a comparable shape as the graphs of the soil consolidation experiment: the VWC decreases faster, directly after the rainfall and declines over time.

When looking at the VWC graph of the different locations after the rainfall from March 3rd in figure 4.3, the graph shows that the VWC at location 1 declines from 35% to 21%, while the VWC on the 3rd location declines much less, namely from 34% to 33%. The consolidation experiment showed that the VWC of the sand samples decrease at a higher rate than the loam samples. The combination of these results indicate that the soil at location 1 presumably consist of a higher percentage of sand than location 3.

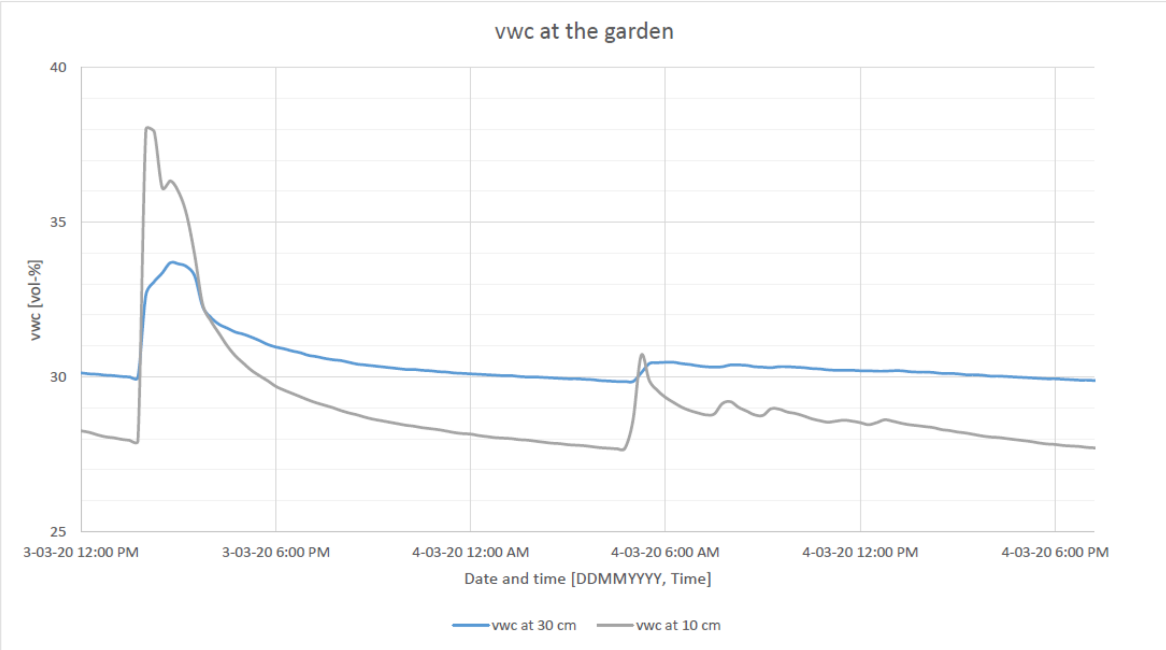


Figure 4.7: Volumetric Water Content in the garden obtained with the Decagon, time period: 3/3/2020 - 4/3/2020

5 Discussion

Seasonal distribution

To answer this part of the research the VWC has been monitored in the garden at HUNRE. However, this garden has not been created by natural processes, it was artificially created. The results indicate that the soil in this garden is nor uniform and thus consists of a mixture of different soil types, including rocks and gravel. Previous studies concerning soil moisture distribution in time at different depths show comparable results to the results from this research [X. Chen, 2004]. The results that the VWC oscillates more in the top layer and slowly stabilizes in deeper located layers as well as that higher VWC values are present in deeper located soils is in accordance to the results of both researches.

Spatial distribution

On February 19th the rate of VWC increase differs between the 3 locations. Namely, the VWC of both location 1 and 2 increases just a bit, while the VWC of location 3 increases much more compared to the day before. This is the only day during the whole research period on which the measurements had been done early in the morning at 9:30 AM. On every other day the VWC had been measured in the afternoon between 13:00 PM and 16:00 PM, see table C.1. There is a possibility that the owners of this small farm water their crops in the morning, which would explain the high VWC value of this day. This however cannot be sure, because there has not been an opportunity to ask the farmers. Another explanation of this sudden rise of VWC can be the high relative humidity that has been measured that day. Figure C.2 shows that there was a relative humidity of 85% on this day. This could also have caused the rise in VWC, because a higher humidity results in a lower evaporation rate, thus less moist could evaporate from the soil on this day compared to the other days.

The ThetaProbe was quite difficult to use in the garden, because a large amount of rocks and gravel was present in the top layer of the soil. This made it very hard to find suitable spots where the ThetaProbe could be inserted into the soil without causing damage to the device. Moreover, the gravel and rocks may have caused inaccurate soil moisture values. The space between the four measuring rods of the ThetaProbe is supposed to consist of soil only, that is to say that if rocks or air bubbles are present in this space, an incorrect soil moisture value is being displayed. With the many rocks present, this might have happened and could also explain the high standard deviation of the measurements at this garden.

The 3 locations that were used in this research have been chosen based on the different soil types. However, both on location 2 and 3 crops are being cultivated. Which meant that these soils most likely are being irrigated by the land owners, to create optimised circumstances for the crops to grow. Therefore a fourth location, which was not affected by humans, had been found to investigate as well. This location however was located a lot further away than the other locations and could only be reached by motorbike. Therefore it was scheduled that this location would be measured only once or twice a week. But because our time in Vietnam ended quite abruptly, we only had 2 measurements from this location when arriving back in The Netherlands. Therefore the choice had been made not to add these values in this research. However in Appendix C table C.3 these values can be found. A picture of this location is given in figure C.12 in Appendix C.

Consolidation experiment

In previous studies [An et al., 2018, Brutsaert, 2014] field experiments concerning the evaporation rate in soil samples consisting of different soil types and different grain sizes have been performed. Accordingly to the results of this current research, in these studies a higher evaporation rate has been measured at the sand samples compared to loam or clay samples. This corresponds to the findings of this research, which has shown that the VWC of the sand samples decreases at a higher rate than the loam samples.

Additionally to the field experiment, Brutsaert's study looks into a mathematical formulation for the evaporation of moist from the soil. This equation shows that the evaporation is inverse exponentially related to the time and VWC. This corresponds to the findings of this research, which shows an equal relation of the VWC decrease in time.

As stated in Chapter 4, there was no access to a suitable drying oven, in which the twelve soil samples could have been dried properly prior to the experiment. This would have resulted in more accurate VWC calculations, that would not drop below zero. However, the soil that was used was dried in the sun for a day, to reduce the amount of water as much as possible. Additionally a larger amount of water could have been used for this experiment, to get more distinct results.

Recommendation

For future studies it would be of interest to continue measuring the soil moisture on locations 2 and 3 as well as the fourth location in order for the dataset to grow wider and become more complete. Gaining more information about the fourth measuring location will create a better understanding in how a soil moisture behaves when it is not affected by any human activity.

Subsequently the seasonal distribution could be complemented, because in this research the two seasonal datasets consist of measurements from 1 month. If these datasets are being expanded, even just to 2 or 3 months, a better understanding in the seasonal distribution of the soil moisture can be made. Subsequently it would be of interest to measure seasonal distribution in different soil types as well, to create the opportunity to compare large datasets concerning different soil types with each other. To create more knowledge of how the soil moisture varies through the year as well as between different types.

6
Conclusion

The seasonal distribution of the soil moisture on the campus of HUNRE has been investigated. A clear difference between the wet and dry seasons has been detected. This difference is mainly concerning the spread of VWC over time. In the wet season there are large fluctuations of the VWC, while during the dry season the VWC barely fluctuates. The average VWC in the wet season (24.2%) is lower than that of the dry season (27.3%) and in the wet season a higher soil temperature has been monitored, in comparison with the dry season.

Regarding the spatial distribution, it can be concluded that the average VWC is mainly influenced by the soil type and soil texture. The average VWC of all 3 locations are respectively 15.418 %, 47.409 % and 24.636 %, thus the soil moisture is the lowest on campus at the garden and highest on location 2, which is the agricultural field. The gradient of the VWC in time of the three locations is quite similar. On each day the VWC of the three locations either all increase in value or decrease compared to the day before, with just a few exceptions. The average VWC value of location 2 indicates that the soil at this location mainly consists of clay and was throughout the research constantly close to saturation. Location 1 and 3 showed the least stable values, with high standard deviations. For location 1 the conclusion can be made that there is no uniform soil type present in the garden, but a mixture of different soil types are present. On location 3 this could be explained by an irrigation schedule.

The decrease of VWC has an inverse exponential relation with time. At first the VWC decreases at a high rate. In time, this rate decreases, and thus the moist evaporates at a lower rate. Additionally the experiment showed that moist in soils with a higher porosity evaporate at a lower rate, thus soils with a low bulk density evaporate at a low rate. Lastly the results have shown that soils containing bigger grain sizes evaporate at a higher rate than soils containing smaller grain size.

Combining this observation with the different values of the different locations the conclusion can be made that the soil on location 1 consists of soil with larger grain sizes, most likely sand, than location 3.

Bibliography

Regional climate characteristics in hanoi. Technical report, National Centre for Hydro-Meteorological Forcasting, 2019.

S. Adla. Laboratory calibration and performance evaluation of low-cost capacitive and very low-cost resistive soil moisture sensors. *Sensors*, Feb. 2020. ISSN 1424-8220.

J. Alma. *Open Air Lab HUNRE*. Bachelor thesis, University of Technology Delft, Dec. 2019.

N. An, C.-S. Tang, X.-P. Gong, B. Shi, and H. Inyang. Effects of soil characteristics on moisture evaporation. *Engineering Geology*, 239:126–135, 2018.

J. Bilskie. Soil water status: content and potential. techreport 2S-I, Campbell Scientific, Inc., 2001.

C. Brouwer, A. Goffeau, and M. Heibloem. *Irrigation Water Management: Training Manual No. 1 - Introduction to Irrigation*. FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.

W. Brutsaert. Daily evaporation from drying soil: Universal parameterizationwith similarity. *Water Resources Research*, 50, 2014.

D. R. Cobos. *Why does my soil moisture sensor read negative? Improving accuracy of dielectric soil moisture sensors*. Decagon Devices and Washington State Universit.

I. Decagon Devices. *5TM Water Content and Temperature Sensors*, July 2017.

D.-T. DevicesLtd. *User Manual for the ML3 ThetaProbe*. Delta-T DevicesLtd, Jan. 2017.

J. Hays. *Land, Geography, Weather and Climate of Vietnam*, May 2014.

KNMI. Uurgegevens van het weer in nederland - download. Technical report, Koninklijk Nederlandse Meteorologisch Instituut, 2020.

N. Koliolios. *Investigating the use of C-band phase closure data to produce soil moisture maps*. mathesis, Delft University of Technology, Jan. 2020.

J. E. Lawrence and G. M. Hornberger. Soil moisture variability across climate zones. *Geophysical Research Letters*, 34, Oct. 2007.

A. Lucio. *How It Works: The Karl Fischer Titration*, July 2013.

N. Mattikalli and E. Engman. *Remote Sensing in Hydrology and Water Management*, chapter 5, pages 65–82. Heidelberg, 01 2000. ISBN 978-3-642-64036-0. doi: 10.1007/978-3-642-59583-7_4.

D. Tarboton. *Rainfall-Runoff Processes*. Utah State University, 2003.

P. P. Urone and R. Hinrichs. Humidity, evaporation, and boiling. Technical report, LibreTexts, 2019.

P. Voroney. *Soils for Horse Pasture Management*, chapter chapter 4, page 75. Academic Press, 2018.

Q. H. X. Chen. Groundwater influences on soil moisture and surface evaporation. *Journal of Hyrdology*, 297, 2004.

A

Appendix: Locations

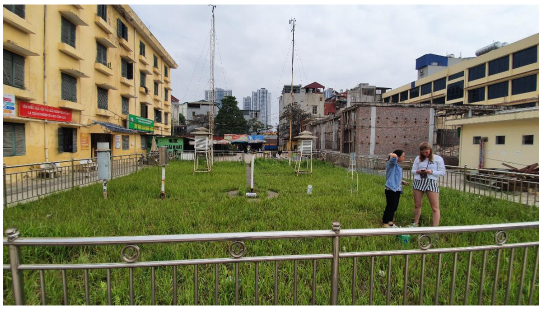


Figure A.1: Location 1 overview

Figure A.2: Location 1 soil detail

Figure A.3: Location 2 overview

Figure A.4: Location 2 soil detail

Figure A.5: Location 3 overview

Figure A.6: Location 3 soil detail

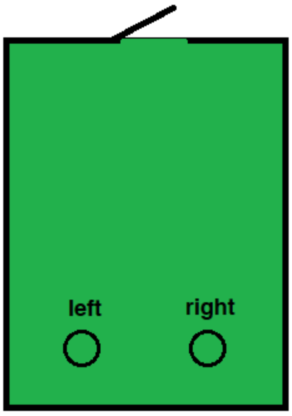


Figure A.7: Positions of Decagon 5 sensors in the HUNRE garden

B
Appendix: Methodology

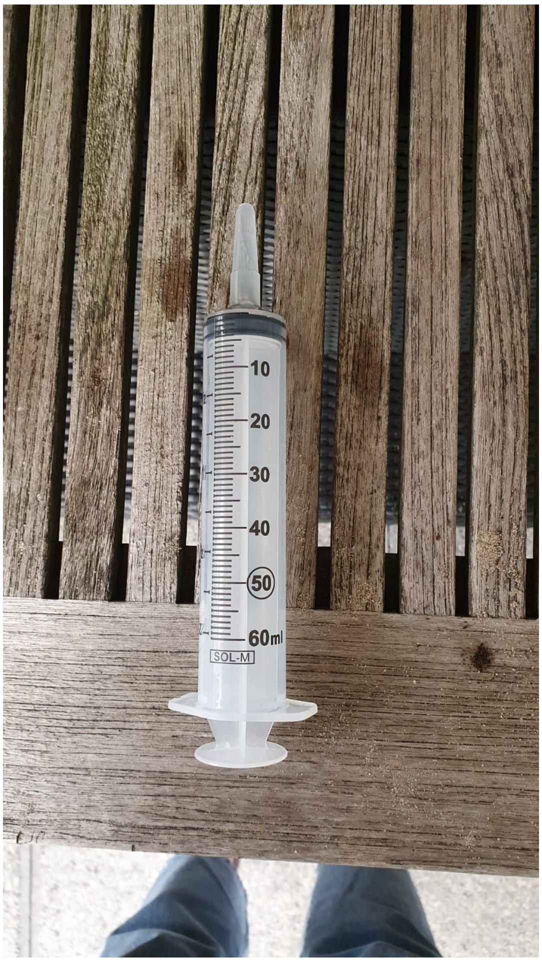


Figure B.1: Syringe used for adding the 100 ml water to the soil samlpes

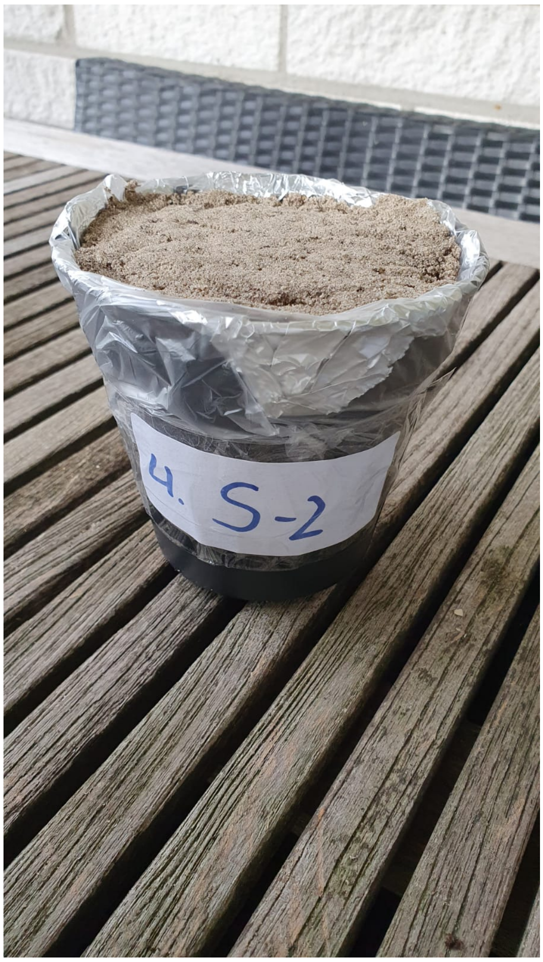


Figure B.2: One of the soil samples (4. S2), ready to be set up in the garden

C
Appendix: Results

Date	Time	Loc 1	Loc 2	Loc 3
17-2-2020	15:00	13.4	46.05	24.6
18-2-2020	15:00	11.96666667	43.7	19.2
19-2-2020	09:30	14.625	47.85	30
20-2-2020	13:00	14.25	46.3	23.35
21-2-2020	13:04	12.75	47.35	20
24-2-2020	15:15	12.4	45.95	18.9
25-2-2020	13:15	15.86	48.26	20.62
27-2-2020	15:00	5.725	47.6	21.7
28-2-2020	15:00	11.58	47.14	16.76
2-3-2020	15:30	10.24	48.52	
3-3-2020	15:00	34.675	49.2*	33.82
4-3-2020	17:00	21.4	49.2*	33.34
5-3-2020	16:00	21.56	49.2*	32.69

Table C.1: Soil moisture contents[%] of the 3 different locations obtained with the ThetaProbe, *assumption of saturated soil moisture content Tarboton [2003]

Date	Loc 1	Loc 2	Loc 3
17-2-2020	3.315116891	0.353553391	0.989949494
18-2-2020	3.247049943	1.272792206	1.838477631
19-2-2020	4.035983978	0.777817459	3.252691193
20-2-2020	4.76200238	1.555634919	5.586143571
21-2-2020	3.496188401	0.212132034	6.505382387
24-2-2020	3.112341027	0.353553391	4.101219331
25-2-2020	5.245664877	3.979698481	5.181891547
27-2-2020	4.944357053	2.704625667	4.974937186
28-2-2020	5.538772427	1.747283606	1.357571361
2-3-2020	2.055966926	1.80748444	
3-3-2020	3.463500156	0	3.624499966
4-3-2020	4.055490106	0	3.323853186
5-3-2020	10.08266	0	3.739385

Table C.2: Standard deviation of the measurements per location

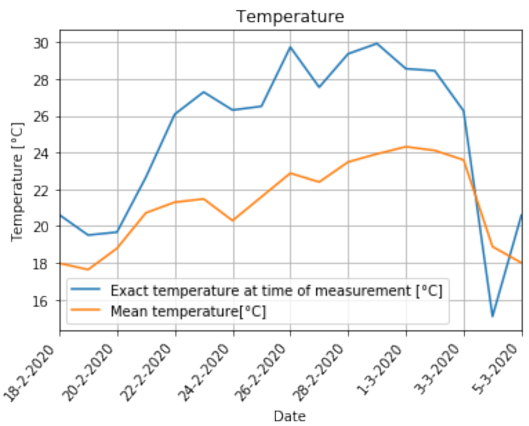


Figure C.1: Temperature: daily average and exact at time of measurement **?**

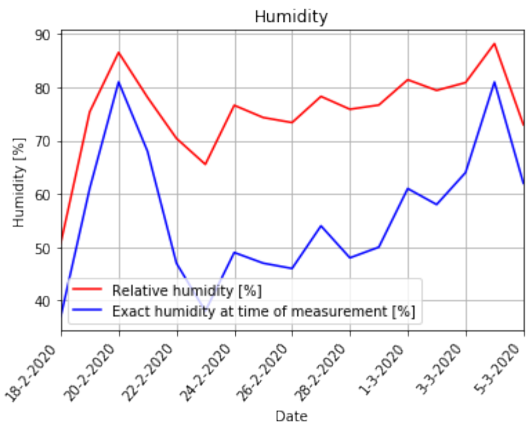


Figure C.2: Humidity: daily relative and exact at time of measurement **?**

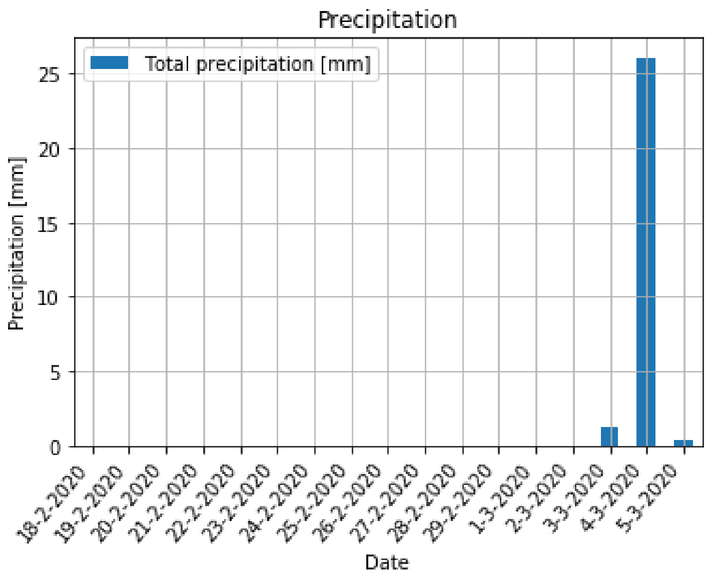


Figure C.3: Precipitation **?**

Figure C.4: location 2: saturated soil after precipitation of March 3rd

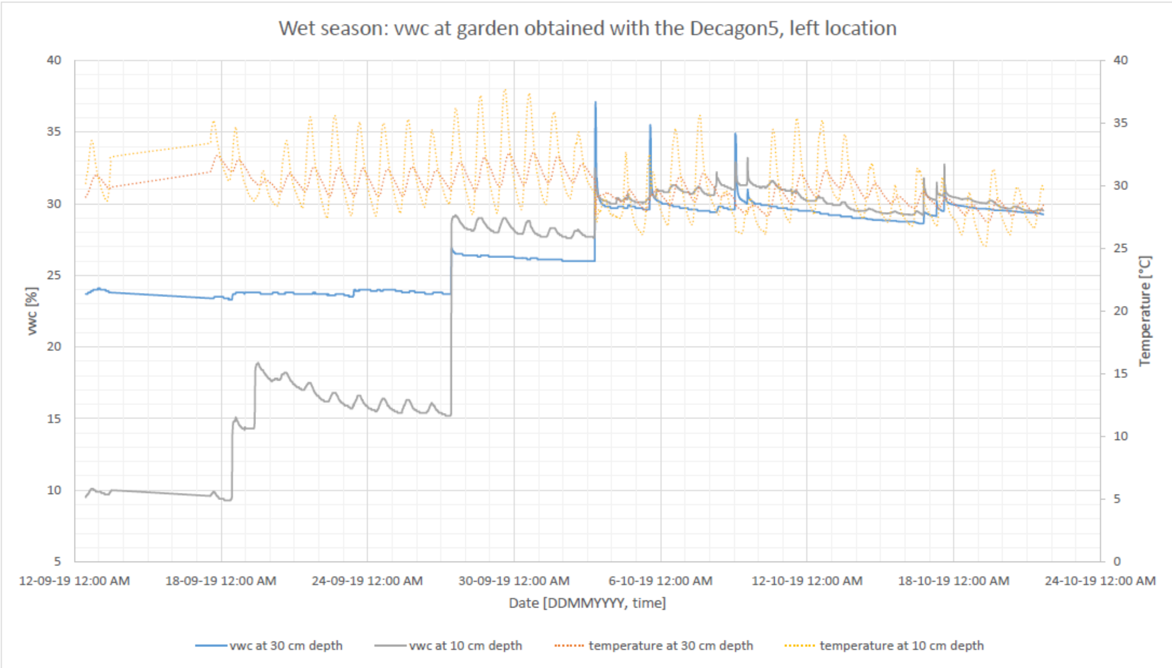


Figure C.5: Values Decagon at 10 and 30 cm depth on the left location in the garden. Measuring period: 10/9/2019-14/10/2019 Alma [2019]

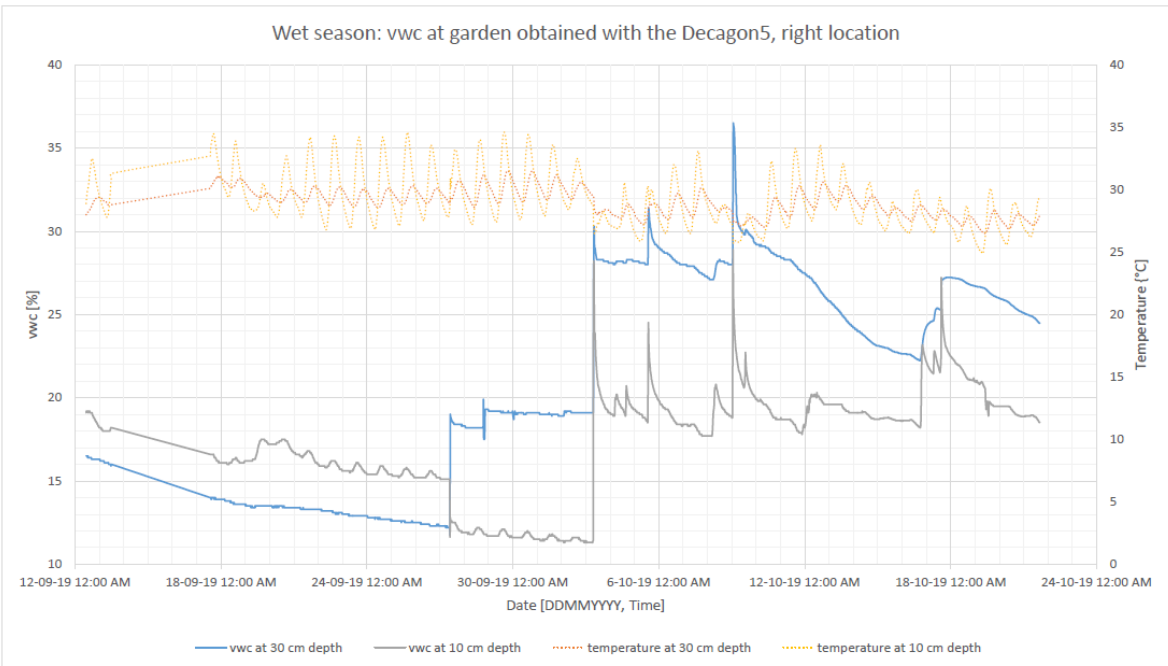


Figure C.6: Values Decagon at 10 and 30 cm depth on the right location in the garden. Measuring period: 10/9/2019-14/10/2019 Alma [2019]

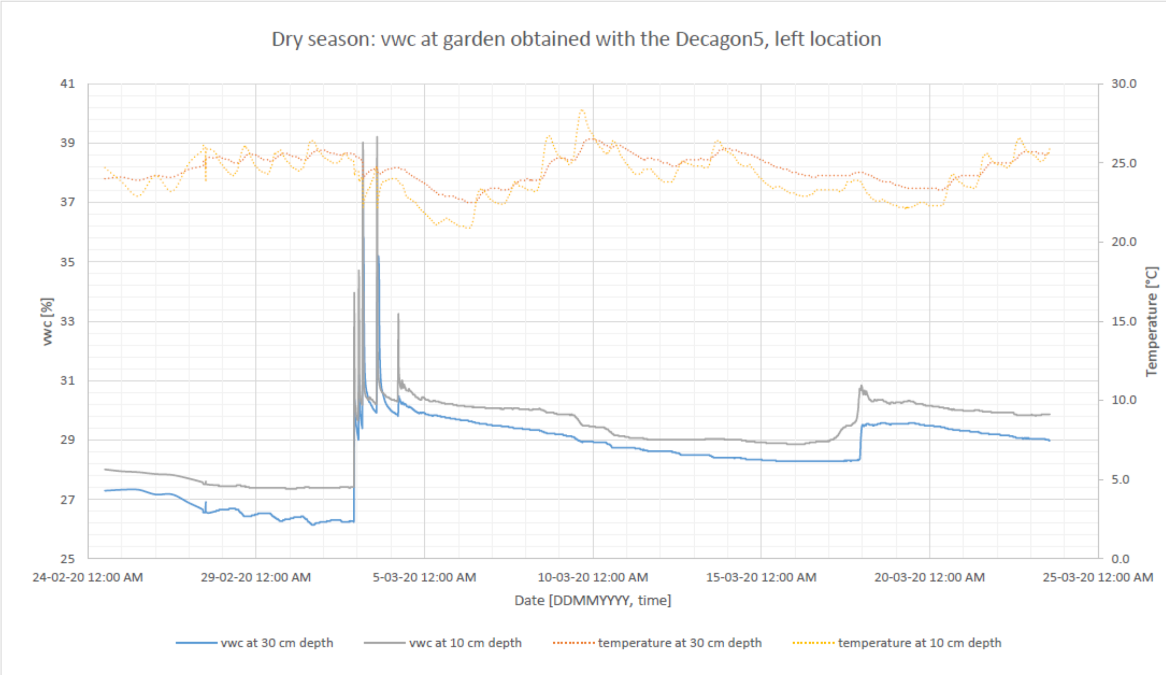


Figure C.7: Values Decagon at 10 and 30 cm depth on the left location in the garden. Measuring period: 24/02/2020-23/03/2020

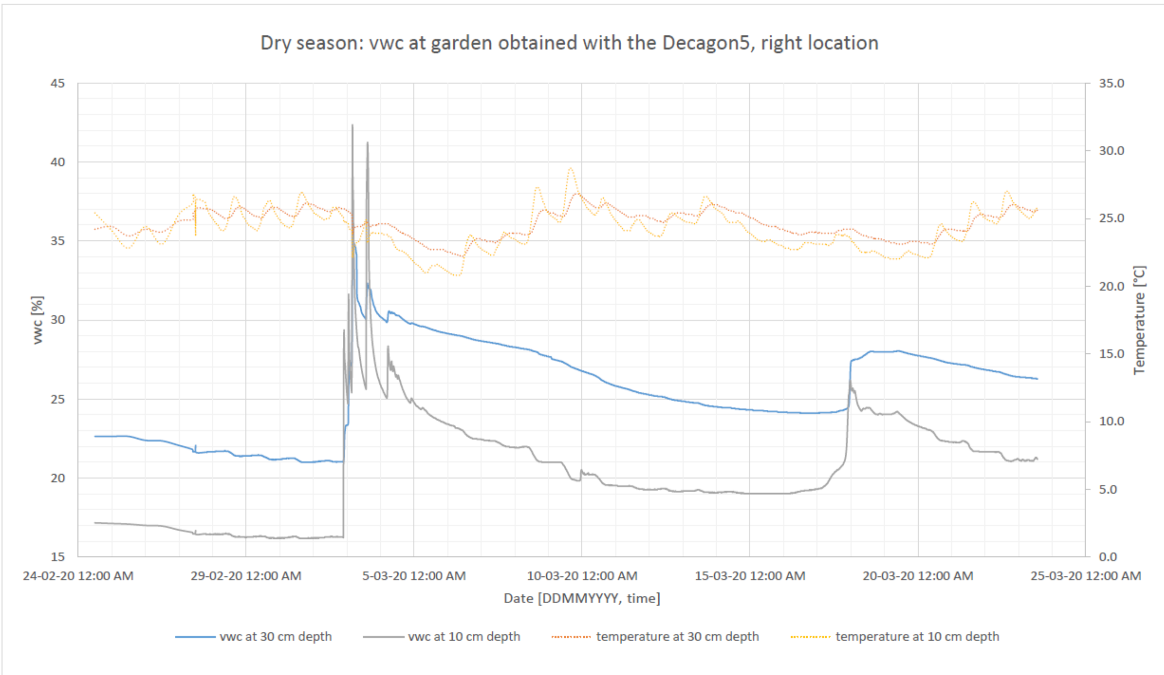


Figure C.8: Values Decagon at 10 and 30 cm depth on the right location in the garden. Measuring period: 24/02/2020-23/03/2020

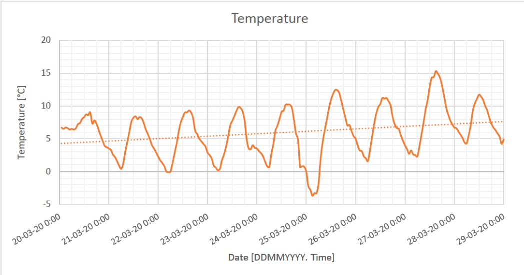


Figure C.9: Temperature in Bilthoven KNMI [2020]

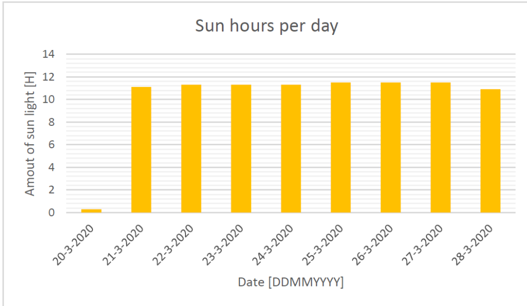


Figure C.10: Daily sun hours in Bilthoven KNMI [2020]

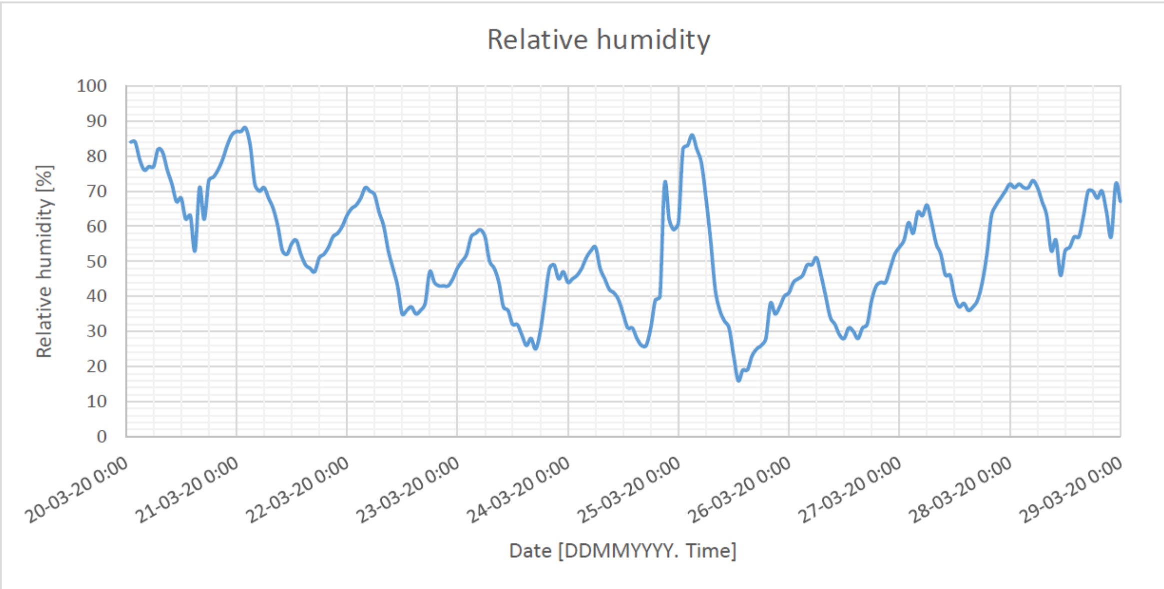


Figure C.11: Relative humidity in BilthovenKNMI [2020]

Date	Loc 4
24-4-2020	26.975
3-3-2020	43.5

Table C.3: Soil moisture on location 4 [%]

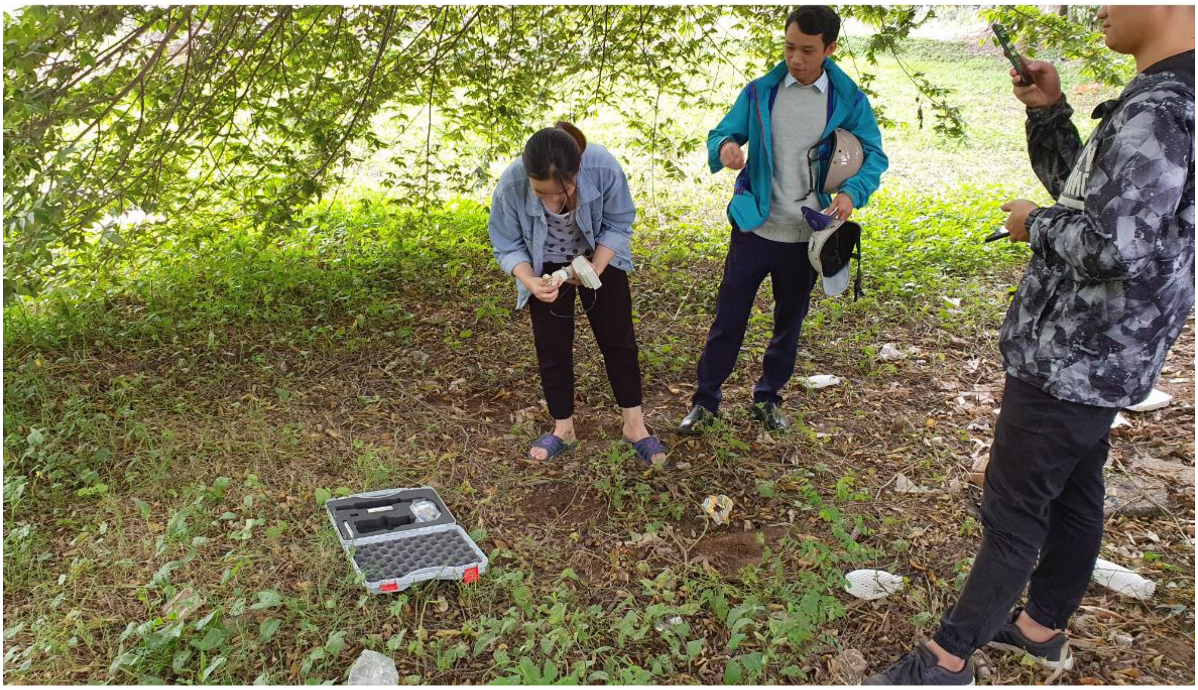


Figure C.12: Location 4 overview

D

Volumetric water content background

D.1. Soil moisture

Soil moisture or volumetric water content (VWC) is known as the fluid present in the soil pores above the ground water level. It depends on multiple factors, such as rainfall, humidity and temperature. The soil moisture or volumetric water content (θ) equals the ratio of the volume of the water to the volume of the wet soil:

$$\theta = \frac{V_w}{V_{wet}}$$

Where V_w represents the volume of the water and V_{wet} represents the volume of the wet soil. This last parameter equals the summation of the volume of the solid particles, water and air. (V_s, V_w, V_a)

$$V_{wet} = V_s + V_w + V_a$$

Every soil has a degree of saturation S_w which is a dimensionless value that lies between 0 and 1. The degree of saturation equals the ratio between the VWC and the porosity (ϕ).

$$S_w = \frac{\theta}{\phi}$$

With,

$$\phi = \frac{V_v}{V}$$

Where V_v represents the volumetric void or pore space in the soil.

D.2. Different VWC measuring methods

The VWC can be measured with use of multiple different measuring methods. Namely direct and indirect methods.

Direct method

One method to measure the VWC is the direct method and sometimes is called Loss on Drying (LOD), because it makes use of a drying oven. This method consists of obtaining a soil sample and putting this into a container of known volume. The mass of this moist sample has to be written down before putting the sample in a drying oven. After drying the sample at 105 °C for 24 hours the dry soil can be weighed again. With use of the following formula the VWC can be calculated directly.Cobos

$$\theta = \frac{M_{moist} - M_{dry}}{V_{sample}}$$

Laboratory methods

There are multiple laboratory methods which can obtain the soil moisture of a soil sample. One example of a laboratory method is the Karl Fischer titration (KFT). This method remains the primary method of water content determination worldwide used by Government, academia and industry. [Lucio, 2013] This method calculates the water content based on the iodine in the Karl Fischer titer and the amount of KF reagent consumed. Many other laboratory methods are available.

Indirect method

This method includes the use of soil moisture sensors and can be called the geophysical method. There are multiple different sensors that can be used for this method to calculate the water content. In contrast to the LOD method, this method is an indirect method, because it uses other soil properties and relates them to the property of interest by calibration. Some of the different measuring techniques that these sensors use in order to calculate the water content are: [Adla, 2020]

- Capacitance based: measures the VWC by electrodes that operates as a capacitor while the surrounding soil functions as the charge storing dielectric medium.
- Resistance based: measures the VWC by measuring the effective conductivity of the soil.
- Impedance based: measures the VWC by responding to the changes in its apparent dielectric constant.

Satellite remote sensing method

The theoretical basis for measuring vegetation water with microwave techniques is based on the large contrast between the dielectric properties of liquid water and dry vegetation. The large dielectric constant of water is the result of the water molecule's alignment of the electric dipole in response to an applied electric magnetic field. [Mattikalli and Engman, 2000]