University College of Southeast Norway
Faculty of Art and Science
–
Master's Thesis
Study programme: Environmental science
Spring 2017

Mahsa Atefeh

Summer season soil temperature conditions, and soil moisture properties on the extensive green roofs in Oslo, Norway

University College of Southeast Norway
Faculty of Art and Science
Institute of Environmental and Health Studies
PO Box 235
NO-3603 Kongsberg, Norway

http://www.usn.no

© 2016 Mahsa Atefeh

This thesis is worth 60 study points

Abstract

Nowadays, green roofs have been investigated more and more in order to improve the quality of municipal environment particularly to reduce the urban heat island effect and storm water runoff. Soil temperature and soil moisture are therefore two key factors in this respect. They should also be considered as important elements for plant distribution and community composition on extensive green roofs.

The aim of this study is to investigate summer season soil temperature conditions, and soil moisture properties on extensive green roofs in Oslo. The study has been performed on 37 plots on 17 extensive green roofs. Soil temperatures were recorded by data loggers 2cm under the soil surface, four times during a day. Soil moisture was determined through dry and moist weight, and porosity after extracted by PVC cylinders. The relationship between soil temperature parameters and soil moisture factors with vegetation cover, also between soil temperature and soil moisture were tested by Principle Component Analyses, regression and correlation analyses, and box plot.

The statistical results indicate that vegetation abundance is highly negatively correlated with soil temperature variables and positively correlated with saturated soil moisture and field capacity porosity. The results of the soil temperature measurements demonstrate that apart from two roofs, soil temperatures have been in an optimum range. The analyses also proved that soil temperatures will be increased or decreased with soil moisture content, demonstrating the interaction of soil temperature and soil water availability.

Contents

List of tables

List of figures

List of appendix

Foreword

Firstly, I would like to express my deepest gratitude to my supervisor Stefanie Reinhardt for the continuous support of my thesis study, for her patience, motivation, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. Furthermore, I am especially indebted to my second supervisor Harald Klempe for his support and useful advises who helped me to do a lot of research and I came to know about so many new things.

I take this opportunity to express my appreciation to all of the department faculty members of University College of Southeast Norway, for their help. Special thanks to Arvid Odland and Jan Heggenes for their guidance and support, specially their help in statistical analyses. I would also like to thank Tom Aage Aarnes for his help with soil moisture analyses.

Furthermore, thanks to all the owners of green roofs who helped me to study on their buildings.

Last but not least, I want to express my very profound gratitude to my ever-loving parents, Manijeh and Habib and my dear sister Mahshid, for providing me with unfailing support and continuous encouragement throughout my years of study. This accomplishment would not have been possible without them.

Mahsa Atefeh

Bø, Norway / 15 May 2017

1 Introduction

1.1 Benefits of Green roofs in cities

The increasing rate of urbanization has led to more area covered by construction, and a corresponding decrease in open-green spaces in many cities (Jim and Tsang, 2011). Nowadays, planted roofs are one of the best ways to increase the green areas in cities (Teemusk and Mander, 2010; Sutton, 2015). These roofs are covered by different kind of vegetation. All green roofs are built with different layers. These layers consisted of a root-barrier, a drainage, a filter membrane, a growing medium and a layer of vegetation (Bianchini and Hewage, 2012; Berndtsson, 2010; Liu and Baskaran, 2005).

Green roofs, can be categorised in two major types, extensive and intensive roofs (Berndtsson, 2010). There is also a third type of green roof, semi-intensive which is a mixture of both extensive and intensive roofs (Yang et al. 2008).

Extensive green roofs consist of a thin layer of soil (generally < 15cm) which is planted with smaller succulent plants such as sedums. This kind of green roof does not need high level maintenance. They have been designed to be virtually self-generating. Intensive green roofs unlikely are relatively heavy, with deep layer of soil in order to keep a variety of plants such as trees and shrubs. This kind of green roofs require a high level of maintenance and irrigation (Liu and Baskaran, 2005; Bianchini and Hewage, 2012; Molineux et al., 2009).

Researches have indicated that installations of green roofs have been promoted worldwide, especially in European countries and United States. Scientific studies are often focused on extensive green roofs because they are easier to compare and more abundant.

Li and Yeung, Li and Yeung (2014) indicate that extensive green roofs are more targeted by researchers because not only they are less costly than intensive green roofs, but also they add less weight to buildings, compared with intensive green roofs. They also believe that extensive green roofs face harsh climate such as high solar radiation, low precipitation and shallow growing substrate.

Green roofs can reduce and delay storm water runoff (Bengtsson, 2002), decrease energy conservation for heating and cooling, mitigate of urban heat island (Akbari et al.

2001) and reduce of noise and air pollution (Van Renterghem and Botteldooren, 2008; Yang et al. 2008; Getter et al. 2009). Aesthetic value and ecological benefit could be considered as the other reasons for designing green roofs in construction projects (Brenneisen, 2003). In green roof systems, basically the vegetation and substrate layers contribute to decrease storm water runoff and peak flows by retaining part of the rainfall and distributing over a long time period (Mentens et al. 2006). Teemusk and Mander (2007) show that extensive green roof can delay the runoff. Establishing green roofs will provide insulation which lead to energy saving (Dunnett et al. 2004) and urban heat island mitigation. If green roofs were covered with different kind of vegetation, the temperature inside the building can be reduced by 3 to 4°C (Peck et al. 1999). Rosenzweig, Gaffin, and Parshall (2006) suggested that by covering half of the buildings in New York with green roofs, the temperature of the city and its surrounding will be different and maybe reduced by around 0.8 °C.

From many years ago, making the isolation has been considered as the most important aim of using green roof in Nordic countries. In Norway, surface of roofs were covered with soil as insulation and then stabilized with vegetation consisting of different plant species (Getter, 2006). In Germany, modern green roofs were introduced in late 1970s (Köhler, 2003). Nowadays in Germany more than 10% of the houses are covered by green roofs. In fact, this country has been considered as leader in this industry (Köhler, 2006). Research there has led to the improvement of the modern green roofs and green roof guidelines (FLL, 2002).

1.2 The importance of soil temperature and moisture for plants

Plant physiological processes such as root growth, nutrient, water uptake and decomposition of organic matter, are fundamentally influenced by soil temperature and moisture. The impact of high soil temperature differs among plants and also genotypes within plant species (Kaspar and Bland, 1992). Franklin and Wigge (2013) pointed out that high temperature will affect phycological and yield processes of plants, depending on the rate of temperature increase, its intensity, high-temperature duration, and the step of plant production development. Generally, the total average temperature for root plant growth are between 4 °C to 30 °C. Higher than this temperature, will reduce root physiological process. (Sutton, 2015; Xu and Huang, 2000). Cooper (1973) found that root diameter will be decreased when temperature increased. Al-Ani and Hay (1983), however, observed soil temperature from 5 to 25°C had only weak influence on diameters of individual root axes. In addition in soils with low temperatures, biological activity will decline. For soil temperatures lower than 5-10 °C, certain process of plants will be slowed down (Rabenhorst, 2005). It has been also found that low temperature could be harmful for plants by reducing their defences (Franklin and Wigge, 2013).

There are many variables which control soil temperature, including meteorological factors such as air temperature, soil physical properties such as albedo of surface, water content and texture, topographical parameters such as altitude, slope and aspect, and vegetation cover (Liu and Luo, 2011).

Soil temperature is more effective factor to reflect microclimatic temperature in alpine vegetation than air temperature (Scherrer et al. 2011) where law stature plants are dominating species and decoupled from air temperature (Körner, 2003). As plants in extensive green roofs are low stature as well, this finding can be expanded for extensive green roofs.

Some studies have been performed in order to measure the soil temperature variables in some particular vegetation such as alpine vegetation. Reinhardt and Odland (2012) had a study about soil temperature variation in mountain plant communities in Southern Norway. These results show that soil temperature is considered as a major parameter which particularly determine the distribution and composition of plants at a high altitude. They, have also emphasised that there is a significant difference between and within group of alpine plant species during the study of one year. In fact, variations in temperature variable lead to plant stress which can have a direct effect on plant growth. Particularly, reproductive process and pollination of plant could be harmfully affected by disposal of plants to higher and lower than their threshold temperature (Klein et al. 2007; Sacks and Kucharik, 2011; Hatfield and Prueger, 2015).
Due to lack of previous research on soil temperature specifically on green roofs, literature review in this respect were not accessible adequately.

Soil moisture should be considered as another important factor which determines many chemical and biological process in the soil such as mineralization rates and decomposition of organic matter (Elberling and Brandt, 2003), water and nutrient uptake (Weih and Karlsson, 2002) and can control plant distribution and community composition related plant growth processes (Domisch et al. 2002). The moisture content behaviour is controlled by climatic condition, plant species and substrate properties. Porosity as a key attribute of soil structure has a large effect on moisture condition. Size and diameter of pores determine how much water will be held inside the soil, available for the plants. If the size of micropores would be less than 0.2 µm diameter, water will be remained in holes tightly by a high under pressure. Hence, there is not any available water for absorption by vegetation. The mesopores at 0.2-60 µm diameter keep water at medium pressure, which plants can uptake water by their roots, since water is available (AW). The macropores which are more than 60 µm diameter holds water loosely by a low suction. So, water drains out easily due to gravity and air can penetrate the pore spaces. So, macropores define air capacity (AC) (Figure 1). Albedo is also included as an effective factor of substrate characteristics which is associated with soil moisture status. Albedo in dark wet soil is lower than dry soil (Bonan, 1989). Simply put, when albedo is low, the amount of reflected energy by the surface will be decreased. Therefore, majority of the energy will be absorbed by the soil and its temperature will be increased which eventually will be led to reduction of the soil moisture.
Moreover, soil thermal property is largely influenced by its water content. Water increases the soil heat capacity, thermal conductivity, heat flow to deeper layers and storing heat, on one hand, and decrease the fluctuation of temperature in the soil, on the other hand.

Presence of vegetation on roofs can reduce the amount of moisture through transpiration. It also has influence on retention capacity and performance of a green roof (Berretta et al. 2014).

Researches on the effects of soil moisture provide some valuable information about water management in order to improve the ecological functions of green roofs. Previous studies have shown that sedum species can tolerate extreme temperature and low water. However, the typical green roof with shallower substrates should be watered at least every 28 days in order to have a convenient growth (VanWoert et al. 2005). They also found that, green roofs with 2-cm media depth, has to be irrigated at least once in every 14 days in order to growth plants.

In the present study, there are some important concepts which will be explained briefly in the following (Jim and Peng, 2012).

- The Field Capacity (FC) defines the upper limit of available water after drainage by gravitation.
- The Wilting Point (WP) denotes the lower limit of available water. It should be noted that for the water availability of lower than this point, plant will be wilted.
- Available Water (AW) is the amount of water held by the soil in order to use for plant growth.

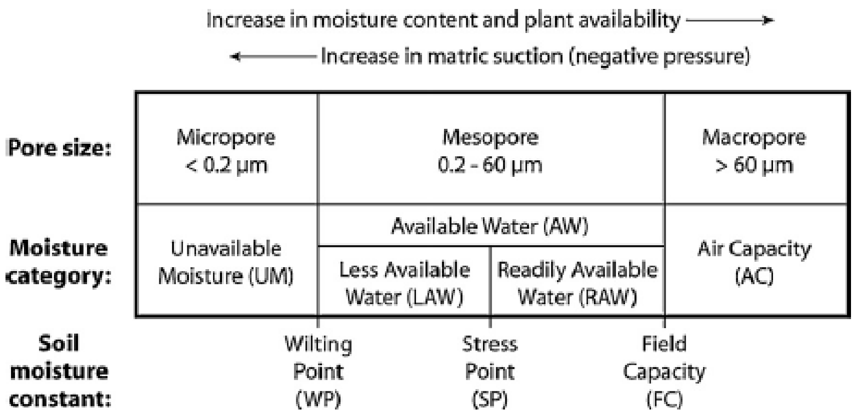


Figure 1. The soil moisture concepts in terms of soil pore size, moisture category and soil moisture constant (Jim and Peng, 2012).

1.3 Green Roofs as Hydrological Systems

Water that descend on a green roof has a hydrological cycle. Soil gains water from rain fall and irrigation. Some amounts of water will be held within plants, in substrate and different drainage layers. The remained part will be lost as evaporation of the substrate, transpiration through vegetation and run off. The most important highlight which should be considered here, is a complex interaction between different components of green roof and physical environment in order to manage the amount of water in stocks and the flow of that between the system and out of that (Berndtsson, 2010). The amount of water which has been absorbed through green roof vegetation compared to the substrate, is not considerable. Differences in plant architecture should not be neglected as an effective parameter on water capture. For example, green roofs consisting of grass, forbs and different types of vegetation can retain more water than green roofs covered by sedum solely (Lundholm et al. 2010).

Anderson, Lambrinos, and Schroll (2010) have estimated that mosses have the ability of holding water as much as around 8 to 10 times of their dried weight. Furthermore, sedum and other succulent species take up 80-90 percent water of their weight in an appropriate environment (Berghage et al. 2007).

1.4 Objective

The objective of this study is to investigate summer season soil temperature conditions, and soil water properties for seventeen extensive green roofs in Oslo. The following questions will be answered:

1. How are summer season soil temperature conditions on studied extensive green roofs?
2. Is there any significant relationship between soil temperature parameters and vegetation groups on studied extensive green roofs?
3. How is the relationship between soil moisture properties and vegetation cover?

2 Material and Methods

The study was conducted in Oslo city in Norway during summer 2016. The data for this project are collected from four main sources:

1. Fieldwork,
2. Laboratory work,
3. Statistical analyses,
4. Earlier master thesis studied on the same location by Bakhtina, 2015.

2.1 Study area

This study was started in June 2016 on seventeen extensive green roofs. The region study of this thesis was located in Oslo city and Bærum municipality. Figure 2 shows the location of the seventeen studied extensive green roofs.

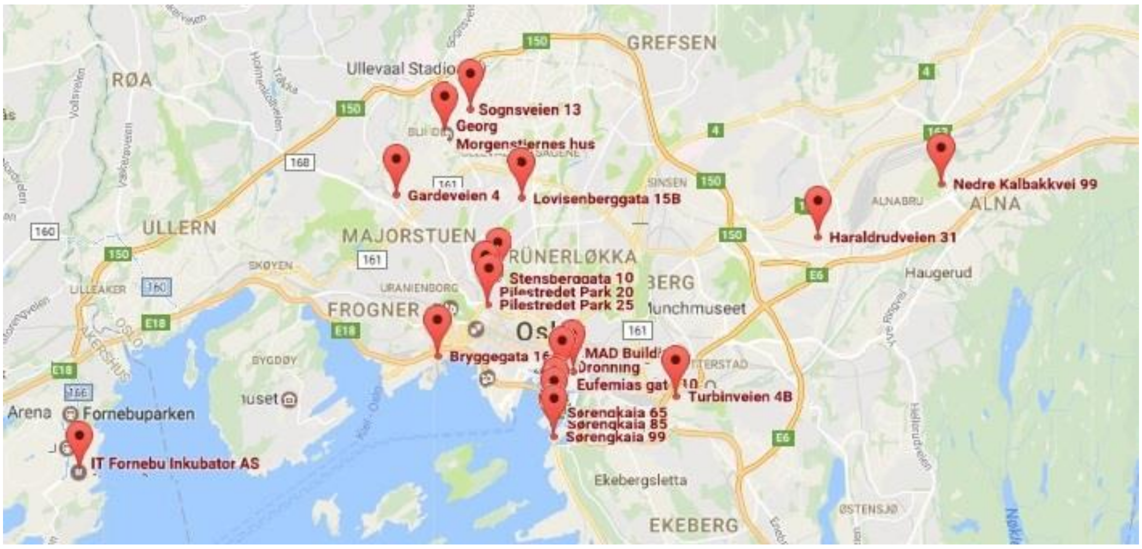


Figure 2. Location of studied extensive green roofs in Oslo

The roofs were constructed on old and new buildings from 2002 until 2014 and they were used in an area with a combination of industrial and residential buildings. The general information about all studied extensive green roofs are summarized in table 1.

Table 1. General information on studied Extensive Green roofs

Roof Number	Abbreviation	Building Name	Building Address	Area(m2)	Supplier Company	Year of Implementation	Numbers of Plot
1	BARN I	Sognsveien barnehage	Sognsveien 13, Oslo	270	Veg Tech	2007	2
2	BARN II	Solbærtorvet barnehage	Gardeveien 4, Oslo	334	Vital Vekst	2010	2
3	KVAR	Kværnerbyen	Turbinveien 4B, Oslo	600	Bergknapp	2013	2
4	HOEG	LovisenbergDiaconal University College	Lovisen breggata 15B, Oslo	320	Zinco	2013	2
5	STEN	PilestredetPark, Stensberggata10,12	Stensberggata 10-12, Oslo	700	Veg Teg	2006	2
6	PI20	Pilestredet Park 20	Pilestredet Park 20, Oslo	380	Veg Teg	2006	2
7	SORE (build85)	Sørenga I,85	Sørengkaia 85, Oslo	110	Bergknapp/Byggors	2011	2
8	SORE (build99)	Sørenga I,99	Sørengkaia 99, Oslo	120	Bergknapp/Byggors	2011	2
9	SORE II	Sørenga II, 65	Sørengkaia 65, Oslo	150	Blomstertak	2012	2
10	BJOR	Barcode Project, 10	Dronning Eufemias gate 10, Oslo	60	Vital Vekst	2009	2
11	BJOR II	Barcode project, 18	Dronning Eufemias gate 18, Oslo	400	Vital Vekst	2013	1
12	KREM	Alfaset Krematorium(cermation center)	Nedre Kalbakkvei 99, Oslo	1050	Vital Vekst	2009	4
13	AKER	Aker Brygge	Bryggegata 16, Oslo	700	Bergknapp	2014	2
14	PI 25	Pilestredet Park 25	Pilestredet Park 25, Oslo	120	Veg Tech	2006	2
15	FORN	Statoil (IT Fornebu)	Martin Linges vei15, Fornebu	9000	Blomstertak	2012	4
16	UNIV	University of Oslo, Blindern	Georg Morgenstierneshus, Blindernveien 31, Oslo	250	ReiersølPlante skole	2002	2
17	GJEN	Norsk Gjenvinning As	Haraldrudveien 31, Oslo	27000	Blomstertak	2006	2

2.2 Field work

All green roofs used in the project were extensive green roofs divided into 17 vegetated roofs, including 37 plots, all used for measuring soil temperature and 17 of them used for soil moisture measurement. The size of measuring section is 30cm x 70cm. The geographic location of each plot was identified with a handheld Garmin GPS 62s and information of vegetation groups obtained by Bakhtina (2015) from the same places. The first section of my field work started June 2016 until end of July. During this period, after contacting with owner of roofs and getting permission from them, measuring the soil temperatures were started. The investigation was based on data-logger used for recording soil temperature (maximum and minimum). A data logger (LogTag TRIX-8, Measuring range: -40°C to 85°C) was located in each plot in order to measure the soil temperature. Each logger was buried approximately 1-2 cm below the surface of the soil depending on depth of soil in each roof. The measuring of two plots in one roof started from 1st of August. The loggers recorded four times in a day until end of July. In the middle of September (two times) all devices were collected. Simultaneously (15th and 20th of September), a sample of soil was collected from each roof. At each plot soil sample were extracted with PVC cylinders and then transferred to laboratory for measuring soil water properties.

2.3 Experimental procedures for soil moisture analyses

Experiments were conducted in soil laboratory where located in University College of Southeast Norway. In the beginning of experiment the measurement of soil moisture was performed by soil water probe and mini tensiometer (Durner and Or, 2005; Campbell, 1988). Soil water probe was inserted in a vertical position for measuring the soil water content, and tensiometer was located in horizontal direction inside a predrilled small hole of soil for showing matric potential value (negative pressure). Here, an experimental analysis was performed on a sample of sand firstly. Then it was done for the intended soil sample. However, because of the low water content in the soil, and several forms of mineral naturally sourced such as clay, sand, gravel and artificial mineral of substrates, results estimated from these two devices could not show a steady relationship between soil water content and pressure of the sample. Therefore, soil water content decided to be determined by weight method. In the second experiment, at first, the whole samples were put in oven with 30°C for 6 days. Then samples were weighted as mass of dry soil (m_s). Then, they were saturated and re-weighted as the mass of wet soil (m_w). The water content determined by difference between m_w and m_s with balance model of BL1500 S. The soil water content value has been calculated using formula (2-1)

$$Soil\ water\ content\ (g) = m_W - m_S \tag{2-1}$$

In order to calculate the porosity, volumes of both water and soil were required. According to formula (2-2), since density of water is equal to one, its volume will be equal to its mass which had been found in the previous step.

$$\rho_W = 1$$

$$Volume\ of\ water\ (cm^3) = \frac{m_w}{\rho_w} = \ m_W \qquad (2\text{-}2)$$

Total volume was calculated by the formula (2-3)

$$Total\ volume\ (cm^3) = \pi.r^2.h \qquad (2\text{-}3)$$

Where r is radius of the cylinder and h is height of saturated soil. Then porosity was found by formula (2-4)

$$Saturated\ soil\ water\ porosity = \frac{V_W}{V_T} \qquad (2\text{-}4)$$

Where V_W is volume of water and V_T is total volume.

In order to analyse the soil field capacity, the saturated soil was put in a climate room with temperature of -5°C in order to drainage, and assuming no evaporation, plant uptake, the water content would decrease by gravitational drainage. After few days, the gravitational drainage rate was negligible, where the soil was at the field capacity point. Soil field capacity was determined by subtraction of dry soil sample weight from moist soil sample weight.

The field capacity value has been calculated using formula (2-5)

$$Field\ capacity\ (g) = m_W - \ m_S \qquad (2\text{-}5)$$

Also, the field capacity porosity has been calculated by using formula (2-6)

$$Field\ capacity\ Porosity = \frac{m_{FC}}{V_T} \qquad (2\text{-}6)$$

In the following, the saturated hydraulic conductivity (K) was determined by using a steady state constant head method based on Darcy's law (Stolte, 1997). In this procedure water should be moved through the soil under a steady state head condition while the quantity (volume) of water flowing through the soil sample is measured over a period. The temperature of water was 17.7°C

The quantity of water has been calculated using formula (2-7)

$$Q = \frac{V}{T} \quad \left({cm^3}/{S}\right) \tag{2-7}$$

Where V is the discharged volume of water (cm^3) and t is a time period (s).

The Hydraulic conductivity has been determined using formula (2-8) (Yeh et al. 2015)

$$K = \frac{QL}{AH} \quad \left({m}/{S}\right) \tag{2-8}$$

Where L is the length of soil sample (m), H is head difference (m) and A represents the cross-sectional flow area (m^2).

2.4 Statistical analyses

Data processing was performed by using SPSS, MS Excel and PCA in MINITAB software.

The average and maximum soil temperature were calculated for the warm period of July which was between 20th and 26th of July. The average soil temperature was calculated by taking average between all observed temperature in this period for each roof, and maximum average soil temperature for each roof was found by taking the average of the maximum temperatures of each plot in the same period.

The principal components analyses (PCA) was performed in order to show the correlations among the variables. In fact, the PCA summarizes the correlation among the variables (Tabachnick et al. 2001). Table 2, gives an overview of all environmental variables and vegetation groups with abbreviations and measurement unit.

Table 2. Summary of all Environmental variables and vegetation groups with abbreviations and measurement units used in PCA diagram

Abbr.	Environmental variables/ Vegetation Groups	Unit
Jmea	Mean soil temperature during warm period of July	°C
Smax	Maximum soil temperature during summer	°C
Ssm	Saturated soil moisture	g
Fc	Field capacity	g
Suc	Abundance of Succulent Species	%
Rsuc	Richness of Succulent Species	n
Moss	Abundance of mosses	%
Rmoss	Richness of mosses	n
Lich	Abundance of lichens	%
Rlich	Richness of lichens	n
Herb	Abundance of herbs	%
Rherb	Richness of herbs	n
Gram	Abundance of graminoids	%
Rgram	Richness of graminoids	n
Woody	Abundance of woody plants	%
Rwoody	Richness of woody plants	n
Bare ground	Abundance of bare ground	%

Regression analyses was performed to find the relation between variables. The confidence interval was considered as 95%. For showing the strength of association between variables correlation coefficient was measured with SPSS (Whitlock and Schluter, 2009). Table 3 interprets the strength of correlation for different values of zero to one.

Table 3. The strength of a correlation (Fowler et al. 1998)

Value of coefficient r (positive or negative)	Meaning
0.00 to 0.19	A very weak correlation
0.20 to 0.39	A week correlation
0.40 to 0.69	A modest correlation
0.70 to 0.89	A strong correlation
0.90 to 1.00	A very strong correlation

At the next step, in order to show the median, smallest and largest values on variables and extreme measurements of the data, Box plots were drawn (Whitlock and Schluter, 2009).

In some cases, the results had been affected by some outlier's points. By eliminating these, the association between these variables was increased by the p value. Besides, the weak correlation between some variables maybe arising by chance or sampling errors. In fact, if the p value will be large, a small sample is a poor estimation which may be not statistically significant, while larger samples will give a good confirmation of the statistical significance of weak correlations. Fowler et al. (1998) also pointed out that large samples give reliable estimation and small samples give less reliable estimation. Particularly if the p value is low, it means the correlation in the population is weak. But the point, here, is that the larger samples do not improve a weak correlation, they reduce the likelihood of a spurious correlation obtaining by chance or sampling error.

3 Results

3.1 Soil temperature variation

Study on the soil temperature of thirty-seven plots from seventeen green roofs shows that the soil temperature varies in different months of summer.

Generally, Soil temperatures in June (average: 17.96°C) were lower than in July. It reached maximum level in July (average: 19.48°C). Then, temperature decreased by some degrees in August (average: 15.95°C) and September (average: 16.09). Soil temperatures did not vary considerably during both August and September.

The variations of soil temperature during summer for all studied extensive green roofs have been shown in the table 4. Results indicate that, in roof number one, soil temperature during 35 days was in the temperature range of 4°C to 30°C, 6 days with less than 4°C, and 36 days it was above 30°C. During one day, the soil temperature was reached above 48°C. In the roof number five, soil temperature had a normal temperature range of 4°C to 30°C during 45 days, two days were less than 4°C, 28 days it was between 30 °C to 48°C and one day it was more than 48°C. The soil temperature of rest of 15 studied extensive green roofs were above 30°C, for up to 15 days.

Table 4. The soil temperature variations during summer in all studied extensive green roofs

		Number of days			
Roof Number	Extensive Green Roofs	Temperature T < 4°C	Temperature 4°C < T <30°C	Temperature 30°C < T < 48°C	Temperature T > 48°C
1	BARN I	6	35	36	1
2	BARN II	0	73	5	0
3	KVAR	0	70	7	0
4	HOEG	0	61	15	0
5	STEN	2	45	28	1
6	PI 20	0	63	6	0
7	SORE 85	0	62	3	0
8	SORE 99	0	61	4	0
9	SORE II	0	58	7	0
10	BJOR	0	50	15	0
11	BJOR II	0	65	0	0
12	KREM	0	60	1	0
13	AKER	0	57	5	0
14	PI 25	0	51	8	0
15	FORN	0	54	4	0
16	UNIV	0	50	0	0
17	GJEN	0	45	0	0

Figure 3 shows the air temperature fluctuation in the period of late of June to middle of September which indicates that the highest temperature is related to late of July and the lowest one is related to middle of August (Data provided by Norwegian Meteorological Institute, (2016)).

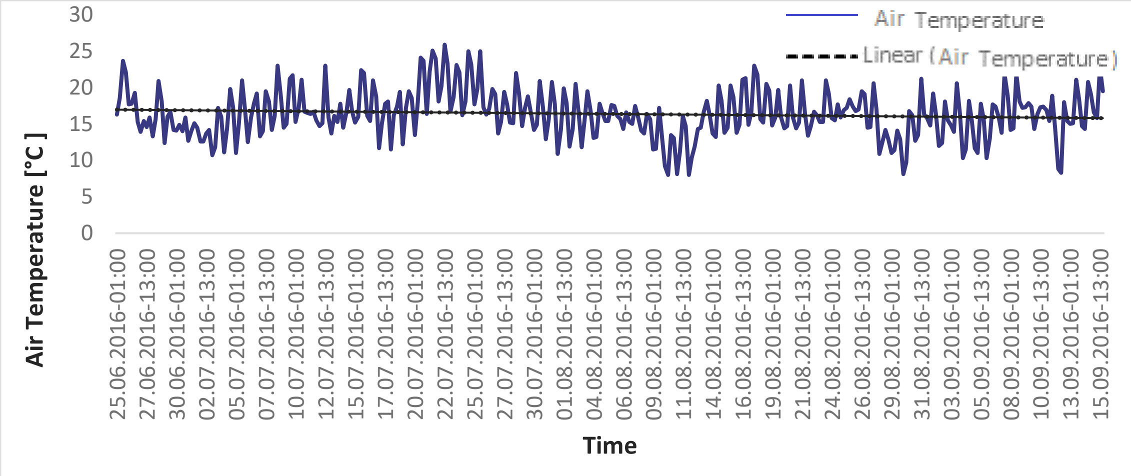


Figure 3. Air temperature measurement – June to September

Figures 4 to 6 illustrate that during the summer, particularly in June and July, soil temperatures showed an increasing trend. By the end of summer and earlier autumn, soil temperatures were decreasing. Figures, below have been shown as an example, rest of them have been presented in the appendix.

The highest soil temperature among all the measured plots was in plot number 64 in July with 53°C while the lowest temperature was in September with - 0.5°C at the same plot in roof number 1 (Figure 4).

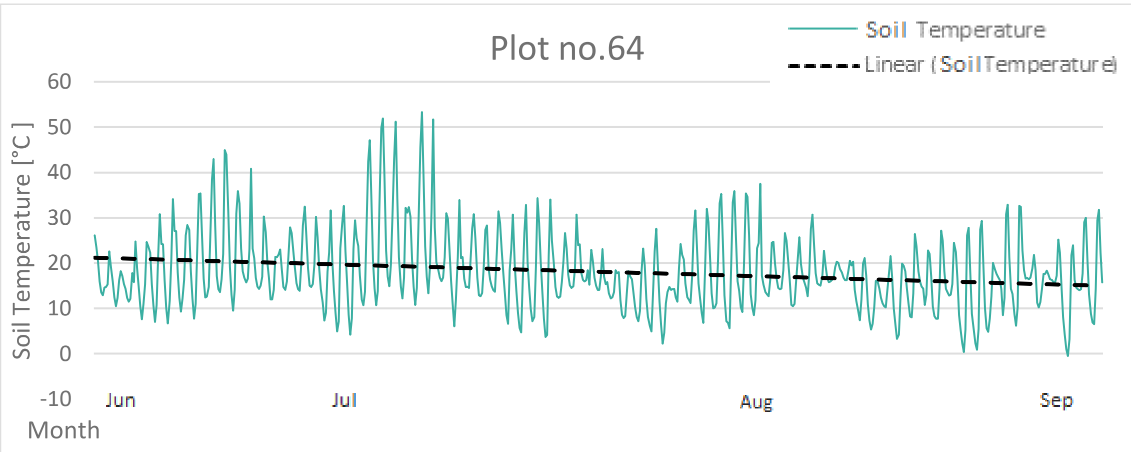


Figure 4. Soil temperature measurement in plot.no 64 of BARN I at summer 2016

Other plots show less variation in soil temperatures, for example plot 67 (Figure 5). Here, soil temperature varied between 11°C and 26 °C in July, and between 9 °C and 23 °C in August.

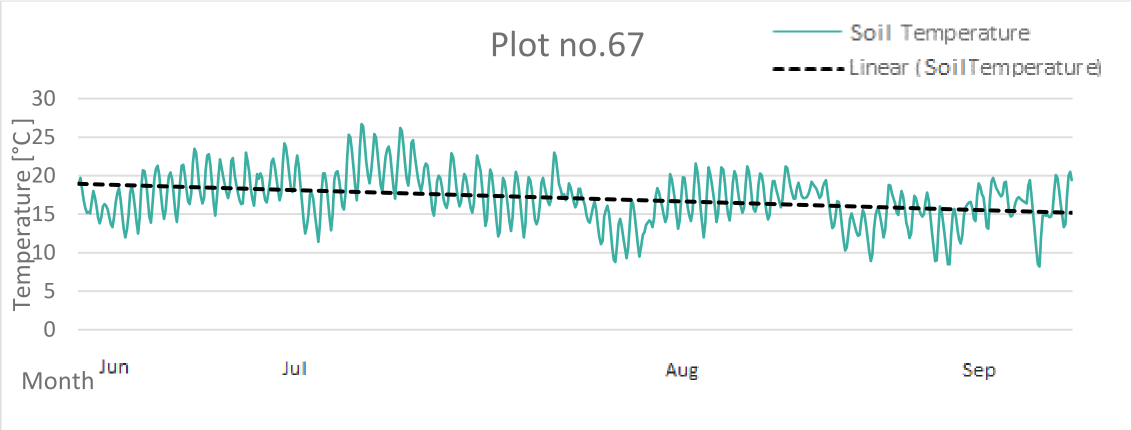


Figure 5. Soil temperature measurement in plot.no 67 of BARN II at summer 2016

Lowest variation in soil temperature was measured on roof 12, in plot 81 (Figure 6) which shows that soil temperature varied between 13°C and 22°C in July.

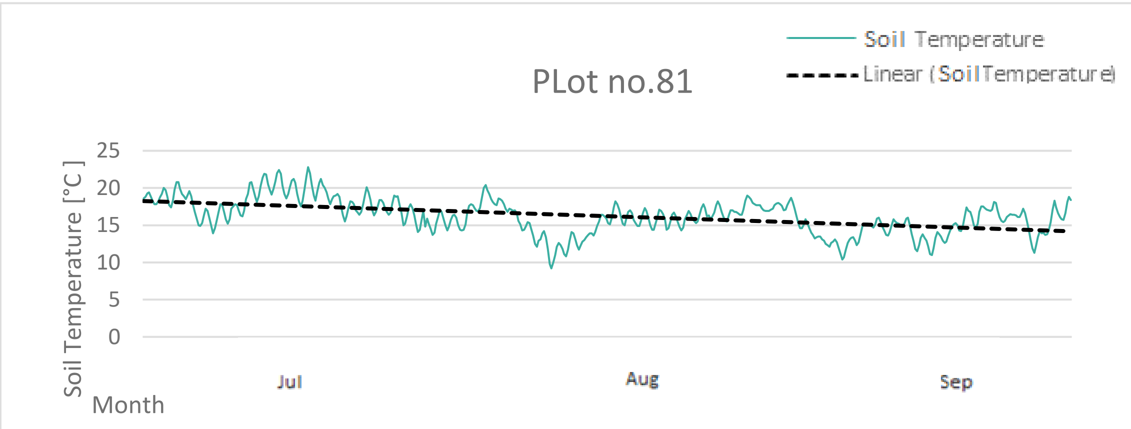


Figure 6. Soil temperature measurement in plot.no 81 of KREM at summer 2016

3.2 Vegetation in relation to environmental variables

A PCA shows that how environmental variables such as soil temperature and soil moisture are related to each other and different groups of vegetation (Figure 7). It is shown that abundance of mosses, lichens, herbs, graminoids and richness of mosses, lichens, herbs and graminoids are positively correlated to each other. However, the correlation between these plants groups and succulent species with maximum soil temperature in summer, and mean soil temperature in July is less. Besides, all groups have a correlation with soil moisture in a positive direction for all studied roofs. Abundance of succulents has positive correlation with soil field capacity, while this relationship has been decreased with mean soil temperature during warm period in July. Soil maximum temperature (Smax) are strongly positive correlated with bare ground, and negative correlated with soil moisture. Figure 7 shows the summarizes of the correlation among the environmental variables with vegetation abundance and plant richness. Eigenvalues for PCA axis 1 was 4.07 and for PCA axis 2 was 2.94.

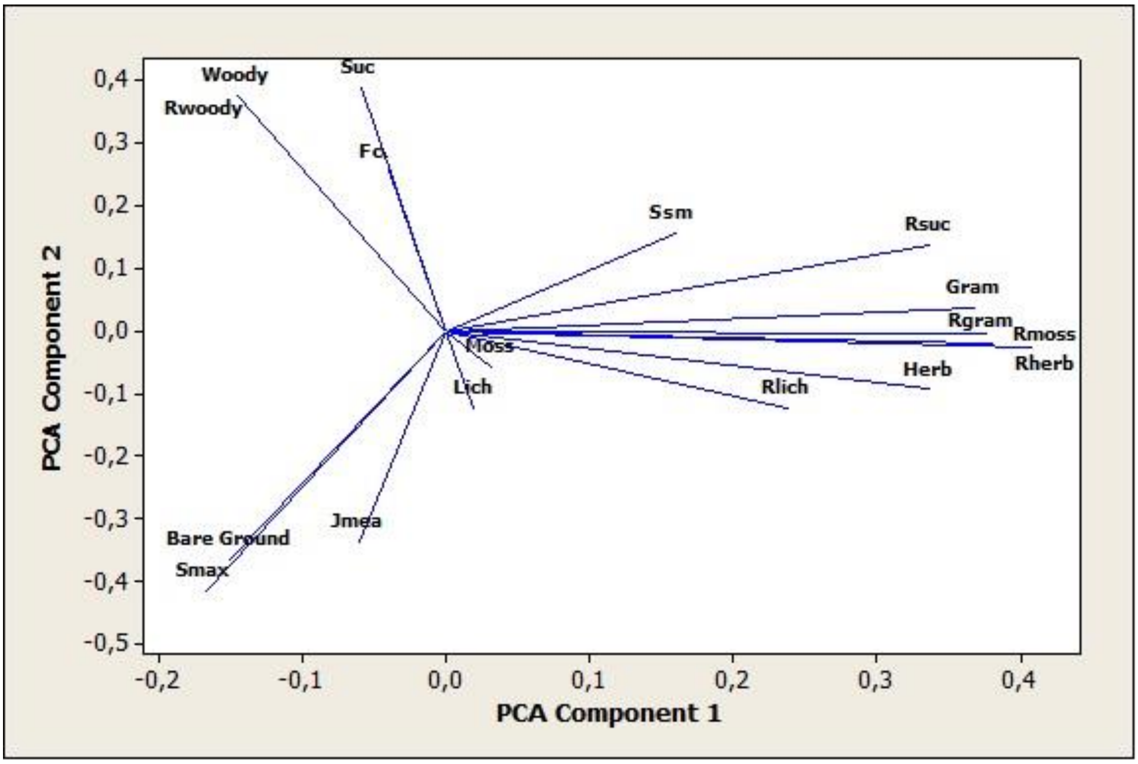


Figure 7. PCA diagram with vectors show the relation between different group of vegetation with soil temperature parameters, soil moisture and field capacity (abbreviations are explained in table 12)

3.3 Relationship between Vegetation parameters and soil temperatures in the warm period of July

3.3.1 Average soil temperature and vegetation cover

Vegetation abundance and richness of vegetation in relation to soil temperature during the warm period in July (20^{th} – 26^{th} of July) are shown in Figures 8 and Appendix 3. Results indicate that there is a negative correlation between average soil temperature and vegetation parameters (vegetation abundance and total richness of species).

The relationship between average soil temperature and abundance of vegetation is significant (p value: 0.023 and R value: - 0.562). It should be noted that the results had been effected by some outlier's points in the observed temperature in Appendix 1. Results show that by eliminating outlier's points, p and R values will be increased (p value: 0.007 and R value: - 0.686). In the following, the observations in warm period (20th – 26th of July) represent that although in the maximum and minimum of soil temperature some parts of vegetation cover are distinguished, the highest percentage of vegetation abundance has been discovered in the average soil temperatures of 19.41°C and 23.41°C in this time (Figure 8 and Appendix 1).

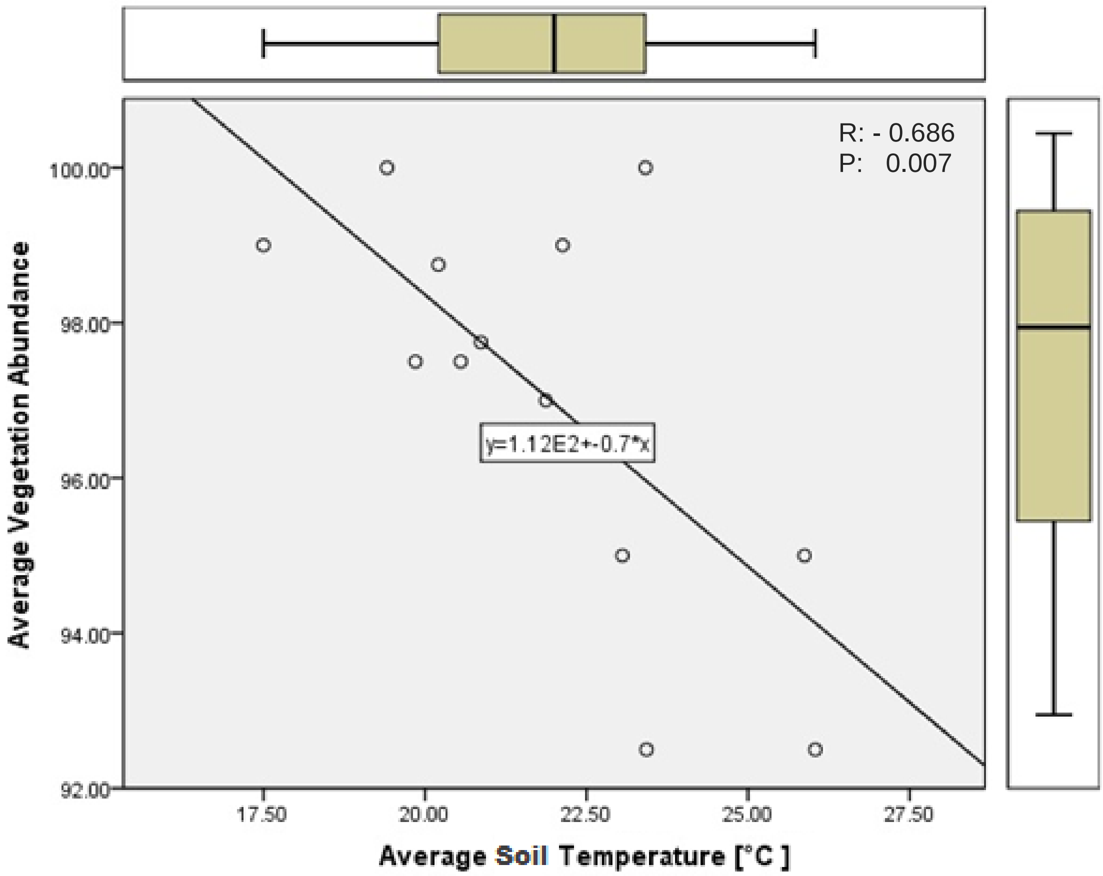


Figure 8. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and Regression between abundance of vegetation and average soil temperature with regression equation without outlier's points during warm period in July

Appendix 2 indicates that average soil temperature and total richness of vegetation groups are negatively correlated (R = - 0.404). The p value of 0.121 demonstrates that there is no statistically significant relation between these variables in all studied plots. Appendix 3 shows that, after removing the outlier's points, the results by considering the p and R values of 0.423 and -0.244, have not been changed perceptibly. Also, in the highest and lowest soil temperature, total richness of vegetation was lower, while total richness of species is mostly existent in the temperature around 20°C to 23°C (Appendix 2 and Appendix 3).

3.3.2 Maximum soil temperature and vegetation cover

Appendix 4 shows the measured results over the whole study period in different sites, which explain that the correlation between the average maximum soil temperature values and vegetation abundance is significant (p: 0.058 and R: - 0.484) respectively.

In figure 9, the outlier's points have been omitted and conclude that the inverse correlation is statistically significant with the p and R values of 0.020 and - 0.612. Results show that the most percentages of vegetation have been registered from 25.55°C to 37.9°C. However, these percentages have been decreased in terms of maximum temperature.

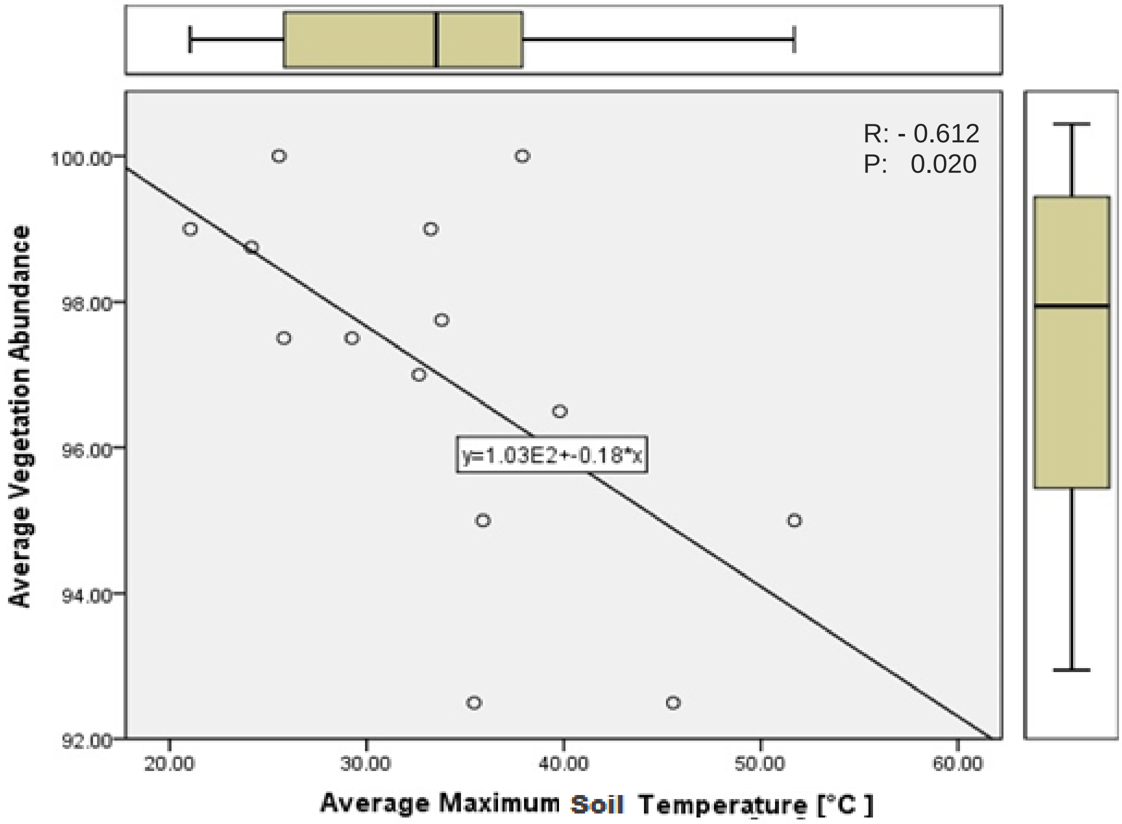


Figure 9. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and Regression between abundance of vegetation and average maximum soil temperature with regression equation without outlier's points during summer

The results in Appendix 5 also indicate that there is a week inverse correlation between total richness of vegetation and average maximum soil temperature with the p and R value of 0.136 and -0.389 in the entire measurement period. The majority of total richness of vegetation is observed up to the temperature of 40°C whereas this trend is decreased after average maximum soil temperature of 40°C. Here, by removing outlier ' points, the correlation of maximum soil temperature with species of vegetation did not change a lot and remained almost the same ($p = 0.279$ and $R = -0.311$). Therefore, there is no significant difference between these two variables (Appendix 6).

3.4 Soil water content on different planted roofs

The findings from a sand sample in table 5 and water retention curve in figure 10 demonstrate that there is a negative correlation between moisture content and matric suction. By increasing of moisture content and water availability for plants, the value of matric potential was decreased. In the following, for the value of -330, the content of water has been reached to the soil field capacity level. Results show that soil moisture has an increasing trend (up to 40 percent) while the negative pressure is decreasing.

Table 5. The soil moisture content in relation to matric potential (negative pressure) in sand

Moister Content %	Matric Potential (hPa)
2.8	-385
6	-330
10.4	-300
10.6	-230
12.6	-180
12.8	-170
13	-150
14	-34
16.6	-35
21.3	-25
23	-21
25.5	-18
27	-15
32.2	-12
38	-10
40.1	-6
40.6	-3

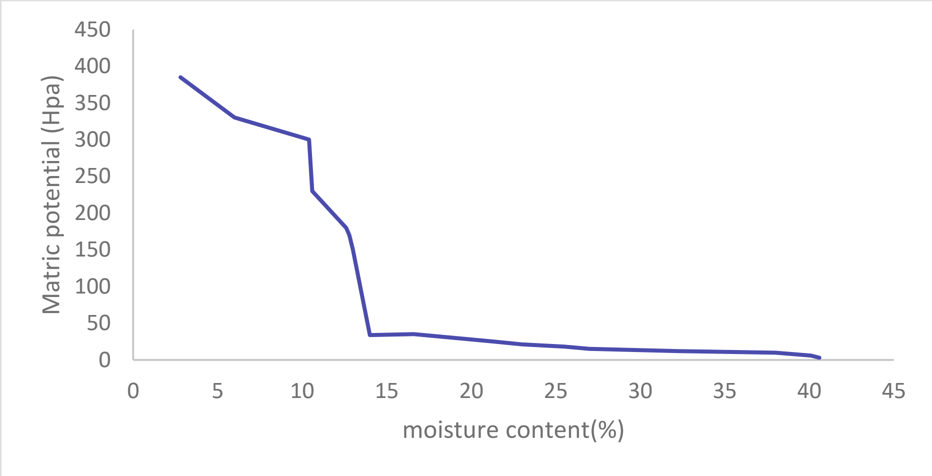


Figure 10. The water retention curve in sand

The recorded results from a green roof soil sample by mini tensiometer and soil water probe show that the water content has been decreased gradually up to field capacity point. However, after that an increase in soil water content has occurred (Table 6). Due to instability of soil moisture measurement which lead to not having accurate results (Figure 11), weight method was decided to use for measuring the soil water content in this study. It has been more discussed in chapter of Material Method and Discussion.

Table 6. The soil moisture content in relation to matric potential (negative pressure) in soil sample (BARN I)

Moisture Content %	Matric Potential (hPa)
7.2	-430
8	-409
6.4	-330
8	-290
8.1	-255
6.2	-240
8.1	-191.8
6.4	-150
8.2	-100
8.2	-75
8.2	-50
8.3	-40
8.4	-30
6.6	-20
8.8	-18
13.2	-15
17	-10
16.8	-6

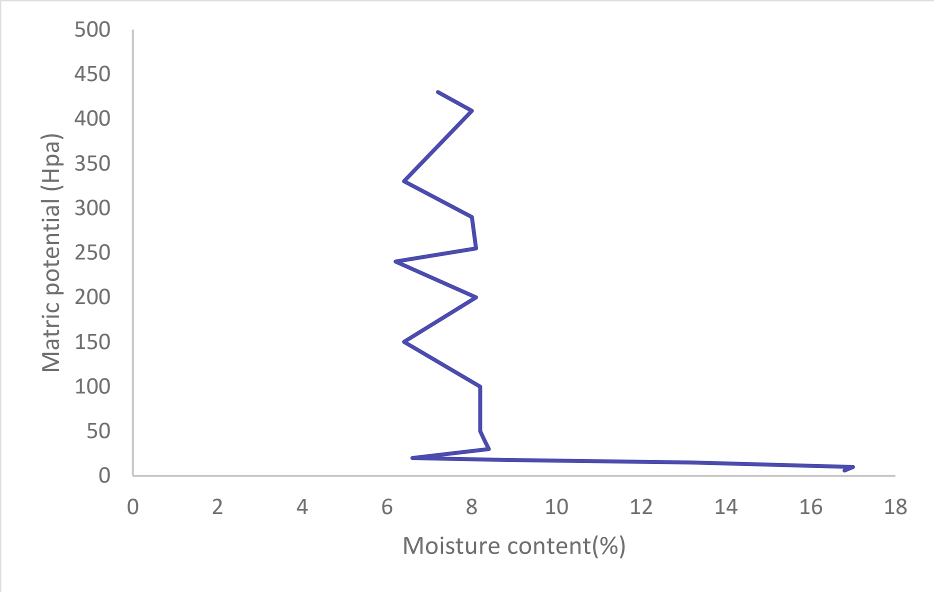


Figure 11. The water retention curve in soil sample (BARN I)

3.5 Water content and soil field capacity and its relationship with vegetation

Averages of soil water analyses (soil water content, weight of sample at field capacity, soil field capacity and hydraulic conductivity) per roof (17plots), are presented in table 7. In addition, the total volume, saturated soil moisture (porosity) and field capacity porosity were illustrated in table 8.

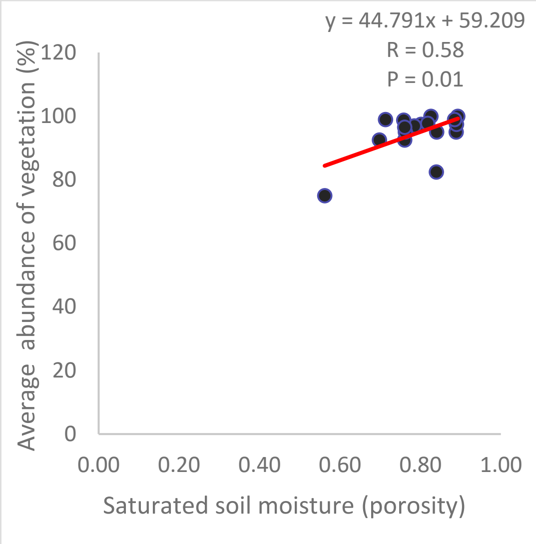
Table 7. Result of soil water analyses for each studied extensive green roofs

Roofs Number	Extensive Green Roofs	Dry weight (g)	Wet weight (g)	Water content (g)	Weight of sample at field capacity (g)	Field capacity (g)	Hydraulic conductivity (m/s)	Plots Name according to Bakhtina, 2015
1	BARN I	200.89	288.1	87.21	259.8	58.91	0.0027	63
2	BARN II	207.4	306.55	99.15	282.9	75.5	0.0010	65
3	KVAR	200	303.45	103.45	274.4	74.4	0.0009	91
4	HOEG	184.5	270.23	85.73	243.95	59.45	0.0022	01
5	STEN	250.85	328.5	77.65	316.82	65.97	0.0001	29
6	PI 20	224.2	325.9	101.7	297.1	72.9	0.0011	35
7	SORE 85	181.36	273.95	92.59	248	66.64	0.0018	53
8	SORE 99	197.36	294.65	97.29	268.93	71.57	0.0006	59
9	SORE II	238	331.19	93.19	306	68	0.0004	19
10	BJOR	182.62	278.33	95.71	240.95	58.33	0.0004	73
11	BJOR II	228.62	291.5	62.88	266.2	37.58	0.0022	77
12	KREM	175.11	259.95	84.84	243.15	68.04	0.0013	81
13	AKER	207.03	288.15	80.85	266.16	58.86	0.0012	71
14	PI 25	250.33	347.45	97.12	324	73.67	0.0007	15
15	FORN	185.5	269	83.5	235.05	49.55	0.0020	26
16	UNIV	236.12	313.1	76.98	279.8	43.68	0.0019	49
17	GJEN	213.41	307.4	93.99	283.9	70.49	0.0006	11

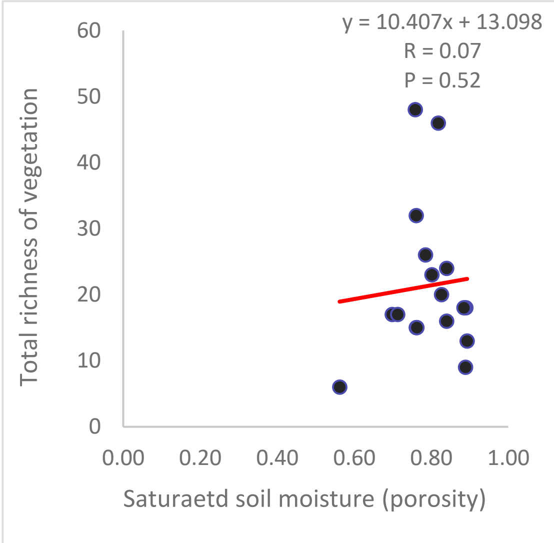
Table 8. Soil moisture analyses on all studied extensive green roofs

Roof Number	Extensive Green Roofs	Volume of soil (cm3)	Porosity	Field Capacity porosity	Plots Name according to Bakhtina, 2015
1	BARN I	98.15	0.88	0.60	63
2	BARN II	123.66	0.80	0.61	65
3	KVAR	115.81	0.89	0.64	91
4	HOEG	102.07	0.83	0.58	01
5	STEN	102.07	0.76	0.65	29
6	PI 20	129.55	0.78	0.56	35
7	SORE 85	104.03	0.88	0.64	53
8	SORE 99	109.92	0.88	0.65	59
9	SORE II	133.48	0.69	0.51	19
10	BJOR	115.81	0.82	0.50	73
11	BJOR II	111.89	0.56	0.34	77
12	KREM	111.89	0.75	0.61	81
13	AKER	106.00	0.76	0.56	71
14	PI 25	127.59	0.76	0.58	15
15	FORN	102.07	0.83	0.49	26
16	UNIV	107.96	0.71	0.40	49
17	GJEN	111.89	0.84	0.63	11

Saturated soil moisture (porosity) is positively correlated ($R = 0.58$ and $p = 0.01$) with vegetation abundance (Figure 12a). However, in figure 12b, the slope of regression line is decreased and the correlation is very weak between saturated soil moisture and richness of species ($R = 0.07$ and $p = 0.52$) during monitoring period.



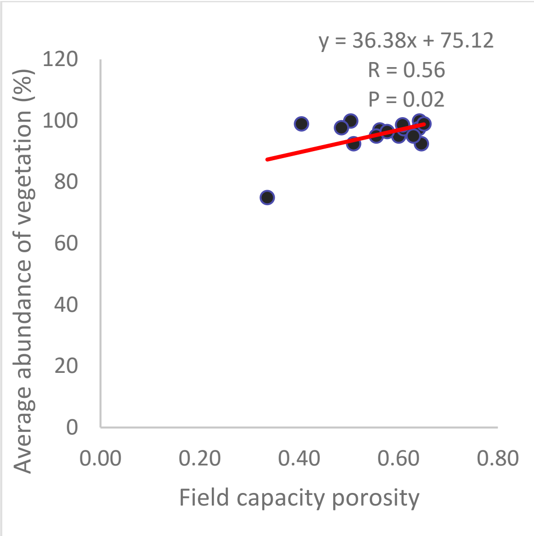
(a)



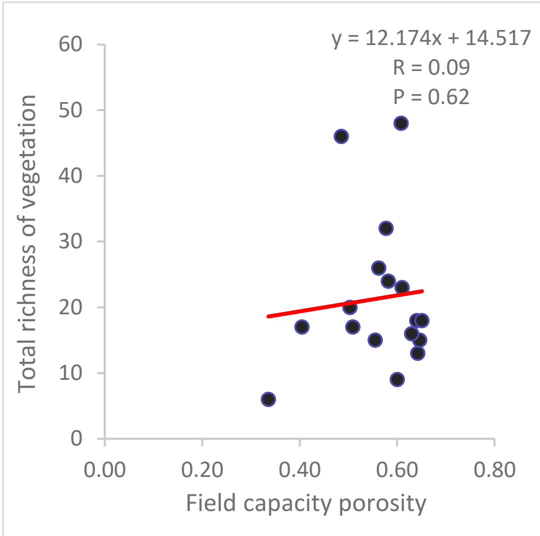
(b)

Figure 12. Regression between saturated soil moisture (porosity) and abundance of vegetation (a) and total richness of vegetation (b) with regression equation, R- value and P- value

The investigation is designed for measuring the field capacity porosity in studied green roofs. Figure 13a shows that there is a positive relationship between abundance of plants and field capacity porosity with the p and R values of 0.02 and 0.56. In figure 13b the slope of regression line is decreased. Therefore, association between two parameters of field capacity porosity and richness species has been positive with very weak correlation (R = 0.09 and p = 0.62).



(a)



(b)

Figure 13. Regression between Field capacity porosity and abundance of vegetation (a) and total richness of vegetation (b) with regression equation, R- value and P- value

3.6 Saturated soil moisture and Hydraulic conductivity

In Figure 14, the result of measuring the saturated soil moisture and hydraulic conductivity in all studied green roofs, after removing outlier's points, shows that there is a negative correlation (the R and p values of -0.56 and 0.04) between these two variables in all studied roofs which can be related to the type of used soil in these areas.

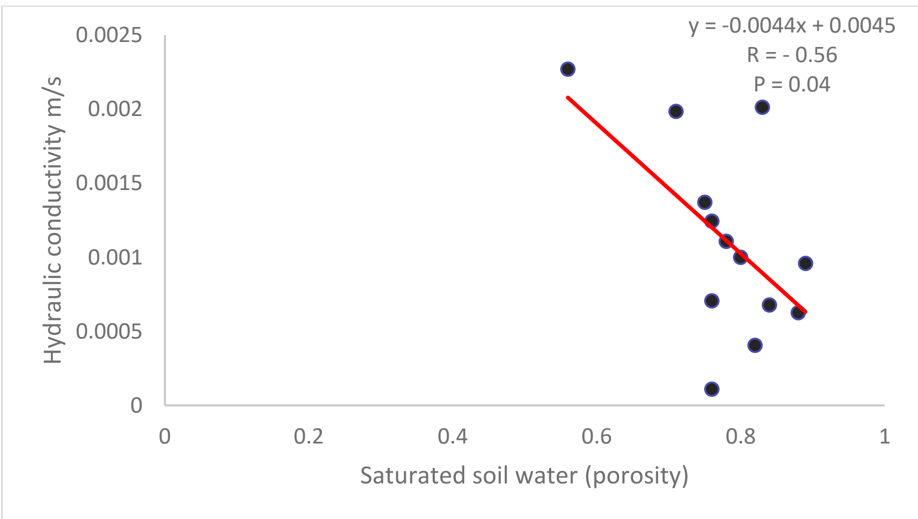


Figure 14. Linear Regression between Saturated soil moisture (porosity) and Hydraulic conductivity with regression equation, R-value and p value

4 Discussion

4.1 Soil temperature and vegetation

During summer between June to September (28.06 to 15.09) soil temperature of most studied plots remained in a normal range of 4°C to 30°C. While in a short period, soil temperature of some of them were increased up to more than 30°C. Generally, the appropriate temperature for the root physiological process is between 4°C to 30°C. For the temperature, more than 30°C, all the process of the roots such as respiration will be reduced quickly and certain process specially the secondary materials synthesis will be done slowly. The negative high temperature effect of more than 30°C will be harmful for plants until it exceeds than 48°C where the root mortality will be occurred. Therefore, plant physiological processes are highly sensitive to temperature (Sutton et al. 2012). In fact, temperature of the soil and its surrounding could affect both root growth processes and its development. The processes of growth such as cell elongation, will increase the length of root and its diameter. However, development processes will control the growth duration and initiation processes of new roots. By considering that both these processes will be affected by soil temperature, it is important to emphasize that every plant species has also its particular maximum, minimum and optimum range.

The results of this study also indicate that soil temperature and vegetation parameters are well correlated and soil temperature can be considered an important factor for the distribution and composition of plants. This could be an explanation for why short extreme temperature events which will be occurred during the summer, would have the most dramatic impact on vegetation cover. Dufault, Ward, and Hassell (2009) also reported that temperature should be considered as an important environmental element which can affect the plant production. This could be impressible by some specific factors such as hot day periods, minimum and maximum temperatures of a day, overall growing season climate and the time of stress relevant to developmental stage. In this study, the maximum soil temperature has been considered as an effective factor on the studied plants. The importance of maximum temperature should be explained as its effect on increasing the daily mean temperature which will be led to have the extreme events and eventually creation of harmful condition for pollen liability, fertilization and grain yield (Meehl et al. 2007). In the present study during warm period especially in July (20th to

26th of July) the soil temperature in all the studied plots in 16 roofs were varied from 10°C to 39°C. Only three out of thirty-five plots in two roofs had highest level of soil temperature which was more than 48°C. The maximum soil temperatures were registered by 50.4°C and 53.3°C on plot 63 and 64 in roof number one, and 49.5°C on plot 31 in roof number five.

On the other hand, too much decreasing in the temperature could have negative effect on the plant ability of grain productivity (Hatfield and Prueger, 2015). The registered soil temperatures by the data loggers show the minimum soil temperature of -0.05 °C which was related to plot 64 in roof number one as well. The inappropriate plant situation of roof number one can proves the importance of maximum and minimum temperature effects on plant viability and could be the best explanation for differences between the vegetation groups. Previous studies have shown that when plants are subjected to a little heat stress (1°C to 4°C above optimal growth temperature), their efficiency will be decreased gradually (Sato, 2006; Timlin et al. 2006; Tesfaendrias et al. 2010). To put it simply, it was found that exposure of these plants on the same roof in the highest soil temperatures could be one of the reasons for given negative impact on viability of the vegetation and will limit the ability of plants to grow in this place. However, it could be vice versa. Simply put, the vegetation maybe reduced first, and it decreased the albedo which has been led to increase the soil temperature. In roof number 5, although the soil temperature was exceeded above 48°C for a short period, it could be observed that the appearance of vegetation cover remained in a good condition in this area. The possibility of moving the data loggers from the determined place is an important highlight which should not be neglected in this respect. In fact, due to raining or wind blowing, the devices on mentioned plot (roof number five), were moved probably and data loggers were exposed with sunlight directly and showed some numbers as highest level, which should be considered as the main reason for remaining roof number five in a good vegetation condition where data loggers showed high temperature. Whereas in roof number four, soil temperatures were reached to 41°C and 42°C in each plot for one day and the vegetation cover was not so rich in this roof. It could be predicted that a negative effect of warmer soil temperature on different group of plant species could lead to lack of the vegetation. In other word, however the maximum soil temperature in roof number four is relatively high (as it has been not reached to mortality point temperature of 48°C),

the vegetation cover in this roof is not as poor as vegetation cover in roof number one where the soil temperature had been exceeded than 48°C.
In addition, the shallowest substrate was more faced with higher soil temperature which have a big influence on vegetation growth. As much as substrate is deeper, the soil condition for maintaining the stability of soil temperature will be more powerful. Providing the larger space for the plants roots of green roofs should be considered as another positive point of deep substrate. This might explain the differences in soil temperatures in studied plots specially in roof number one which has the highest level of soil temperature associated with variable of depth substrate. Boivin et al. (2001) found that temperature fluctuations of shallower extensive green roof substrates are more than deeper substrates, particularly during growing season period.

During summer, it is predictable that there is a mutual interaction between soil temperature and vegetation cover. In fact, the condition of soil temperature can affect plant growth, and vegetation cover can affect soil temperature on the other hand. Vegetation cover might be important for the soil temperature conditions during warm period. Since the temperature amplitude are different between bare ground and sites which are covered with plants. Vegetation cover which includes abundance and total richness of species, had a strong influence on decreasing the root zone temperature, compared with bare ground resulting in warmer root zoon temperatures. In fact, due to absence of vegetation cover in bare ground, albedo will be decreased and eventually soil temperature will be risen. In the present study, the PCA shows that soil temperature seems to be correlated with bare ground and temperature was in maximum level in this site which strengthen the assumption that vegetation cover affects soil temperatures.
The genus sedum as a low growing succulent plant which is a popular choice for extensive green roofs, had been considered as almost dominant plant species in most of the studied plots in this study, reported by Bakhtina (2015). Many of sedum species are considered to be able to cope with extreme temperature and limited water supply (VanWoert et al. 2005).
Furthermore, sedum species can decrease peak soil temperature and provide a condition for increasing performance of neighbouring plants in water deficit situation during summer period. Butler and Orians (2011) show that *S*edum album, *S*edum rupestre,

*S*edum sexangulare and *S*edum spurium decreased peak of soil temperature by 5-7°C. Butler and Orians (2009) found that during a warm period, the soil sample with only Agastache Black Adder is a hybrid of Ag. Rugosum and Ag. foeniculum was considerably hotter than soil sample with mixture of one of the four of this sedum species. Beside this, soil modules with *S*edum sexangulare would be cooler than soil in modules with *S*edum album. Although any analysis about this subject has not been done in this study, the results of soil temperature could support this fact that sedum has the ability of decreasing the soil temperature on green roofs. Sedum species not only could decrease the soil temperature, but also could contribute to reduce the abiotic stress on non-sedum species (Butler and Orians, 2009).

4.2 Soil moisture and vegetation

The result of this study clearly indicates that saturated soil moisture (porosity) and vegetation abundance are well correlated. As much as the porosity of soil increases, the space for holding of water in soil will be increased. In other word, condition for retention of soil water will be improved which can provide required water for plant growth.
Besides soil temperature, soil moisture also has a large effect on plant distribution and community composition. The lack of water in soil will decrease the synthetic activity and shoot growth. In this respect, Boyer (1970) mentioned that water stress will reduce both leaf growth and photosynthesis processes.

Since vegetation abundance is correlated with saturated soil moisture (porosity) in figure 12a, the question arises which soil moisture factors should be considered as the most effective elements in plant growth. Field capacity and wilting point are two important parameters which fix the upper and lower limits of water storage in the soil and be most affective factors for responses of plants to soil moisture conditions (Veihmeyer and Hendrickson, 1950). Kramer and Boyer (1995) expressed that severe water shortage in soil will decrease or even stop the growth of root which usually happens in dry soils which have been reaching wilting point. Statistical results of the present study show that vegetation abundance and richness of different groups of plant species including graminoids, herbaceous, lichen and mosses, and richness of succulent has a close association with saturated soil moisture which shows the importance of water content of soil for plant growth. According to PCA on figure 7 in the section of Result, succulent species abundance is well correlated with soil field capacity confirming that field capacity as one of the main soil moisture parameters, is an important factor for vegetation by providing suitable condition for maintenance of required water. The morphology of succulent species enable them to store large amounts of water inside and cope with drought situations when required. Emilsson and Rolf (2005) pointed out that succulent can tolerate a period without water through both biochemical and morphological adaptations. They can be adapted to water stressed environmental condition by crassulacean acid metabolism (CAM), in which its stomata will be open at night for uptake of CO_2, and close during the day to reduce evapotranspiration and daytime water loss.

In another study, Berghage et al. (2007) indicate that, succulent species and sedum are able to maintain up to 90% water by weight under the good water condition.

Sayed (2001), reported that *S*edum album and *S*edum acre are two types of sedum species which can express crassulacean acid metabolism in case of drought.

Returning to the result of this study, statistical results showed that in most of the studied plots, these two sedum species have been observed in extensive green roofs which probably refer to CAM mechanism which help them to adapt with water stressed environmental condition.

The point to bear in mind is that, although soil moisture has a direct effect on vegetation abundance, the influence of vegetation on moisture content behaviour should not be neglected. However this topic has not been focused in this study, previous study by Berretta, Poë, and Stovin (2014) shows that existence of vegetation cover on the roofs will reduce the soil moisture by transpiration and moderate the wetness, particularly when rainfall occur. This has been important for reduce the storm water runoff and improve the green roof function. This might explain that soil moisture behaviour to be largely affected by vegetation on extensive green roofs.

The other factor could be expected to be affective on soil moisture behaviour is substrate physical characteristics. Hydraulic property is as an important soil water characteristics, and are related to size and connectedness of pore spaces strongly affected by soil structure (Tuller and Or, 2004). When pressure becomes more negative or moisture content becomes less, the hydraulic conductivity of the medium will decrease (Yeh et al. 2015). However, in this study, the soil moisture (porosity) was significant negative correlated with hydraulic conductivity under saturated condition due to grain size. Simply put, by increasing the saturated soil moisture, the hydraulic conductivity was decreased. With small pores, water takes a sinuous path through grains and there is a high resistance to flow of water (Dingman, 2002). Since the mineral base of soil samples probably is a combination of fine grained soils which have a high porosity (many small pores) leading to reduction of hydraulic conductivity. Furthermore, the result of the study indicates that since the substrate of studied extensive green roofs were probably composed of fine and coarse grained soils, the amount of both saturated soil moisture porosity and field capacity porosity were relatively high. Therefore, soil water retention will be increased which lead to improvement of plant performance. However, in order to determine the size range of particles present in a soil, mechanical soil analysis is needed which has been not included in this study. Dingman (2002) has indicated that fine-grained soils such as clay have a high porosity leading to a high field capacity, in contrast coarse gained soils like sand have large pores which provide for lots of gravity drainage and therefore a low field capacity. The substrates of most roofs are with minimal fines (Luckett, 2009) but, Olszewski and Young (2011) expressed that recent researches shows that greater proportions of fines can be more sustainable for specific systems with shallower substrate and can improve plant efficiency by increasing overall moisture and nutrient retention.

It should be noted that instability of soil moisture measurements led to not having an accurate result by using of mini tensiometer and soil water probe. Therefore, our founding did not represent the expected stable interaction between increasing soil moisture and decreasing of negative pressure which was held by the soil matrix. To put it simply, it may be concluded that this method was not suitable for this type of soil and it could be explained by this assumption that our studied soil is composed of different mineral components of naturally sourced clay, sand and gravel or artificial minerals. So, composition of the soil was not naturally and therefore, it seems to be that moisture could not be measured by tensiometer. The low water availability in this type of soil also should not be neglected as another reason for such unexpected result. Durner and Or (2005) believe that using the tensiometer is not a proper method where soil water content becomes restricted. Consequently, weight method was preferred to be used as the optimal solution in order to measure the soil water content in this study.

Soil depth should be considered as one of the main efficient factor on soil moisture and plant growth. The shallow substrate in roof number one could be another reason that has been led to not having a good condition of vegetation cover in this roof. In fact, deeper substrates probably have provided greater moisture retention and root protection from temperature fluctuations. However, in the shallowest depth of 2.5cm, some species such as *S*edum album and *S*edum acre are able to grow (Durhman et al. 2007). The point to bear in mind is that both substrate depth and plant species growth factors should not be neglected when a green roof system will be established.

As it was mentioned before, water deficit should be considered as a treatment on mortality of plants specially for non-sedum species on green roofs. Butler and Orians (2009) have argued that sedum play the role of a nurse for growth and survival of neighbouring plants during the water stress. They explained that *S*edum album expresses two different behaviours depending on water condition. When there is not enough water, *S*edum album will be a facilitator and when there is abundant of water, it will be appeared as a competitor. In the situation of water abundance, *S*edum album also decreases the neighbour plant's growth. It is because of that in the case of *S*edum album existence, these plants have lower coverage and allocate less mass to roots compared to the situation in which there is not *S*edum album. However, it is effective for increasing the performance of the neighbours (leaf retention) in the condition of water limitation.

The mechanism of the *S*edum album as the positive effect of this type of sedum is about reducing water loss of its substrate. Because of the transpiration, plants normally will increase the speed of water loss from the soil. However, recent research shows that the green roofs in which *S*edum acre has been used, are able to hold more water compared with the plots without this kind of sedum (Butler and Orians, 2009). This might explain that presence of sedum species on all studied extensive roofs could support the hypothesis of Butler and Orians (2009) which indicate that sedum helps to increase the performance of less stress tolerant plants and reduce water loss from soil on green roofs.

4.3 Soil temperature and Soil moisture interaction

As it has been mentioned before soil water content affects soil temperature by changing the heat capacity of soil and thermal conductivity (Van Wijk, 1965) resulting a negative correlation between soil temperature and soil moisture (Redding et al. 2003; Bond-Lamberty et al. 2006) . The statistical analysis of this study (figure 7) confirms this fact by exposing the negative correlation between soil temperature and saturated soil moisture in our studied extensive green roofs. In fact, in case of water existence in the soil, major part of the heat energy will be used for water evaporation. Therefore, a small part of heat will be flowed in the soil while in a dry soil, the surface of soil will be heated by the absorbed energy and a considerable amount of heat will be flowed in the soil. A soil with high temperature has a double effect on the vegetation performance. To put it simply, the warm soil will have a negative effect on vegetation performance on the one hand, and decreases the moisture of soil, on the other hand. Reduction in soil moisture will lead to less performance of vegetation cover again.

5 Conclusions

Soil temperature in 88% of studied extensive green roofs were in an optimum range whereas in 12% of roofs soils warmed up to more than the others. Vegetation abundance was highly negative correlated with soil temperature, confirming that negatively effect of soil temperature on different group of plant species could lead to lack of the vegetation in these roofs. Variation of soil temperature has a large impact on vegetation growth and vegetation cover again will affect the albedo. On the other hand, albedo will influence soil temperature by its effect on vegetation cover. Thus, soil temperature features such as maximum and minimum are important factors to distinguish between different vegetation groups. In addition, shallow substrate experienced much more temperature fluctuation and less water retention, and would also provide intense stress on plant species.

Moreover, the relationship between soil temperature and vegetation are interactive. Simply put, soil temperature and vegetation condition could be effected by each other simultaneously. Vegetation cover could be expected to reduce the soil temperature, compared with bare ground resulting in warmer root zoon temperatures.

On the other hand, there is an interaction between soil temperature and soil moisture. The PCA results of this study demonstrate that there is negative correlation between these two variables. Soil moisture coupled with high soil temperature would be harmful for vegetation growth.

Vegetation abundance has also a significant positive correlation with saturated soil moisture and field capacity porosity. Soil moisture in relation to hydraulic conductivity, determined by soil structure, is an important factor for the availability of plant required water.

6 References/bibliography

2016. "Norwegian Meteorological Institute." http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL.

Akbari, Hashem, Melvin Pomerantz, and Haider Taha. 2001. "Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas." *Solar energy* 70 (3):295-310.

Al-Ani, MK Abbas, and RKM Hay. 1983. "The influence of growing temperature on the growth and morphology of cereal seedling root systems." *Journal of experimental botany* 34 (12):1720-1730.

Anderson, Malcolm, John Lambrinos, and Erin Schroll. 2010. "The potential value of mosses for stormwater management in urban environments." *Urban Ecosystems* 13 (3):319-332.

Bakhtina, Marina. 2015. "Vegetation composition of extensive green roofs in Oslo, Norway." Master Master Thesis, Faculty of Art and Science, University College of Southeast Norway.

Bengtsson, L. 2002. "AVRINNING FRÅN GRÖNA TAK (Runoff from green roofs)." *Vatten* 58:245-250.

Berghage, Robert, Al Jarrett, David Beattie, Kathleen Kelley, Shazia Husain, Farzaneh Rezai, Bret Long, Ayako Negassi, Robert Cameron, and William Hunt. 2007. "Quantifying evaporation and transpirational water losses from green roofs and green roof media capacity for neutralizing acid rain." *National Decentralized Water Resources Capacity Development Project*.

Berndtsson, Justyna Czemiel. 2010. "Green roof performance towards management of runoff water quantity and quality: a review." *Ecological Engineering* 36 (4):351-360.

Berretta, Christian, Simon Poë, and Virginia Stovin. 2014. "Moisture content behaviour in extensive green roofs during dry periods: The influence of vegetation and substrate characteristics." *Journal of Hydrology* 511:374-386.

Bianchini, Fabricio, and Kasun Hewage. 2012. "How “green” are the green roofs? Lifecycle analysis of green roof materials." *Building and Environment* 48:57-65.

Boivin, Marie-Anne, Marie-Pierre Lamy, André Gosselin, and Blanche Dansereau. 2001. "Effect of artificial substrate depth on freezing injury of six herbaceous perennials grown in a green roof system." *HortTechnology* 11 (3):409-412.

Bonan, Gordon B. 1989. "A computer model of the solar radiation, soil moisture, and soil thermal regimes in boreal forests." *Ecological Modelling* 45 (4):275-306.

Bond-Lamberty, Ben, Karen M Brown, Carol Goranson, and Stith T Gower. 2006. "Spatial dynamics of soil moisture and temperature in a black spruce boreal chronosequence." *Canadian journal of forest research* 36 (11):2794-2802.

Boyer, JoS. 1970. "Leaf enlargement and metabolic rates in corn, soybean, and sunflower at various leaf water potentials." *Plant physiology* 46 (2):233-235.

Brenneisen, Sthephan. 2003. "The benefits of biodiversity from green roofs: key design consequences." Proceedings of the 1st North American Green Roof Conference pp323-329.

Butler, Colleen, and Colin M Orians. 2009. "Sedum facilitates the growth of neighboring plants on a green roof under water limited conditions." Proceedings of the 7th

North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Atlanta, GA. Toronto: The Cardinal Group.
Butler, Colleen, and Colin M Orians. 2011. "Sedum cools soil and can improve neighboring plant performance during water deficit on a green roof." *Ecological Engineering* 37 (11):1796-1803.
Campbell, GS. 1988. "Soil water potential measurement: an overview." *Irrigation Science* 9 (4):265-273.
Cooper, Allen John. 1973. "Root temperature and plant growth; a review." *Commonw Bur Hortic Plant Crops Res Rev*.
Dingman, SL. 2002. Water in soils: infiltration and redistribution. Physical hydrology. upper saddle river, New Jersey: Prentice-Hall, Inc.
Domisch, Timo, Leena Finér, and Tarja Lehto. 2002. "Growth, carbohydrate and nutrient allocation of Scots pine seedlings after exposure to simulated low soil temperature in spring." *Plant and Soil* 246 (1):75-86.
Dufault, Robert J, Brian Ward, and Richard L Hassell. 2009. "Dynamic relationships between field temperatures and romaine lettuce yield and head quality." *Scientia horticulturae* 120 (4):452-459.
Dunnett, N, N Kingsbury, Planting Green Roofs, and Living Walls. 2004. "Timber Press." *Portland Oregon*.
Durhman, Angela K, D Bradley Rowe, and Clayton L Rugh. 2007. "Effect of substrate depth on initial growth, coverage, and survival of 25 succulent green roof plant taxa." *HortScience* 42 (3):588-595.
Durner, Wolfgang, and Dani Or. 2005. "Soil water potential measurement." *Encyclopedia of hydrological sciences*.
Elberling, Bo, and Kristian K Brandt. 2003. "Uncoupling of microbial CO 2 production and release in frozen soil and its implications for field studies of arctic C cycling." *Soil Biology and Biochemistry* 35 (2):263-272.
Emilsson, Tobias, and Kaj Rolf. 2005. "Comparison of establishment methods for extensive green roofs in southern Sweden." *Urban Forestry & Urban Greening* 3 (2):103-111.
FLL, FORSCHUNGSGESELLSCHAFT LANDSCHAFTSENTWICKLUNG LANDSCHAFTSBAU EV–. 2002. "Richtlinie für die Planung, Ausführung und Pflege von Dachbegrünungen–Dachbegrünungsrichtlinie." *Bonn, Ausgabe Januar*.
Fowler, Jim, Louis Cohen, Phil Jarvis, and Lou Cohen Jim Fowler. 1998. Practical statistics for field biology.
Franklin, Keara, and Philip Wigge. 2013. *Temperature and plant development*: John Wiley & Sons.
Getter, Kristin L, and D Bradley Rowe. 2006. "The role of extensive green roofs in sustainable development." *HortScience* 41 (5):1276-1285.
Getter, Kristin L, D Bradley Rowe, G Philip Robertson, Bert M Cregg, and Jeffrey A Andresen. 2009. "Carbon sequestration potential of extensive green roofs." *Environmental science & technology* 43 (19):7564-7570.
Hatfield, Jerry L, and John H Prueger. 2015. "Temperature extremes: effect on plant growth and development." *Weather and Climate Extremes* 10:4-10.
Jim, CY, and Lilliana LH Peng. 2012. "Substrate moisture effect on water balance and thermal regime of a tropical extensive green roof." *Ecological Engineering* 47:9-23.

Jim, CY, and SW Tsang. 2011. "Biophysical properties and thermal performance of an intensive green roof." *Building and Environment* 46 (6):1263-1274.

Kaspar, TC, and Wl L Bland. 1992. "Soil temperature and root growth." *Soil Science* 154 (4):290-299.

Klein, Julia A, John Harte, and Xin-Quan Zhao. 2007. "Experimental warming, not grazing, decreases rangeland quality on the Tibetan Plateau." *Ecological Applications* 17 (2):541-557.

Köhler, Manfred. 2003. "Plant survival research and biodiversity: Lessons from Europe." First Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show.

Köhler, Manfred. 2006. "Long-term vegetation research on two extensive green roofs in Berlin." *Urban Habitats* 4 (1):3-26.

Körner, Christian. 2003. *Alpine plant life: functional plant ecology of high mountain ecosystems; with 47 tables*: Springer Science & Business Media.

Kramer, Paul J, and John S Boyer. 1995. *Water relations of plants and soils*: Academic press.

Li, Wai Chin, and KKA Yeung. 2014. "A comprehensive study of green roof performance from environmental perspective." *International Journal of Sustainable Built Environment* 3 (1):127-134.

Liu, Karen KY, and A Baskaran. 2005. *Using garden roof systems to achieve sustainable building envelopes*: Institute for Research in Construction, National Research Council of Canada.

Liu, Xinsheng, and Tianxiang Luo. 2011. "Spatiotemporal variability of soil temperature and moisture across two contrasting timberline ecotones in the Sergyemla Mountains, Southeast Tibet." *Arctic, Antarctic, and Alpine Research* 43 (2):229-238.

Luckett, Kelly. 2009. *Green roof construction and maintenance*: McGraw-Hill.

Lundholm, Jeremy, J Scott MacIvor, Zachary MacDougall, and Melissa Ranalli. 2010. "Plant species and functional group combinations affect green roof ecosystem functions." *Plos One* 5 (3):e9677.

Meehl, Gerard A, Thomas F Stocker, William D Collins, AT Friedlingstein, Amadou T Gaye, Jonathan M Gregory, Akio Kitoh, Reto Knutti, James M Murphy, and Akira Noda. 2007. "Global climate projections."

Mentens, Jeroen, Dirk Raes, and Martin Hermy. 2006. "Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?" *Landscape and urban planning* 77 (3):217-226.

Molineux, Chloe J, Charles H Fentiman, and Alan C Gange. 2009. "Characterising alternative recycled waste materials for use as green roof growing media in the UK." *Ecological Engineering* 35 (10):1507-1513.

Olszewski, Michael W, and Courtney A Young. 2011. "Physical and chemical properties of green roof media and their effect on plant establishment." *Journal of Environmental Horticulture* 29 (2):81.

Peck, Steven W, Chris Callaghan, Monica E Kuhn, and Brad Bass. 1999. *Greenbacks from green roofs: forging a new industry in Canada*: Citeseer.

Rabenhorst, Martin C. 2005. "Biologic zero: a soil temperature concept." *Wetlands* 25 (3):616-621.

Redding, TE, GD Hope, M-J Fortin, MG Schmidt, and WG Bailey. 2003. "Spacial patterns of soil temperature and moisture across subalpine forest-clearcut edges in the southern interior of British Columbia." *Canadian Journal of Soil Science* 83 (1):121-130.

Reinhardt, Stefanie, and Arvid Odland. 2012. "Soil temperature variation in calciphile mountain plant communities in Southern Norway." *Reinhardt, S.(2013). The importance of snow for mountain vegetation in the Hardangervidda area (Southern Norway): plant distribution, plant phenology, plant diversity, and effects of global climate change. PhD thesis, Telemark University College.* http://hdl*. handle. net/2282/1420*.

Rosenzweig, Cynthia, Stuart Gaffin, and Lily Parshall. 2006. "Green roofs in the New York metropolitan region: research report." *Columbia University Center for Climate Systems Research and NASA Goddard Institute for Space Studies. New York*:1-59.

Sacks, William J, and Christopher J Kucharik. 2011. "Crop management and phenology trends in the US Corn Belt: Impacts on yields, evapotranspiration and energy balance." *Agricultural and Forest Meteorology* 151 (7):882-894.

Sato, S. 2006. "The effects of moderately elevated temperature stress due to global warming on the yield and the male reproductive development of tomato (Lycopersicon esculentum Mill.)." *HortResearch-Chiba University (Japan)*.

Sayed, OH. 2001. "Crassulacean acid metabolism 1975–2000, a check list." *Photosynthetica* 39 (3):339-352.

Scherrer, Daniel, Samuel Schmid, and Christian Körner. 2011. "Elevational species shifts in a warmer climate are overestimated when based on weather station data." *International journal of Biometeorology* 55 (4):645-654.

Stolte, J. 1997. "Manual of soil physical measurements." *Technical document* 37.

Sutton, Richard K, John A Harrington, Lee Skabelund, Peter MacDonagh, Reid R Coffman, and Gord Koch. 2012. "Prairie-based green roofs: literature, templates, and analogs." *Journal of Green Building* 7 (1):143-172.

Sutton, Richard K. 2015. "Introduction to Green Roof Ecosystems." In *Green Roof Ecosystems*, edited by Richard K. Sutton, 1-25. Cham: Springer International Publishing.

Tabachnick, Barbara G, Linda S Fidell, and Steven J Osterlind. 2001. "Using multivariate statistics."

Teemusk, Alar, and Ülo Mander. 2007. "Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events." *Ecological engineering* 30 (3):271-277.

Teemusk, Alar, and Ülo Mander. 2010. "Temperature regime of planted roofs compared with conventional roofing systems." *Ecological Engineering* 36 (1):91-95.

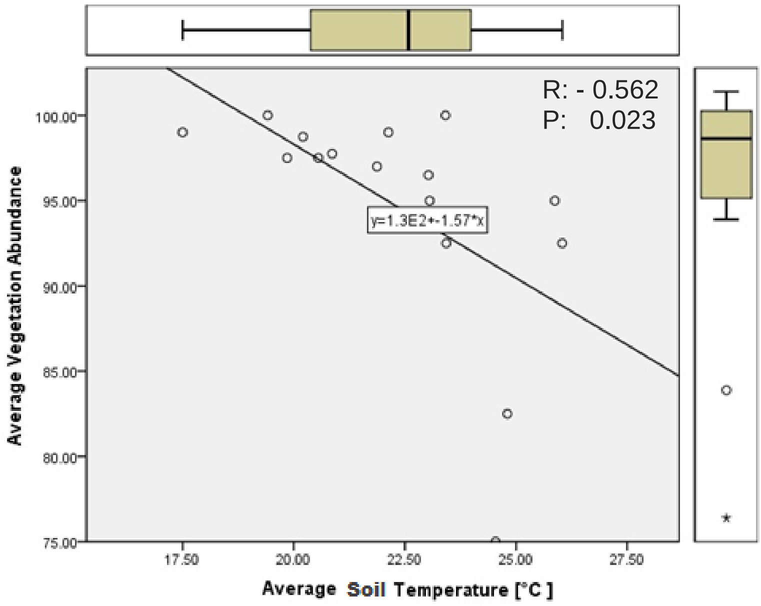
Tesfaendrias, Michael T, Mary Ruth McDonald, and Jon Warland. 2010. "Consistency of long-term marketable yield of carrot and onion cultivars in muck (organic) soil in relation to seasonal weather." *Canadian Journal of Plant Science* 90 (5):755-765.

Timlin, Dennis, SM Lutfor Rahman, Jeffery Baker, VR Reddy, David Fleisher, and Bruno Quebedeaux. 2006. "Whole plant photosynthesis, development, and carbon partitioning in potato as a function of temperature." *Agronomy Journal* 98 (5):1195-1203.

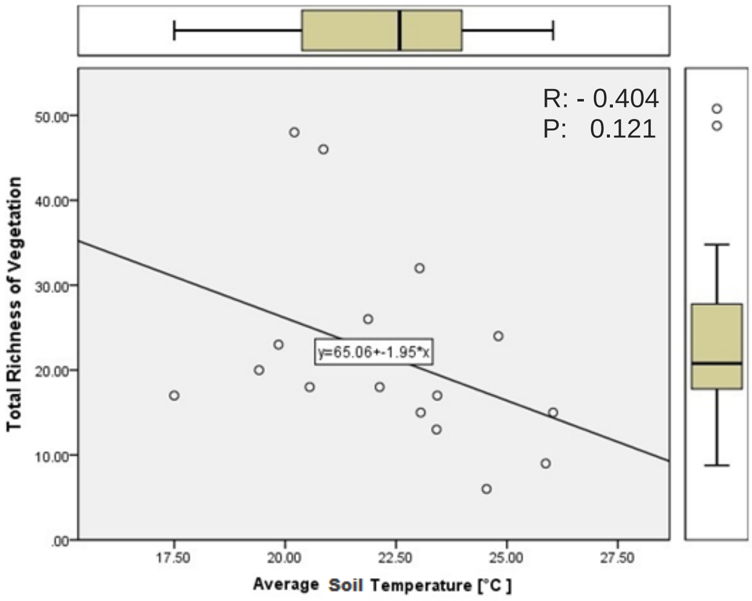
Tuller, Markus, and Dani Or. 2004. "Retention of water in soil and the soil water characteristic curve." *Encyclopedia of Soils in the Environment* 4:278-289.

Van Renterghem, Timothy, and Dick Botteldooren. 2008. "Numerical evaluation of sound propagating over green roofs." *Journal of Sound and Vibration* 317 (3):781-799.
Van Wijk, WR. 1965. "Soil microclimate, its creation, observation and modification." In *Agricultural Meteorology*, 59-73. Springer.
VanWoert, Nicholaus D, D Bradley Rowe, Jeffrey A Andresen, Clayton L Rugh, and Lan Xiao. 2005. "Watering regime and green roof substrate design affect Sedum plant growth." *HortScience* 40 (3):659-664.
Veihmeyer, FJ, and AH Hendrickson. 1950. "Soil moisture in relation to plant growth." *Annual review of plant physiology* 1 (1):285-304.
Weih, Martin, and P Staffan Karlsson. 2002. "Low winter soil temperature affects summertime nutrient uptake capacity and growth rate of mountain birch seedlings in the subarctic, Swedish lapland." *Arctic, Antarctic, and Alpine Research*:434-439.
Whitlock, Michael C, and Dolph Schluter. 2009. *The analysis of biological data*: CSIRO.
Xu, Qingzhang, and Bingru Huang. 2000. "Growth and physiological responses of creeping bentgrass to changes in air and soil temperatures." *Crop Science* 40 (5):1363-1368.
Yang, Jun, Qian Yu, and Peng Gong. 2008. "Quantifying air pollution removal by green roofs in Chicago." *Atmospheric environment* 42 (31):7266-7273.
Yeh, Tian-Chyi, Raziuddin Khaleel, and Kenneth C Carroll. 2015. *Flow through heterogeneous geologic media*: Cambridge University Press.

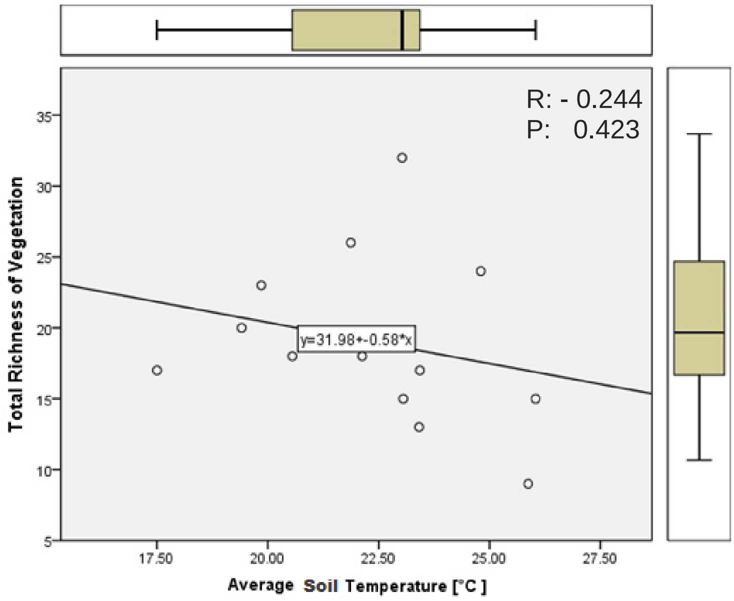
7 Appendix



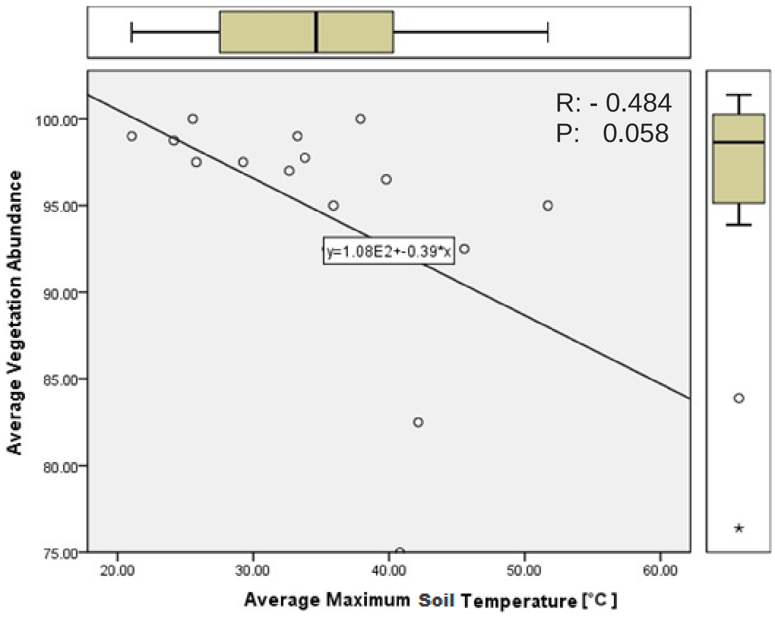
Appendix 1. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and Regression between abundance of vegetation and average soil temperature with regression equation during warm period in July



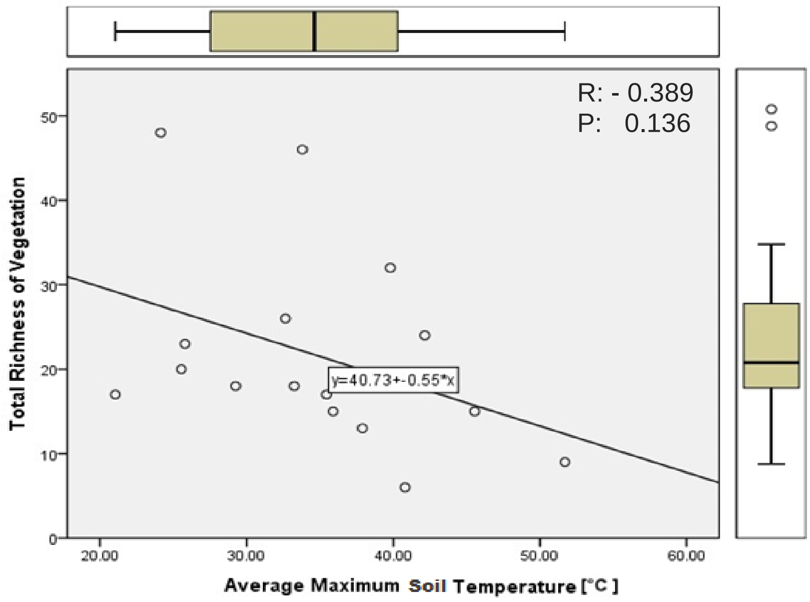
Appendix 2. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and Regression between total richness of vegetation and average soil temperature with regression equation during warm period in July



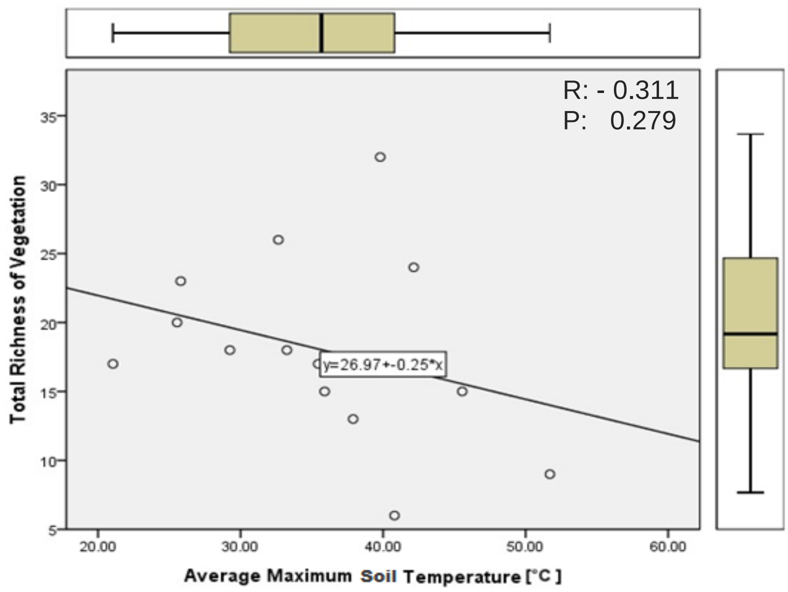
Appendix 3. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and Regression between total richness of vegetation and average soil temperature with regression equation without outliers points during warm period in July



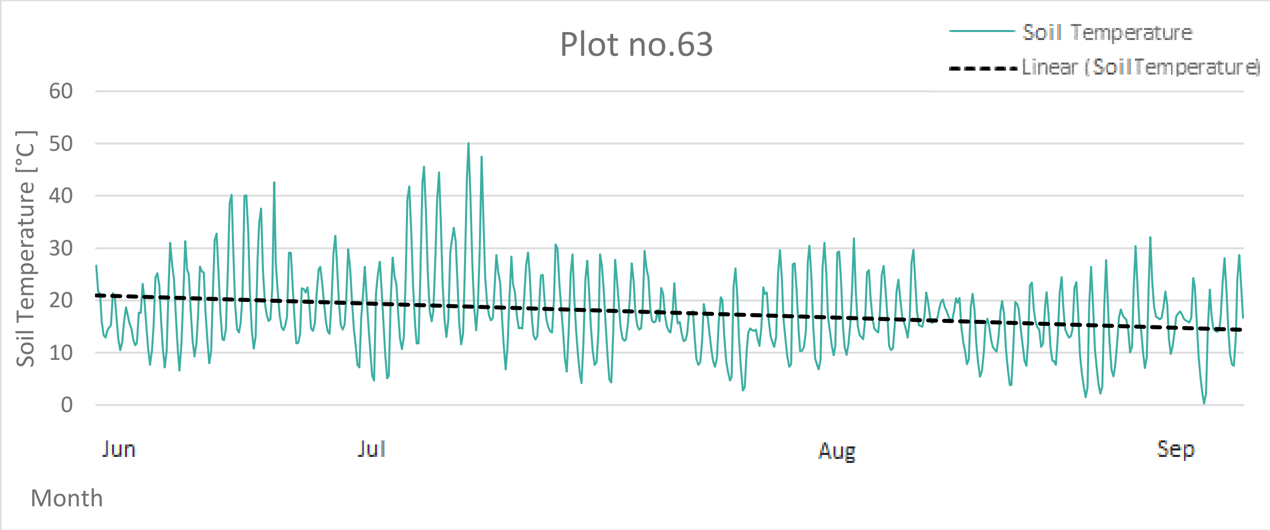
Appendix 4. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and Regression between abundance of vegetation and average maximum soil temperature with regression equation during summer



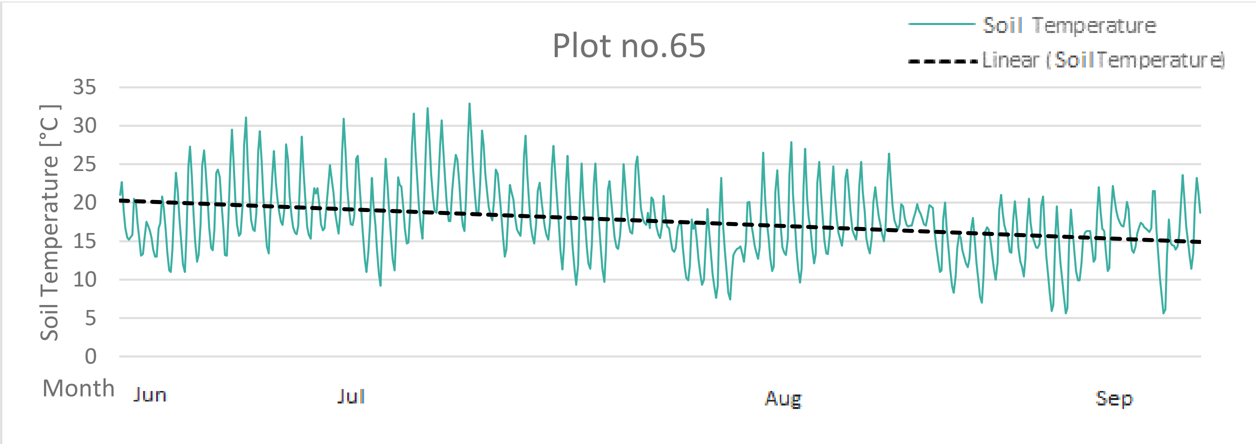
Appendix 5. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and Regression between total richness of vegetation and average maximum soil temperature with regression equation during summer



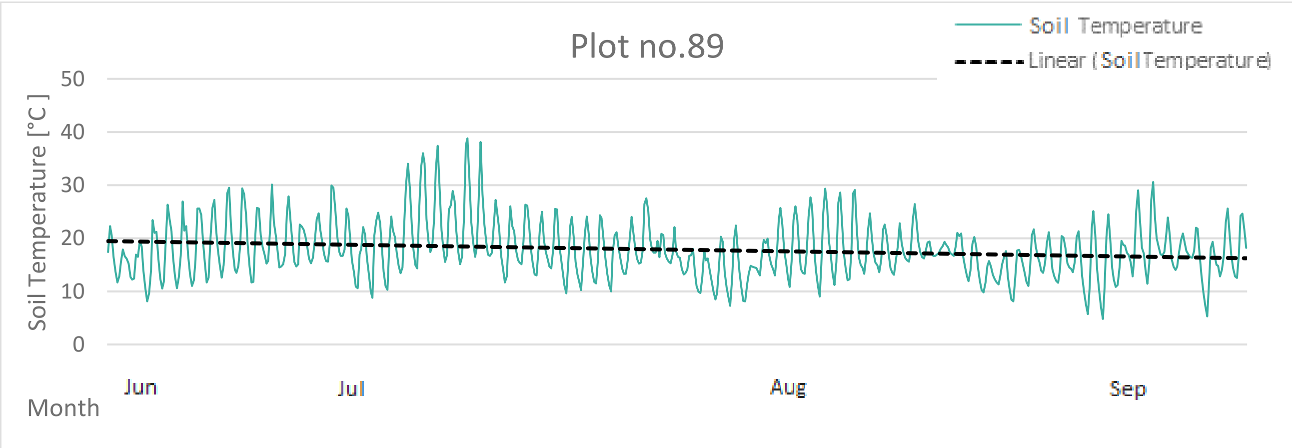
Appendix 6. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and Regression between total richness of vegetation and average maximum soil temperature with regression equation without outliers points during summer



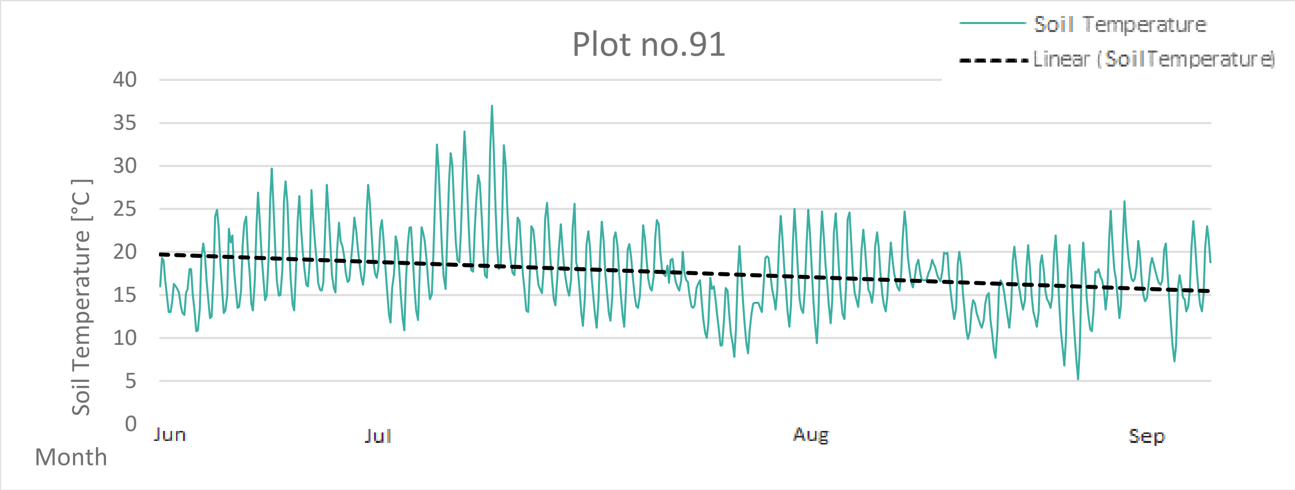
Appendix 7. Soil temperature measurement in plot.no 63 of BARN I at summer 2016



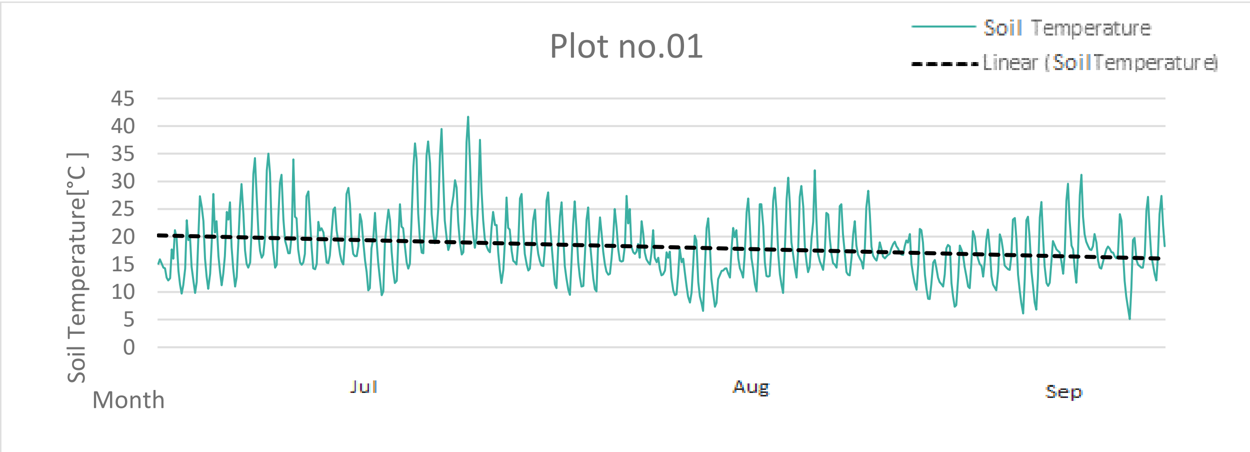
Appendix 8. Soil temperature measurement in plot.no 65 of BARN II at summer 2016



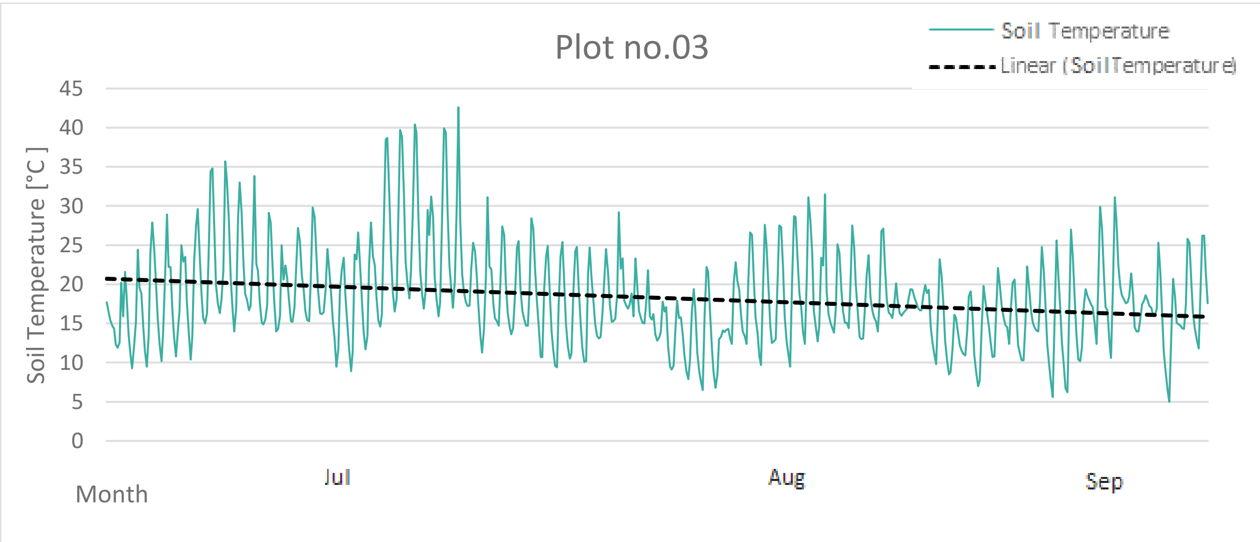
Appendix 9. Soil temperature measurement in plot.no 89 of KVAR at summer 2016



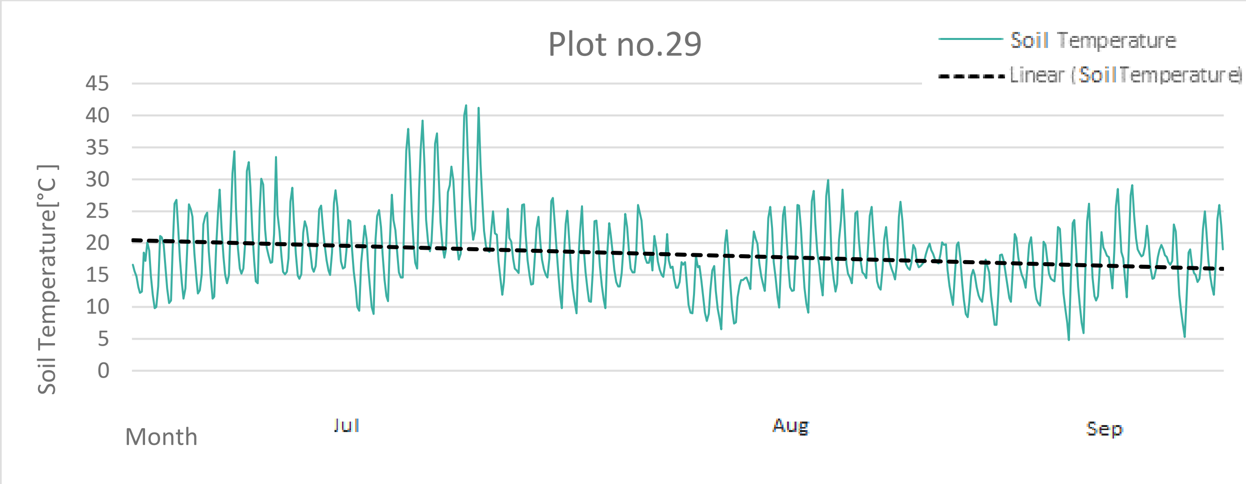
Appendix 10. Soil temperature measurement in plot.no 91 of KVAR at summer 2016



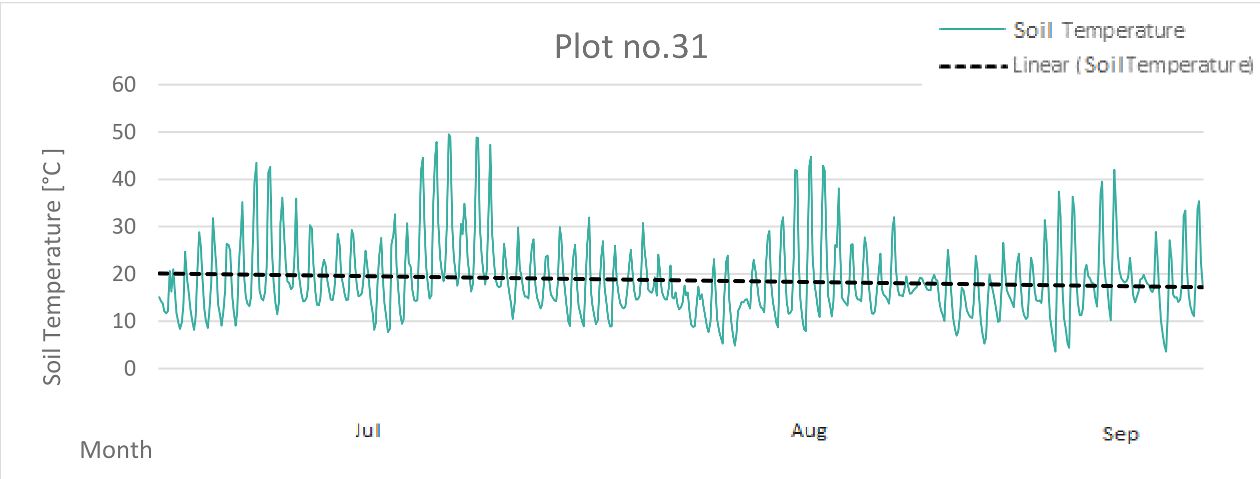
Appendix 11. Soil temperature measurement in plot.no 01 of HOEG at summer 2016



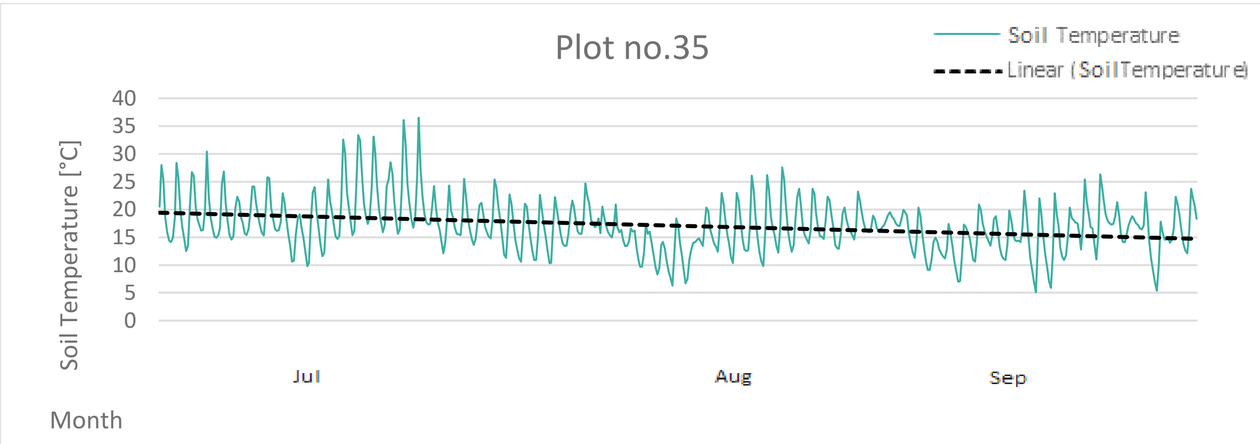
Appendix 12. Soil temperature measurement in plot.no 03 of HOEG at summer 2016



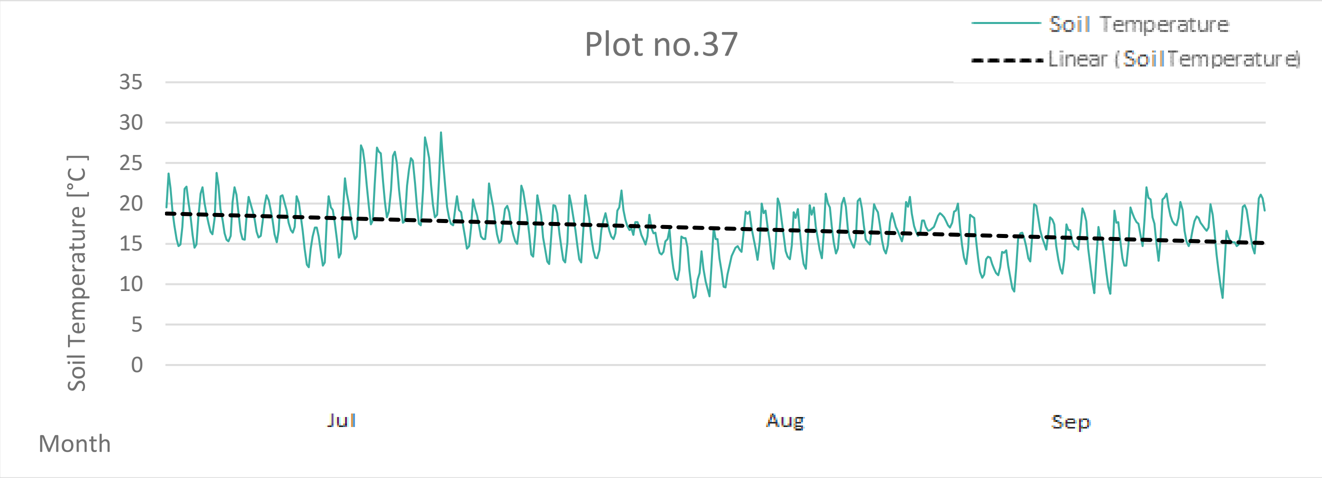
Appendix 13. Soil temperature measurement in plot.no 29 of STEN at summer 2016



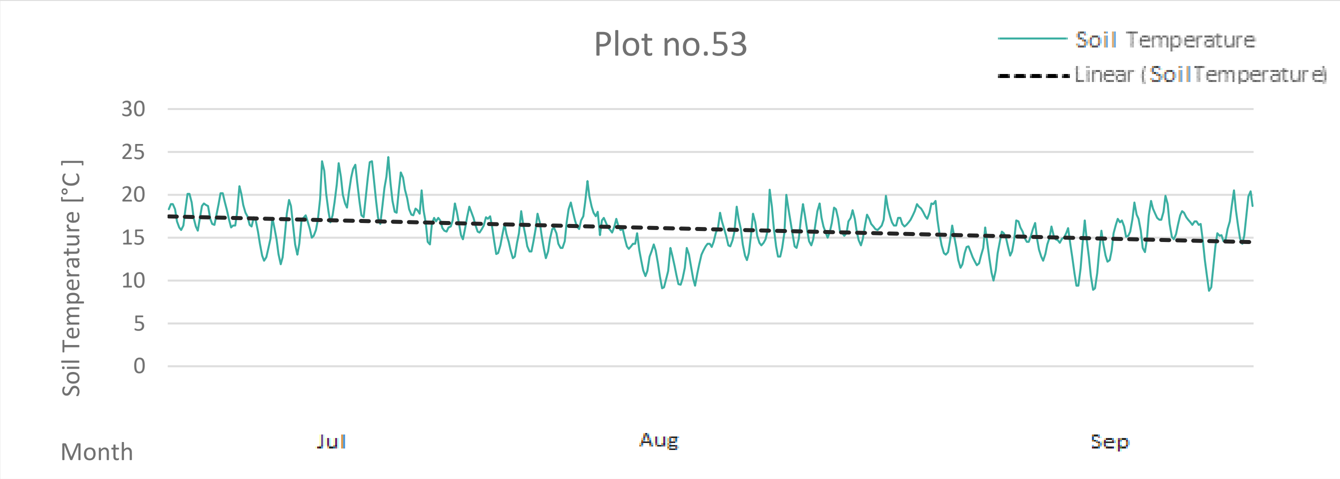
Appendix 14. Soil temperature measurement in plot.no 31 of STEN at summer 2016



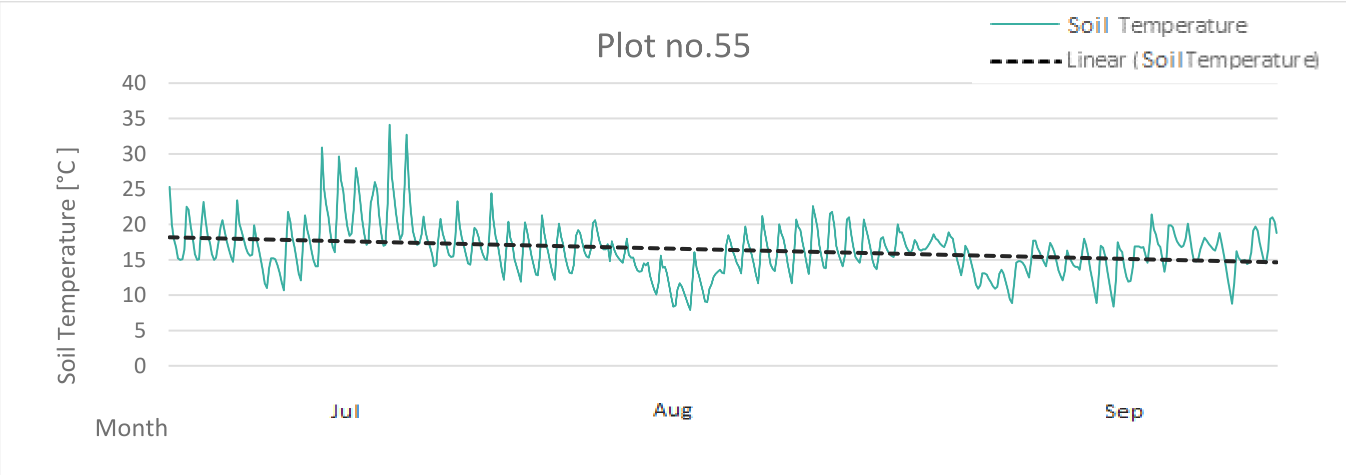
Appendix 15. Soil temperature measurement in plot.no 35 of PI 20 at summer 2016



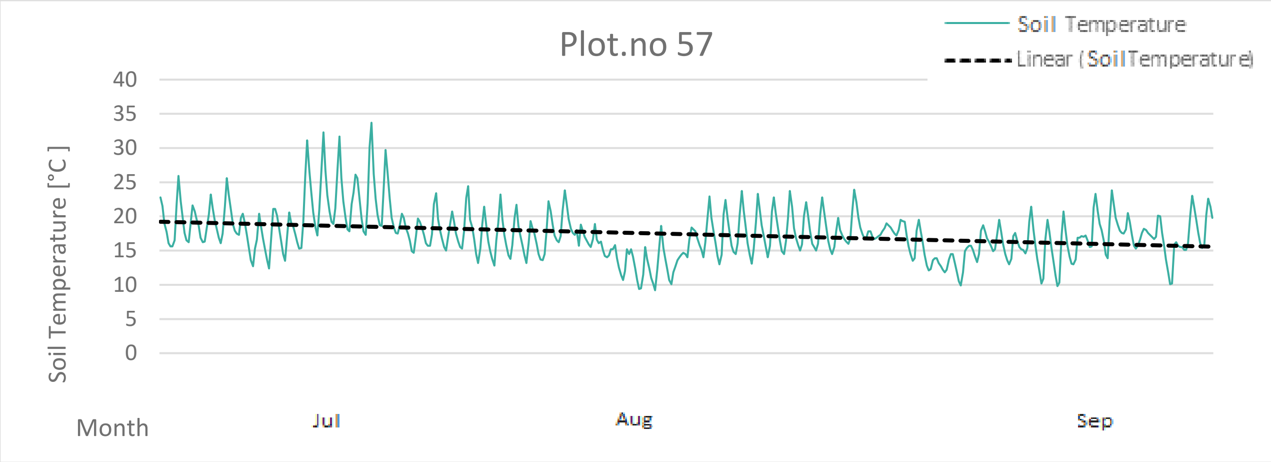
Appendix 16. Soil temperature measurement in plot.no 37 of PI 20 at summer 2016



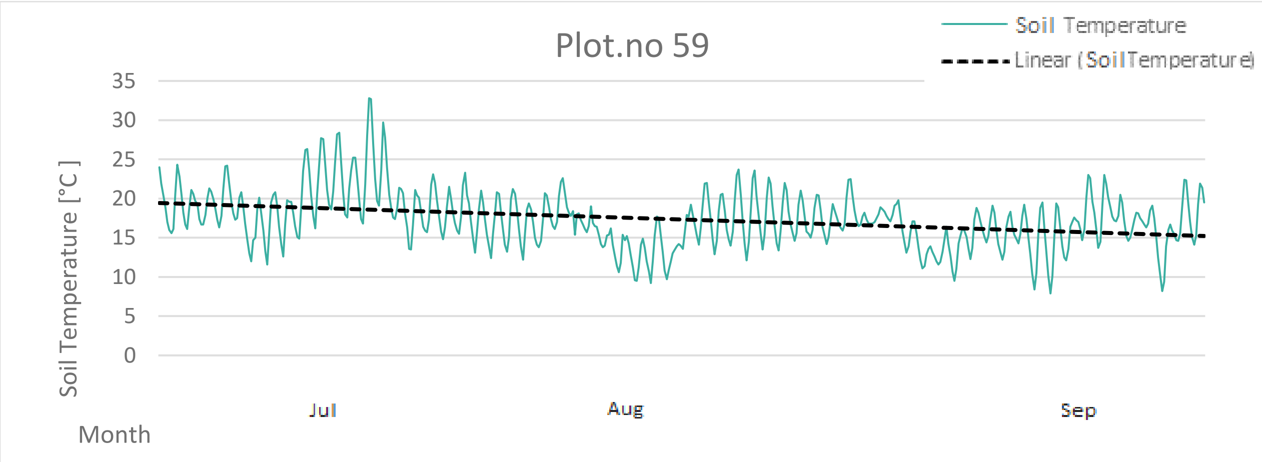
Appendix 17. Soil temperature measurement in plot.no 53 of SORE I,85 at summer 2016



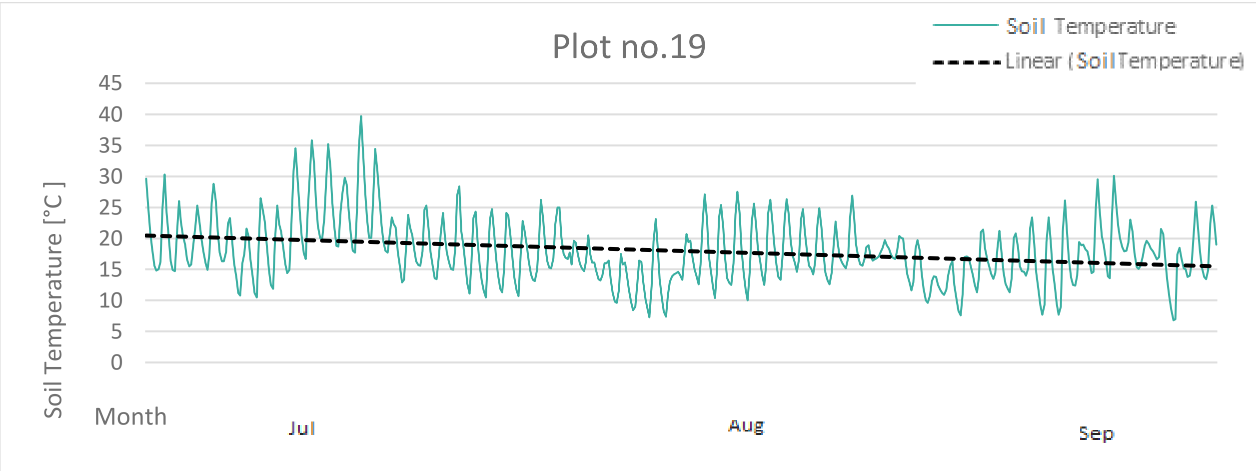
Appendix 18. Soil temperature measurement in plot.no 55 of SORE I,85 at summer 2016



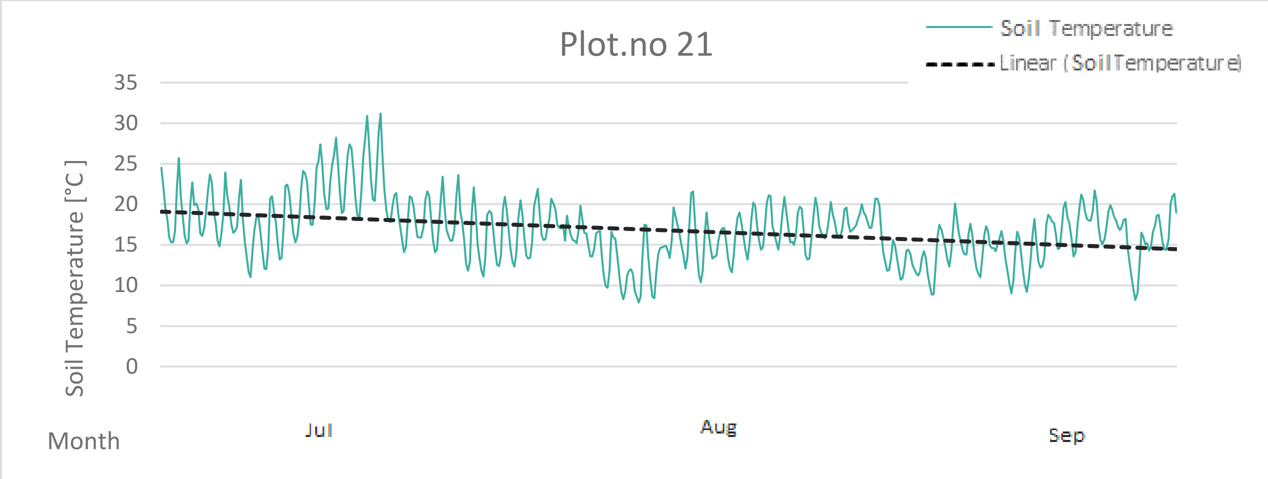
Appendix 19. Soil temperature measurement in plot.no 57of SORE I,85 at summer 2016



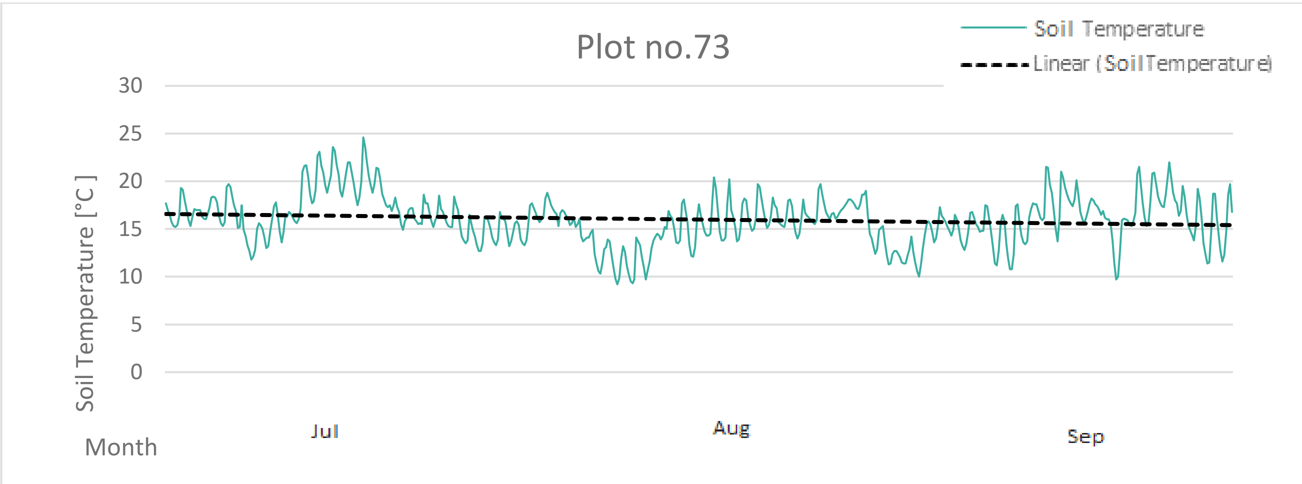
Appendix 20. Soil temperature measurement in plot.no 57of SORE I,99 at summer 2016



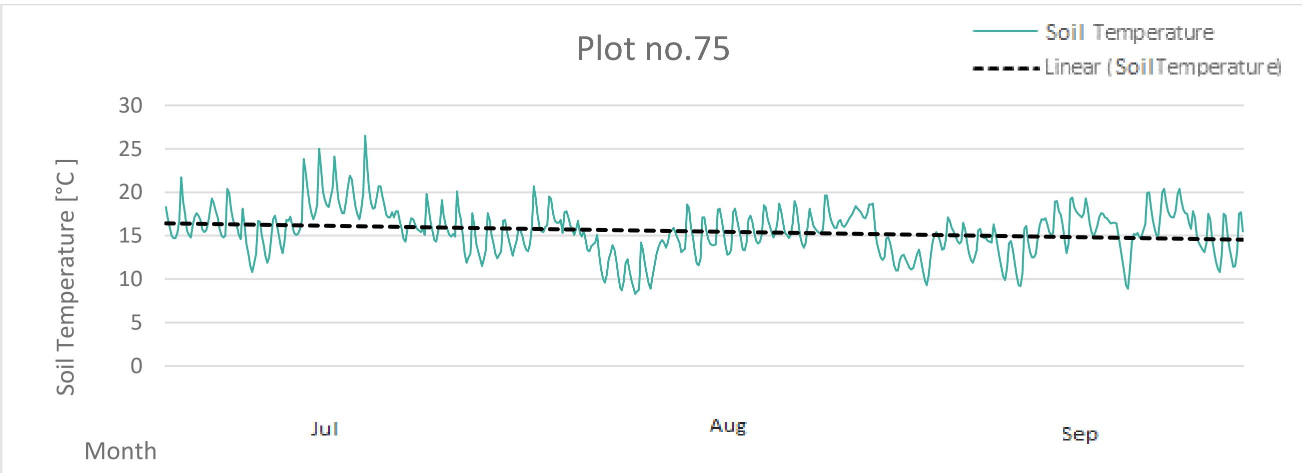
Appendix 21. Soil temperature measurement in plot.no 19 of SORE II at summer 2016



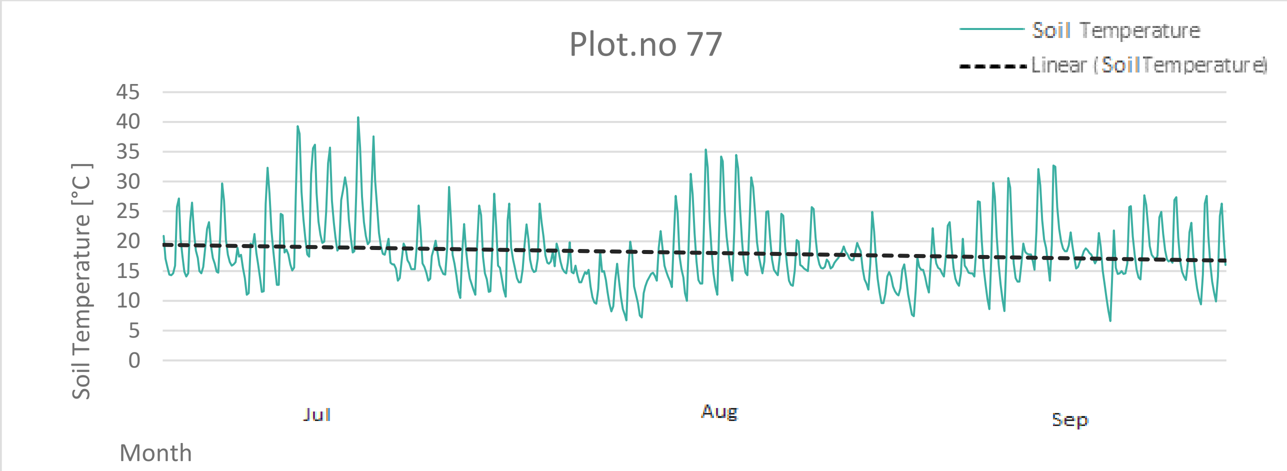
Appendix 22. Soil temperature measurement in plot.no 21 of SORE II at summer 2016



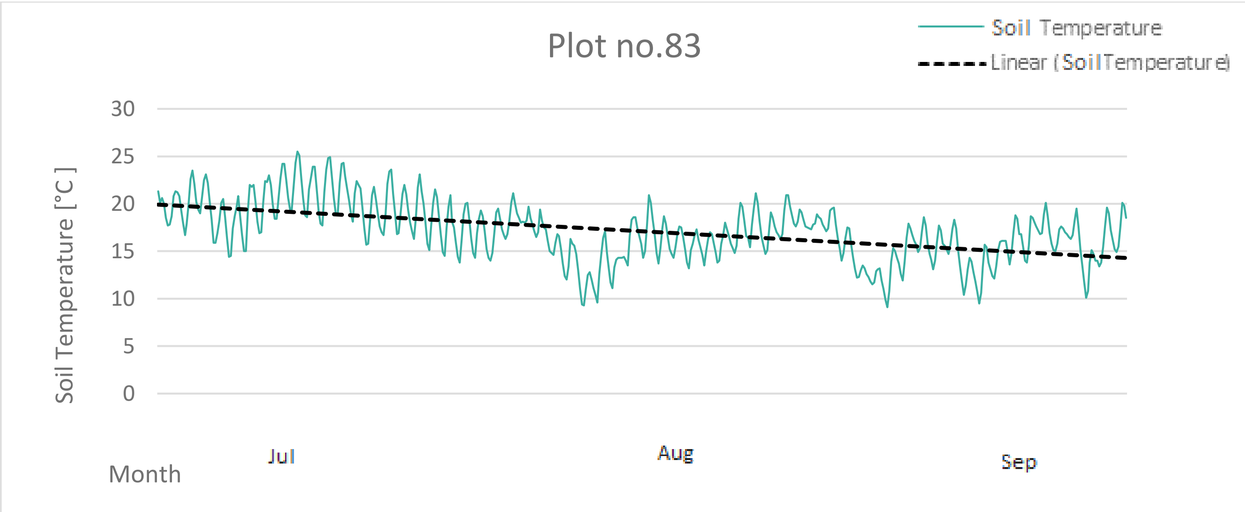
Appendix 23. Soil temperature measurement in plot.no 73 of BJOR I at summer 2016



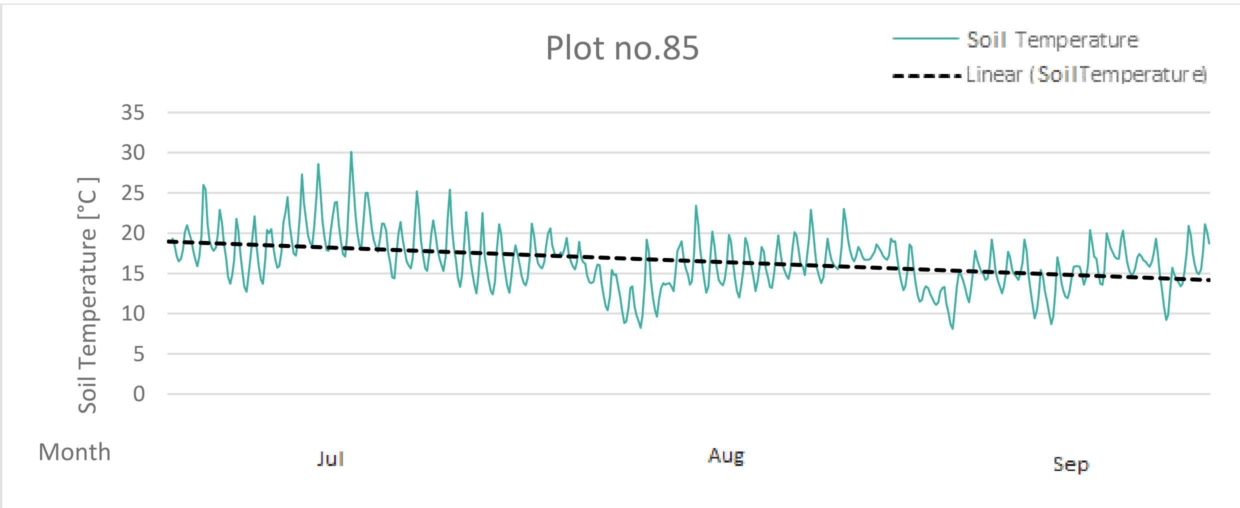
Appendix 24. Soil temperature measurement in plot.no 75 of BJOR I at summer 2016



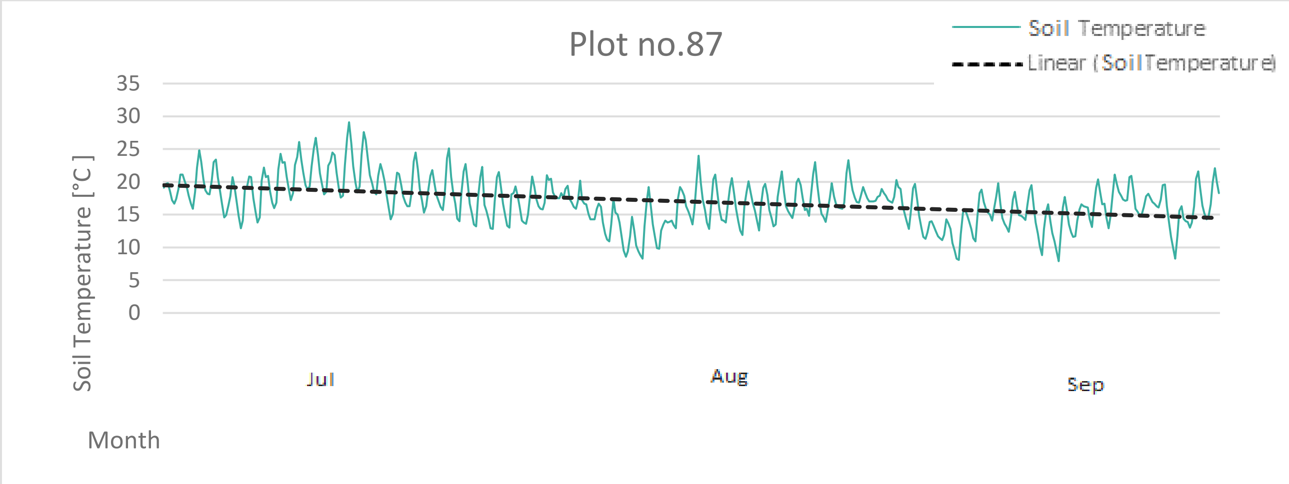
Appendix 25. Soil temperature measurement in plot.no 77 of BJOR II at summer 2016



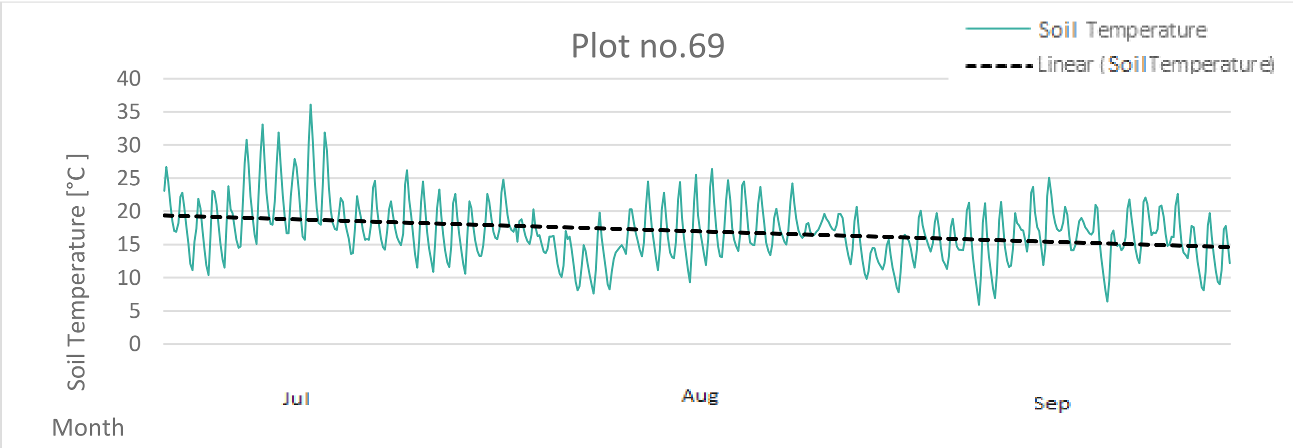
Appendix 26. Soil temperature measurement in plot.no 83 of KREM at summer 2016



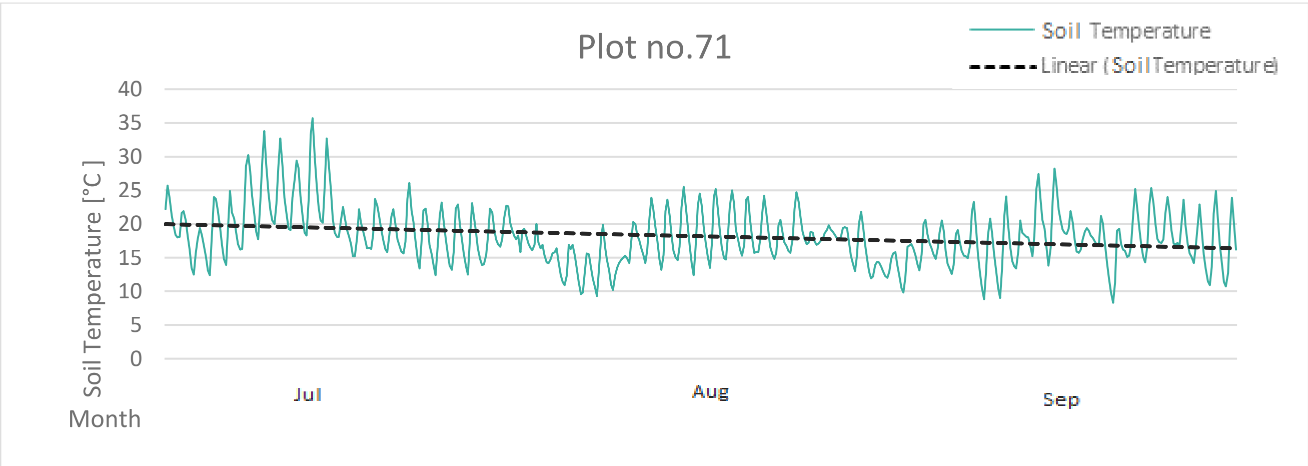
Appendix 27. Soil temperature measurement in plot.no 85 of KREM at summer 2016



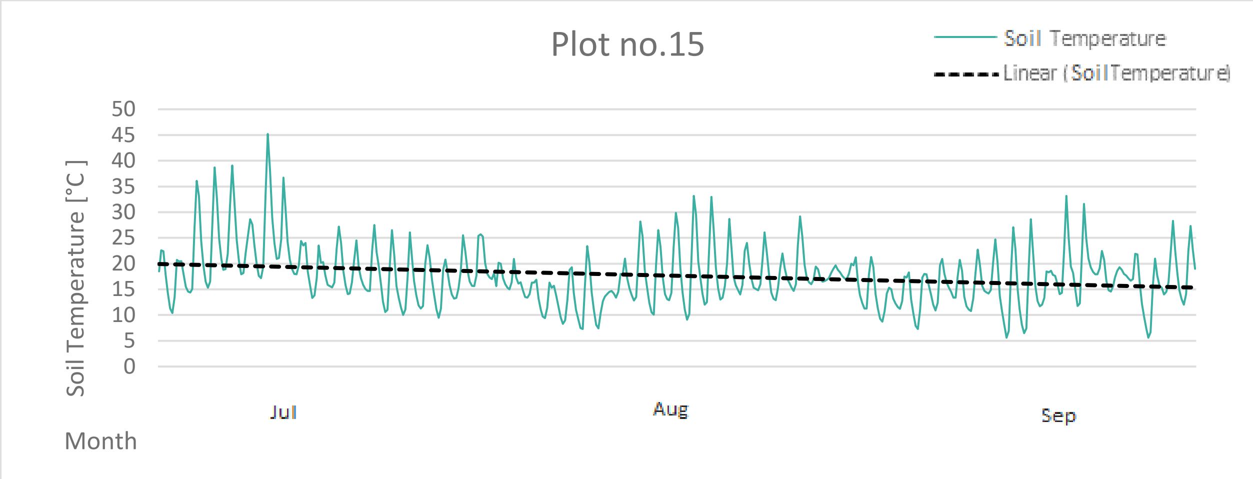
Appendix 28. Soil temperature measurement in plot.no 87 of KREM at summer 2016



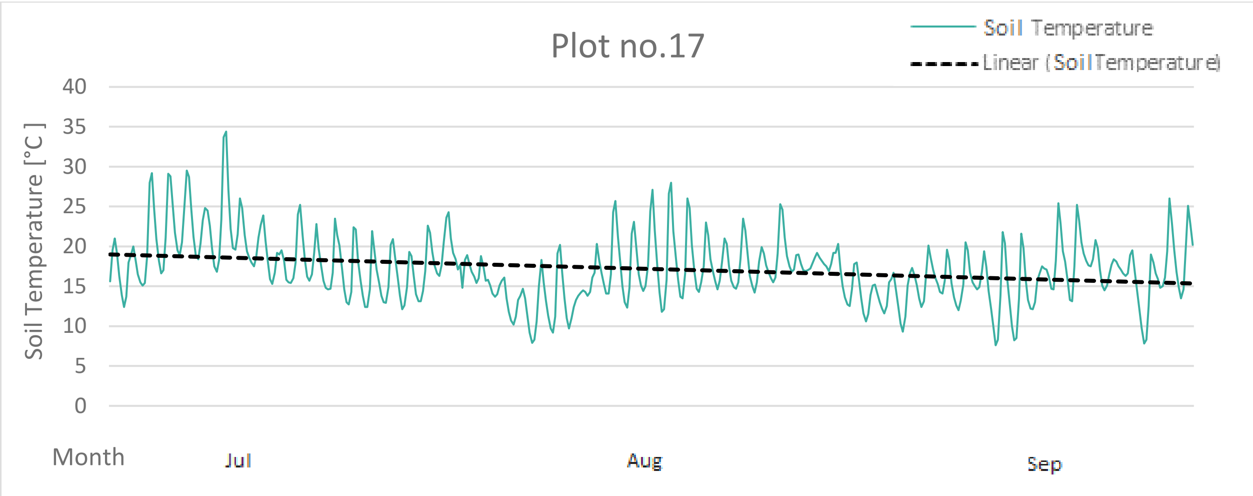
Appendix 29. Soil temperature measurement in plot.no 69 of AKER at summer 2016



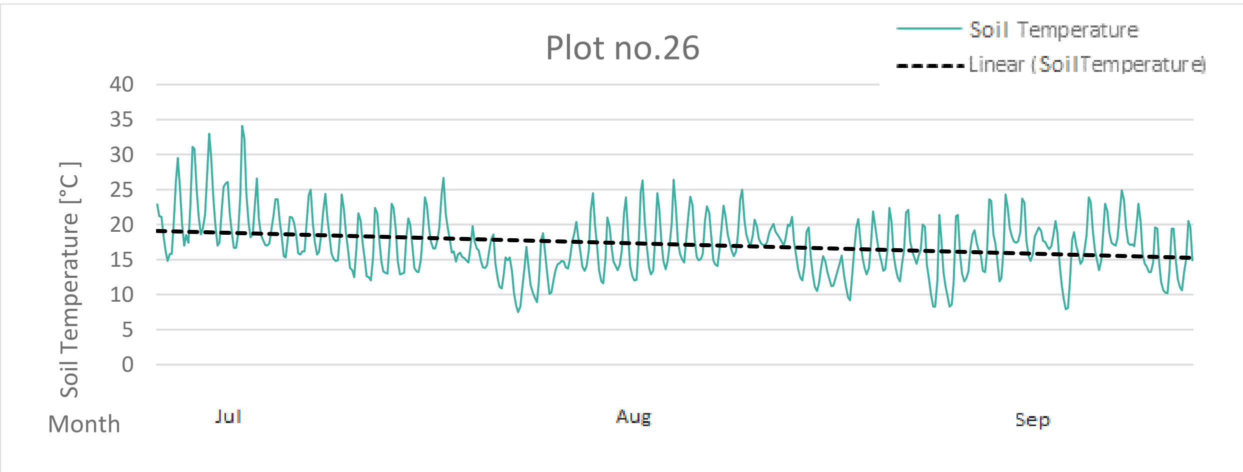
Appendix 30. Soil temperature measurement in plot.no 71 of AKER at summer 2016



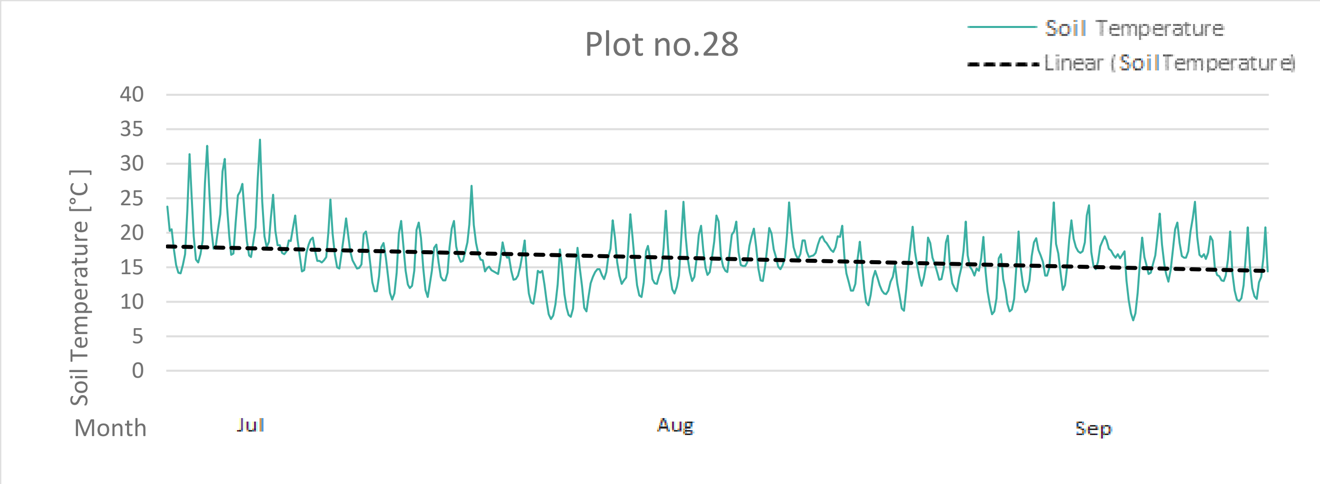
Appendix 31. Soil temperature measurement in plot.no15 of PI 25 at summer 2016



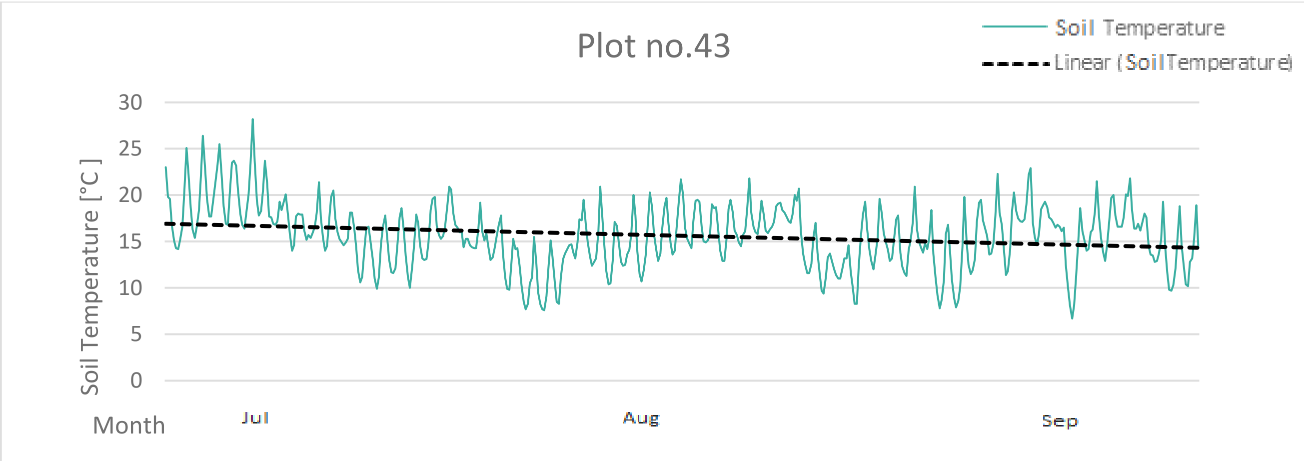
Appendix 32. Soil temperature measurement in plot.no17 of PI 25 at summer 2016



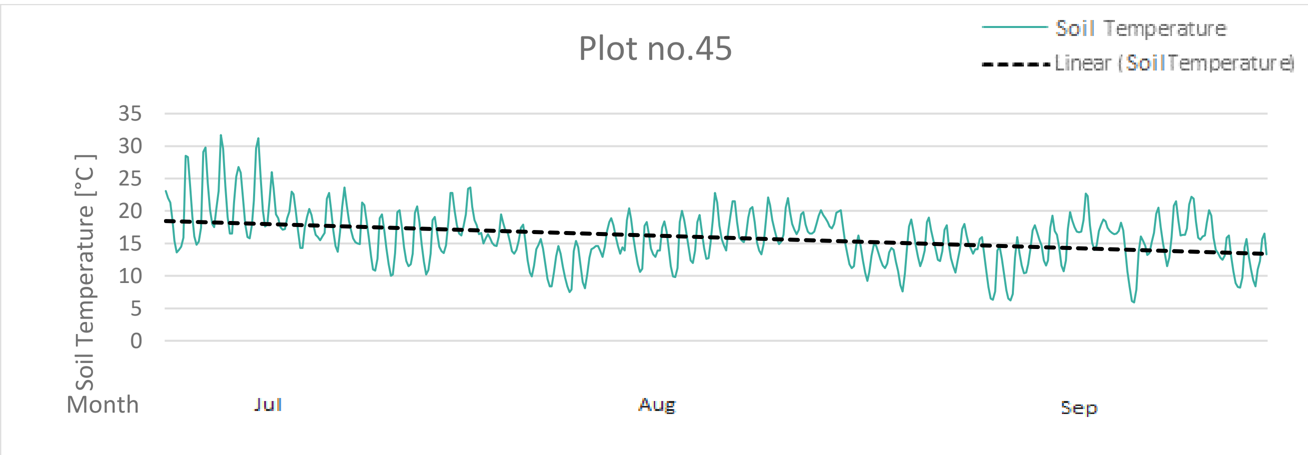
Appendix 33. Soil temperature measurement in plot.no26 of Forn at summer 2016



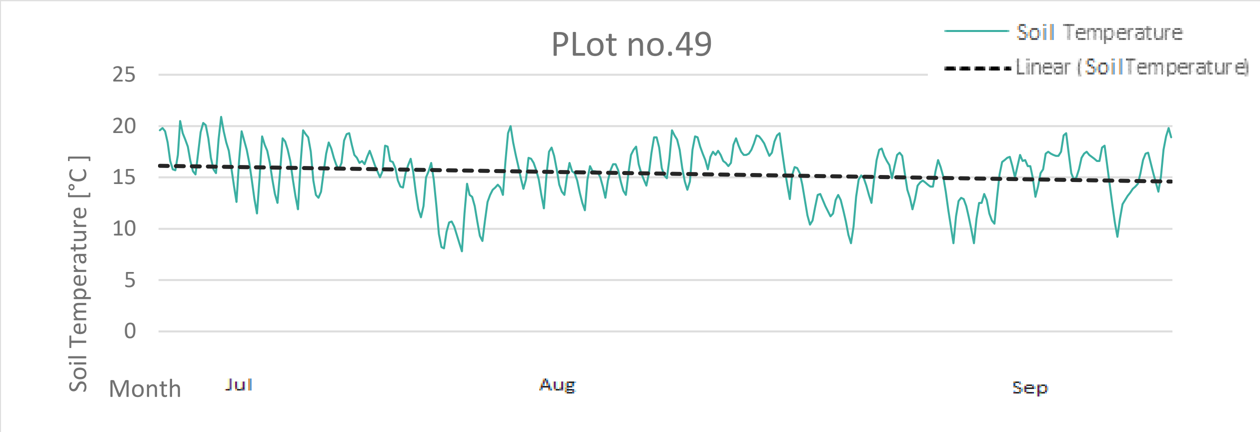
Appendix 34. Soil temperature measurement in plot.no28 of Forn at summer 2016



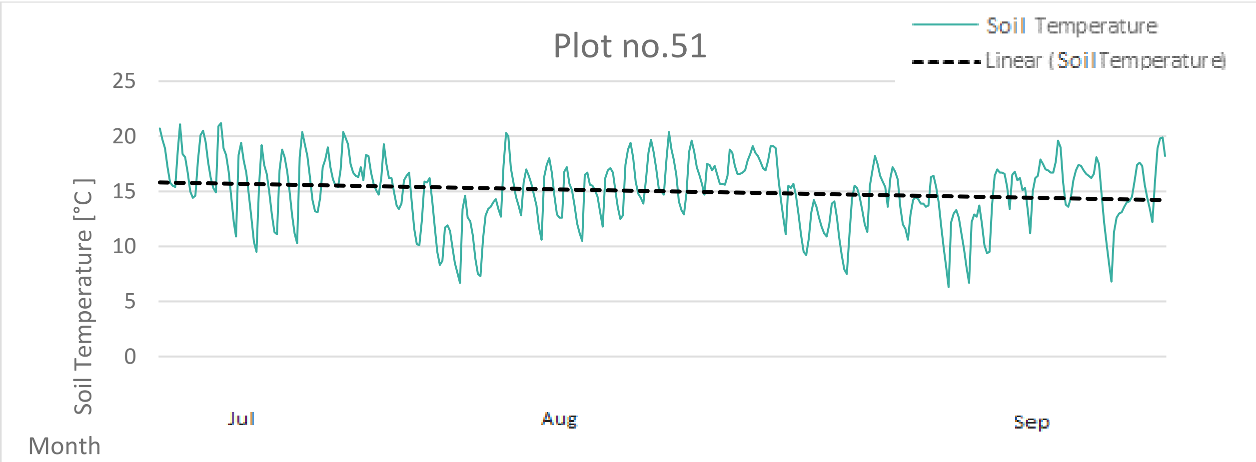
Appendix 35. Soil temperature measurement in plot.no 43 of Forn at summer 2016



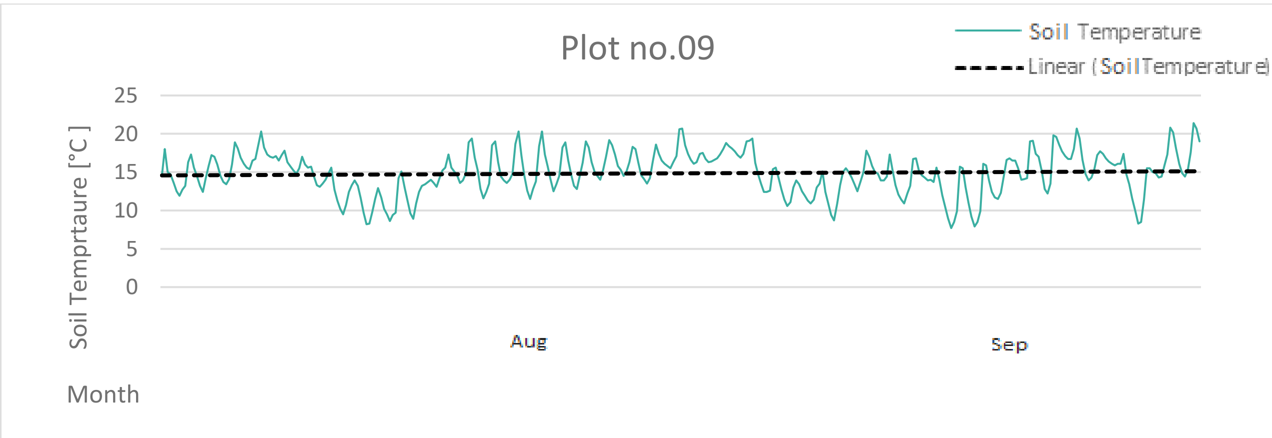
Appendix 36. Soil temperature measurement in plot.no 45 of Forn at summer 2016



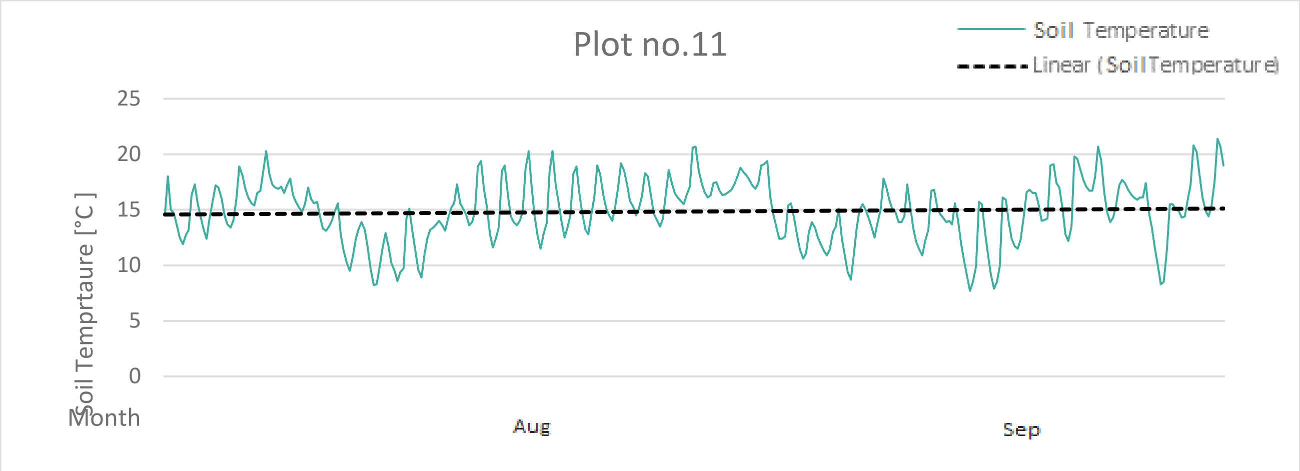
Appendix 37. Soil temperature measurement in plot.no 49 of UNIV at summer 2016



Appendix 38. Soil temperature measurement in plot.no 51 of UNIV at summer 2016



Appendix 39. Soil temperature measurement in plot.no 09 of GJEN at summer 2016



Appendix 40. Soil temperature measurement in plot.no 11 of GJEN at summer 2016