SPATIAL AND TEMPORAL DISTRIBUTION OF WATER REPELLENCY AND ITS INFLUENCING FACTORS IN FOREST SOILS

Experimental research of spatial and temporal distribution of water repellency and its influencing factors in the study area of Holzbach in the Hunsrück low mountain range in Germany

MSc Thesis by A.I Marruedo Arricibita

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Preface & Acknowledgement

This thesis research has been the first real research that I have experienced by my own. I have learnt how to make decisions by myself in order to get a target and how to deal with the problems that can arise while the research is ongoing. I also have increased my knowledge in the field of water repellency and erosion processes which is something that I´m really interested on.

First of all, I would like to thanks my family for the emotional, moral and economical support that they always gave to me in order to complete my academic education and my personal goals. Secondly, I also would like to thanks my friends that always have been there supporting me during the realization of this thesis research.

Special thanks also to Manuel Seeger, my supervisor in Wageningen University, who offered me this thesis research topic which I enjoyed a lot, and his help and advices during the writing of the report. I also would like to highlight René Wengel as an appreciated colleague of the department of Physical Geography in Trier University and as a great field work partner. Also I would like to thank Verena Butzen for her help during my stay in Trier and in general to the entire department stuff of Physical Geography in Trier University for giving me the opportunity of working with them and their materials.

A.I. Marruedo Arricibita

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Abstract

Water repellency has been suggested to be directly related to soil moisture content and may affect directly runoff and erosion risk. This study aimed to research on the spatial and temporal variation of water repellency, the relationship of water repellency with moisture content and on its influence on generation of runoff and erosion in the forestry area of Holzbach in the Hunsruck low mountain range in Germany. Regarding the spatial variation of the studied variables, 21 rainfall experiments were carried out in 7 different study sites, with 2-4 repetitions of the experiment on each site. WDPT and soil sampling with 100 cm^3 cylinders were carried out on each rainfall experiment site before and after the rainfall experiment. For insights into the temporal variation of the studied variables, the analyses were carried out on two different dates. Suspended sediment load, suspended sediment concentration, runoff of the rainfall simulations and volumetric moisture content of the test sites were measured in laboratory. Water repellent conditions were observed in both forest types; coniferous (Spruce) and deciduous (Beech) forests. No temporal variation trends of water repellency or of volumetric moisture content were observed in any of them. The influence of more variables depending on time is suggested, such as: precipitation, temperature, humidity and evapo-transpiration. Significant differences between both forest types were found. Beech forest showed more wettable conditions, higher soil moisture content and later generation of runoff than Spruce forest. In both forest types, no direct relationship between water repellency and volumetric moisture content was observed. Non-linear relationship is suggested between both variables, including the influence of more abiotic and biotic variables. Any transition zone was observed in any of the forest types when relating row data of water repellency and volumetric moisture content, opposite to several researches' suggestions. However, in Spruce forest a threshold value of 30% moisture content was observed above which no water repellent conditions were observed except for non-normal values. On the other hand, a significant correlation between water repellency and suspended sediment load was observed in Spruce forest; suggesting influence of water repellency on runoff risk. Water repellency was observed in both forest types within the study area. Spatial and temporal distribution of water repellency is thought to be of high complexity, which is not possible to characterize only with the studied few variables. Influence of more variables in water repellency of the studied forests is suggested.

Key words: forestry, water repellency, spatial variation, temporal variation, volumetric moisture content, non-linear relationship, runoff, WDPT, biotic factors, threshold value, transition zone.

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1. Introduction

The forests of North West Europe (NWE) are covering about 17.4 million ha of Europe. According to ForeStClim (2011), the climate change is influencing the natural environments in NWE zone, increasing the pressure of climate pattern changes over these environments (FAO 2006). Like long-lived ecosystems, their adaptation to climate change could be more difficult than the adaptation to the current climate conditions and could be easily influenced by the effects of this phenomenon. Since "sustainable management of these natural resources is of vital importance for the advancement of the entire NWE zone"(FAO 2006)(ForeStCLim, 2011), management strategies should be adapted to climate change in order to preserve in a near future, the conservational functions of the forests, (ForeStCLim, 2011). Furthermore, natural environments such as forest are of high importance at economical, environmental and social scale (Derkson 2008).

Germany is considered within the NWE zone. NWE as well as Germany are part of the project called "Transnational Forestry Management Strategies in Response to Regional Climate Change Impacts" (ForeStClim), which "endeavors since 2008 to form a platform for 21 organizations and uncounted individuals all over North West Europe" (Schuler et al. 2010).

About 31% of the area in Germany is covered by forests, 57.5% of that forest is composed by conifers. Forestry is the second most important land use of this country (Roering, 2004). Since, the changing climate pattern influences the conservational properties and functions of the forests, the importance of the conservational, recreational and nature protection functions is increasing in Germany (Hausler et al. 2001). This is leading to a forest management that aims to get the maximum profit in the ecosystem goods production.

According to Roering (2004), the management system of German forests provides different protection levels depending on the uses of the forests regarding the 2002 Ministerial conference on the "Protection of Forests in Europe". One of those protection levels is "Forests with Protective Functions", 27.8% of German forests that means 2,980,850 ha belong to this level (Roering 2004).

The conservational or protective functions of forests can be described as follows:

Regulation of the water balance: Forest helps to diminish the effects of the floods, by storing and filtering the water and releasing it in a slowly and steady way (Hausler and Scherer-Lorenzen 2001).

Regulation of the climate: "Forests can affect the local climate or mesoclimate." (Hausler et al. 2001). In the report of Hausler et al., (2001) it is mentioned that The United Nations by means of the Kyoto Protocol of the Climate Convention, have assigned to the forests the important role of being carbon sinks; this fact is being used as an argument to increase the implementation of (re)-afforestations (monocultures) and intensification of forestry use (Hausler et al. 2001).

Protection from erosion: The protection of soils against the erosion is not only observed in the mountainous areas but also in the hilly areas in Germany, concerning a large portion of its topography (Hausler et al. 2001).

Flood and erosion processes are part of the forests conservational functions and thus are directly linked with soil physical properties. Accordingly, changes in soil physical properties influence the soil erosion and flood processes risk. Therefore the study of soil water repellency, which is a physical property of the soil, becomes of great importance when facing problems such as flooding and soil erosion.

In addition, one of the principal consequences of the climate change is the temporal and spatial change of climate patterns. On the German region of Holzbach in the Hunsrück low mountain range the climate patterns are changing. The winters are less cold, the snow events are diminishing and there are more rainfall events (Jonge et al. 2011). The summers tend to be drier and the precipitations are of high intensity with low frequency rainfall events (Jonge et al. 2011). These patterns especially in summer make the soils of German forests drier; influencing on the soil physical properties, such as water repellency.

Under the scope of the EU project "Transnational Forestry Management Strategies in Response to Regional Climate Change Impacts" (ForeStClim) a research of the influence of soil water repellency in the study area Holzbach is being carried out. The aim of this research is to understand the surface processes that occur in this area, in terms of spatial distribution and quantitative understanding of these processes and to predict the possible effects of climate change on the German forests (Schuler et al. 2010).

As part of this research, the present thesis research is focused on the spatial hydrological response of water repellency to its influencing factors. As well as its influence on overland flow generation in the study area of Holzbach in the Hunsrück low mountain range in Germany.

2. Main research question(s)

The main research questions can be formulated as follows:

- ✓ *Which is the spatial-temporal distribution of soil water repellency and factors influencing water repellency in the study area of Holzbach in the Hunsrück low mountain range in Germany during the dry season in summer?*

a. Sub-questions

- ✓ *Which are the volumetric moisture content values on each sample site?*
- ✓ *How is the spatial-temporal distribution of the volumetric moisture content values in the study area?*
- ✓ *How is the spatio-temporal distribution of soil water repellency related to volumetric soil moisture content of the study area during the dry season in summer?*

- ✓ *Which is the water drop infiltration rate of soils on each sample site and the sediment yield by overland flow and surface runoff coefficients on each rainfall experiment site?*
- ✓ *How is the spatial distribution of the water drop infiltration rates of the soils, sediment yields and runoff coefficients in the study area?*
- ✓ *How is the spatial distribution of soil water repellency related with the generation of runoff erosion in the study area during the dry season in summer?*

3. Purpose/Objectives

Water repellency becomes an issue that is necessary to understand, due to its consequences facing runoff generation and erosion (Jonge et al. 2011). Various researches (Witter et al. 1991, Jungerius and Harkel, 1994, Burch et al. 1989) have mentioned the importance of water repellency enhancing soil erosion. However there are some knowledge gaps that are still without any explanation (Doerr et al. 2000). The still lacking knowledge about water repellency is vital to understand and characterize the percentage and timing values during rainstorm events where it is very likely to observe runoff processes (Doerr et al. 2000).

This thesis research is focused on two of the knowledge gaps mentioned by Doerr et al. (2000): 1st the isolation of the erosion impact (runoff and stream flow processes) of water repellency from other factors and 2nd the spatial and temporal distribution of water repellency.

According to Shakesby et al. (2000) one of the key factors that influence the increment in erosion risk is the spatial contiguity of water repellency (Leighton-Boyce, Doerr et al. 2007). Furthermore, Leighton-Boyce et al. (2007) says that the "prediction of the effects of repellency on the hydrological response must clearly take into account the spatial distribution and persistence of repellency throughout a rain event" apart from other factors.

Taking into account these facts, the main purpose of this research is the characterization of the spatial and temporal distribution of water repellency in forest soils and the question if this spatial distribution is directly related to soil volumetric moisture content and soil runoff and erosion risk in the study area of Holzbach in the Hunsrück low mountain range in Germany, during the summer dry period.

4. Concepts and theories

a. Soil water repellency

According to (Doerr et al. 2000), "soil water repellency reduces the affinity of soils to water such that they resist wetting for periods ranging from few seconds to hours, days or weeks". This phenomenon has hydrological and geomorphologic consequences, such as decreasing of the infiltration capacity of soils, enhanced overland flow and increased soil erosion risk (Doerr et al. 2000).

The origin of water repellency is based on the characteristics of the water molecule. A water molecule is formed by two atoms of Hydrogen and one atom of oxygen, with positive charges and negative charges respectively. Due to this polarity, hydrogen bonds will be created forming aggregates (cohesion). This bipolarity can also induce attraction to charged surfaces (adhesion) (Doerr et al. 2000).

i. Water repellency in the soils

If the sand or soil is hydrophobic, the water will not cover the soil particles but instead the soil pores, whereas if the soil is hydrophilic the soil particles will be covered by water (Doerr et al. 2000).When hydrophobic components are present within hydrophilic materials, that material will be less wettable (Doerr et al. 2000).

ii. Substances responsible for water repellency

"It is commonly accepted that it is caused by organic compounds derived from living or decomposing plants and microorganisms" (Doerr et al. 2000). However, the specific compounds that are responsible for water repellency have not been discovered yet neither how this substances are bonded to soil particles (Doerr et al. 2000).

According to Doerr et al. (2000), the main sources of hydrophilic substances are: vegetation, soil fungi and microorganisms as well as soil organic matter and humus. The non-biological factors that influence water repellency are: Texture, clay content and soil temperature.

b. Soil moisture content and water repellency

Several articles (Dekker and Ritsema, 1994, Doerr et al. 2000) mention the direct relationship between moisture content of soil and water repellent conditions. It is suggested that when low moisture content in soil high water repellent conditions are found and when high moisture content in soils low water repellent conditions will be found. On the other hand, some other researchers suggest (Leighton-Boyce et al. 2005, Keizer et al. 2008) that water repellent conditions not only vary depending on moisture content of the soil. More variables such as temperature, relative humidity and evapo-transpiration rate might be influencing water repellent conditions.

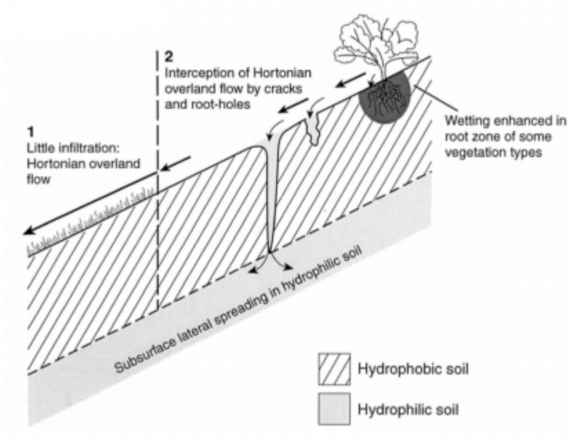
c. Runoff generation in water repellent soils

Surface runoff is the water flow that occurs when the soil is saturated with water when it infiltrates into the soil to full capacity and the excess water from rain, melt-water, or other sources flows over the land (Beven 2004). According to Buczko et al., (2002) the infiltration in water repellent soil is lower than in wettable soils. In consequence the generation of surface runoff also called overland flow, will be greater in water repellent soils. After long dry periods and following rainstorms more runoff will be generated; more than after wet periods (Buckzo et al. 2002).

d. Relationship water repellency – runoff erosion

A water repellent soil layer will decrease the infiltration capacity of water into the soil, the rainfall water will pond and in consequence, the overland flow will be promoted (Hortonian overland flow). However, it is not clear if Hortonian overland flow or saturation overland flow or both are the key effects of water repellency (Doerr et al. 2000). These water repellency effects were demonstrated using rainfall simulators on experimental plots (Doerr et al. 2000).

a)



b)

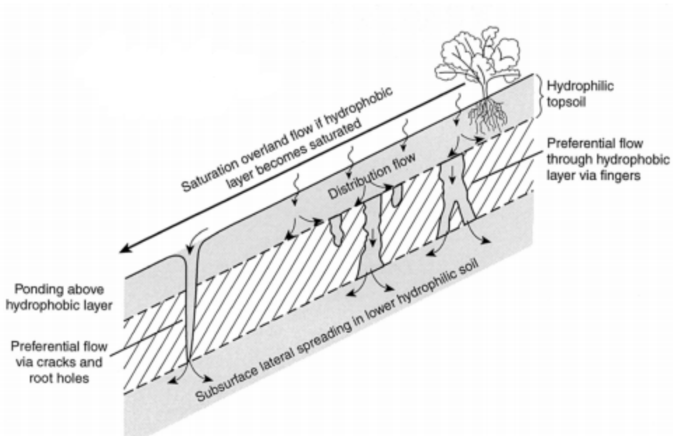


Figure 1: *"Schematic illustration of possible hydrological responses of soil with (a) a hydrophobic layer located on the surface, and (b) a hydrophobic layer sandwiched between hydrophilic soil" (Doerr et al. 2000)*.

After dry periods, water repellency tends to be more severe, in consequence the generation of overland flow will be higher due to the lower infiltration capacity of the soils (Doerr et al. 2000). This issue might be referred to the changing pattern on the climate in the study area which is changing towards a higher frequency of dry periods and following heavy rainstorm events in summer (Jonge et al. 2011).

e. Soil erosion

Erosion processes have always been attributed to soil hydrophobicity (Doerr et al. 2000). However, the majority of the researches about water repellency have deduced the link between the water repellency and soil erosion, instead of demonstrating this relationship with direct causal links (Doerr et al. 2000). Only a few studies (e.g Osborn et al., 1964) have achieved to isolate the erosion effect of water repellency from other causal effects. This demonstrates that it is difficult to determine how much of the erosion is produced due to water repellency (Doerr et al. 2000).

Since "the erosion impact of hydrophobicity in soils depends strongly on the degree of contiguity of the hydrophobic surface" (Shakesby et al. 2000), knowledge on spatial and temporal distribution of water repellency acquires great importance. This is a knowledge gap which is still without clear answer.

5. Research Methodology

Study area

The study area is located in the Holzbach area in the Hunsrück low mountain range in Germany. It is situated 20 km southeast of Trier, in the south-western part of Germany, and covers an area of 2.2 km2. The area is part of the Rhenish Slate Mountains and the bedrock is mainly composed of Lower Devonian age (Jonge 2010).
The climate is sub-Atlantic with a mean annual precipitation of 1160 mm (Butzen et al. 2011). The average temperature is 8.7°C. The soils are mainly acidic Cambisols, Podsols and stagnic Cambisols. The study area is almost completely covered by forest (97 %) and 3 % are covered by grassland (Butzen et al. 2011).

The land use of the area is forest, composed mainly by spruce, beech forest and mixed forest. The largest part in the south and west is covered with old spruce forest, in the eastern part mainly beech stands are located, and smaller areas are covered by fir, sessile oak or Japanese larch.(Butzen et al. 2011).

The design

This thesis research is the continuation of a previous thesis research about the dynamics of water repellency in the same area (Jonge 2010). The sample, measurement and rainfall experiment sites were chosen once I was in the study area. The water drop penetration time (WDPT) and volumetric moisture content measuring were carried out among all the study area in order to have an overview of the study area. Taking into account the overview data of the study area, rainfall experiments sites, WDPT and volumetric moisture content sample sites were chosen.

Unit of analysis: My research is defined as an experimental study research. It consists on an experimental study of the spatial and temporal distribution of water repellency and the influencing factors in water repellency in the study area of Holzbach in the Hunsrück low mountain range in Germany.

Sampling strategy: WDPT (water drop penetration test) data was acquired on each rainfall experiment site under different land uses: spruce forest and beech forest. On each measurement site, WDPT on dry conditions and on wet conditions (after the rainfall experiments) was tested.

In order to measure the volumetric moisture content (v.m.c) of soils, soil samples were taken; one before the rainfall simulation and one after the rainfall simulation, on each Rainfall experiment site.

7 Rainfall experiment sites were chosen regarding the previous study area overview. On each site between two and four repetitions of the rainfall experiment were done.

Boundaries:

Boundaries of the study area are limited by the Holzbach catchment in the Hunsrück low mountain range in Germany. In figure 1 the study area of Holzbach catchment can be observed

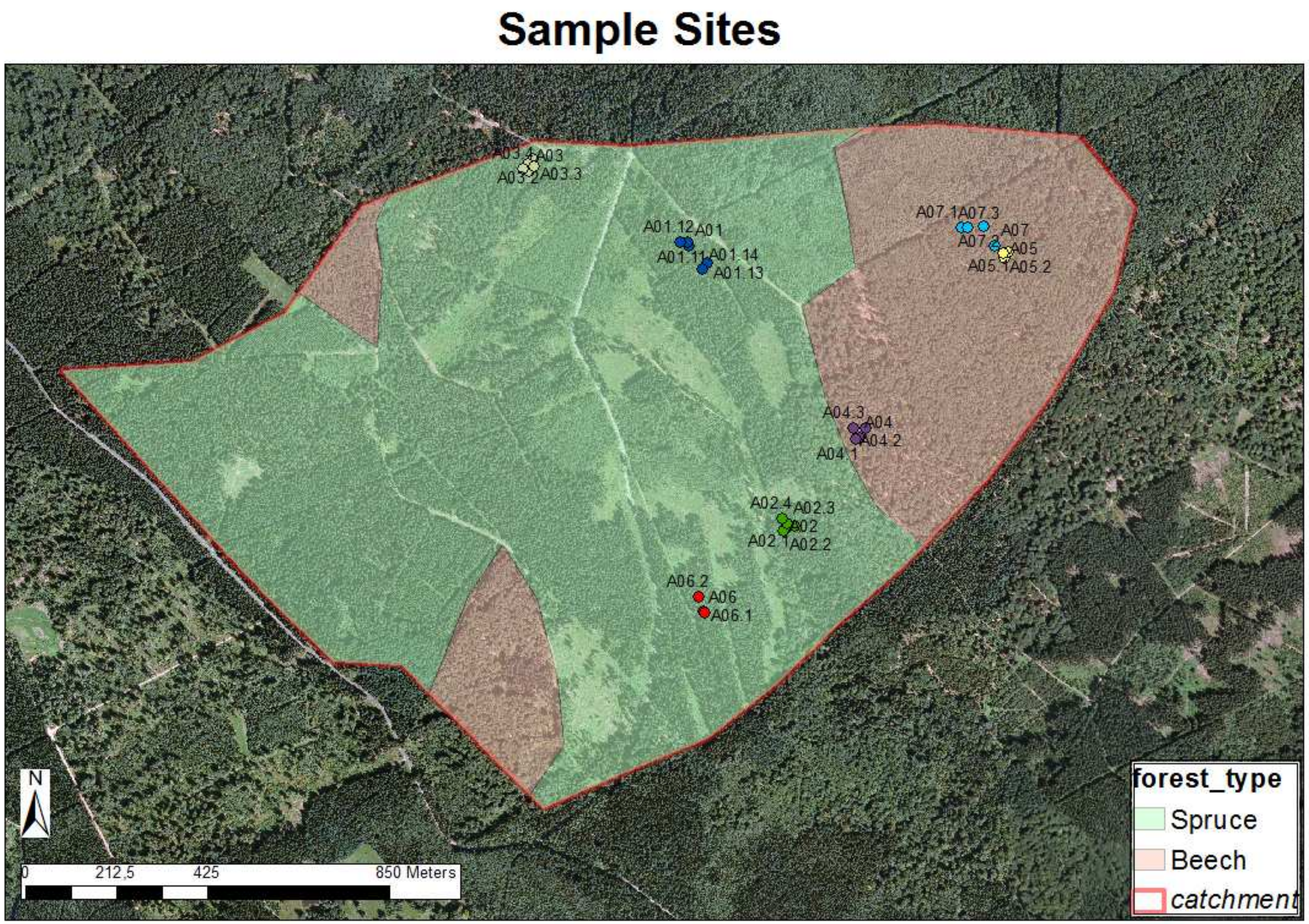


Figure 2 *Study area and sample sites in the Holzbach catchment in the Hunsrück low mountain range in Germany.*

Qualitative/quantitative data collection: Data collection of my research was quantitative. Data was obtained from:

- Field measurements of the Rainfall Simulator, WDPT test and soil moisture samples
- Laboratory measurements of sediments load and runoff water of the Rainfall experiments outputs and volumetric moisture content of the soil samples.

Assessment of water repellency and runoff generation

Field measurements:

Rainfall Simulator:

A rainfall simulator was used in order to describe overland flow generation at the sample sites. It was also used to get samples of sediment load released and runoff water. I used a nozzle-type portable rainfall simulator. Its portability allows working in remote areas and in steep slope zones (Cerdá et al. 1997) like the study area. "The rainfall simulator is an improvement of the design of Calvo et al. (1988) and has been used in different research areas in Europe" (Cerdá et al. 1997). Its basic components are a nozzle, a structure to install the nozzle in 2 m height above ground and the connections with the water supply and the pumping system. It also includes a wind protector to avoid interferences during the measurements (Cerdá et al. 1997).

WDPT (water drop penetration test):

In order to measure the water repellency of the study area the WDPT was selected. The tools needed were a small bottle with distilled water and small pipe. The test was done on each measuring site in two different locations: in the ring of the Rainfall Simulator before and after the rainfall experiment and outside the ring. On every location the water repellency of each humus layer (Ol, Of, Oh) and mineral soil was tested. On each layer the time needed to infiltrate into the layer of three different drops was measured. The infiltration time was measured until 15 minutes; once that time was exceeded the measurement of water drop penetration time was stopped. After 15 minutes the water repellency of the measuring site was already considered severe without need of measuring longer time.

Table 1 *Water Drop Penetration Time (WDPT) classes, associated intervals and descriptive ratings to classify the persistence of soil water repellency (Doerr et al. 2006).*

WDPT class	0	1	2	3	4	5	6	7	8	9	10
WDPT intervals/ss	≤5	6–10	11–30	31–60	61–180	181–300	301–600	601–900	901–3600	3601–18000	> 18000
Persistence rating [a]	None (wettable)	Slight			Moderate			Severe		Extreme	

[a]Modified from Bisdom *et al.* (1993).

Soil sampling:

A sampling soil cylinder with a volume of 100 cm^3 was used in order to get the volumetric moisture content value of the soil. Samples of the humus layer and mineral soil layer were taken, separately. These samples were weighted before the drying in the oven and after the drying, (105 degree, 24 hours) in order to compute the volumetric moisture of the soil samples in the humus and mineral soil layer.

Laboratory work:

Rainfall Simulator:

In the laboratory I separated the sediment samples obtained with the Rainfall Simulator from the runoff water using a small filtering paper, blue ribbon filters. These filter where previously treated. First they were watered for 24 hours in demineralized water. After that, they were dried 24 hours in the oven. After this treatment the influence of the filter materials such as glue or paper became lower. After the pre-treatment of the filters, runoff water was filtered and the filters with the sediments obtained from the water runoff samples were carried to the oven. The samples were dried in the oven during 24 hours at 105 degrees. The amount of runoff water and sediments were measured gravimetrically with a scale.

Soil samples:

The cylinders of soil samples were dried in the oven at 105° during 24 hours. The volumetric moisture content was measured following the formula below:

$$v.m.c=(m_{wet}-m_{dry})/v_{cylinder}*\rho_{water}$$

Data analysis:

Geographic Information Systems (GISs) "are computer-assisted systems for the capture, storage, retrieval, analysis and display of spatial data."(Clarke 1986). By using this tool I analyzed the data obtained in the field and in the laboratory work. I included the data obtained from the sediment load and runoff water measured in the laboratory work and the infiltration rates measured using the rainfall simulator. I also included the water repellency values obtained in the field.

SPSS is a computer program used for statistical analysis (Field 2009). Using this computer program I analyzed statistically the correlation between different studied parameters and the significant differences regarding different grouping variables.

Correlation analysis: Data obtained in the field and laboratory work was not normally distributed. Therefore, non-parametric correlation analysis was used: based on Spearmans´s correlation coefficient (rs).

Differences between k independent groups: In order to observe significant differences between different groups, depending on the grouping variable, the Kruskal-Wallis test was used. This test is also applied for non-parametric data. Three grouping variables were used: Area, Forest Type and Topography.

Multiple Regressions: Data obtained in the field and laboratory work was normalized using logarithms. After that, multiple regressions were carried out using the normalized data. The aim of this analysis was:

- See the degree of correlation and influence of independent/input variables on the dependent/output variables of significant correlations.
- See if there is any degree of influence or correlation of not significantly correlated independent /input variable with the dependent/output variable, but significantly correlated with a second independent/input variable.

6. Results

Rainfall experiments: Water runoff generation and sediment release

22 Rainfall experiments were carried out within the study area. In the charts below, the most representative rainfall experiments are shown, which describe the general behavior observed in the field on water runoff generation and sediment release: sediment load (g/m^2), suspended sediment concentration (g/l), rainfall amount in the experiment (l/m^2) and runoff generated in the experiment Q (l/m^2).

Rainfall experiment graphs are classified in three representative groups in order to describe the general trends of suspended sediment load, suspended sediment concentration and Q generation values:

Type 1

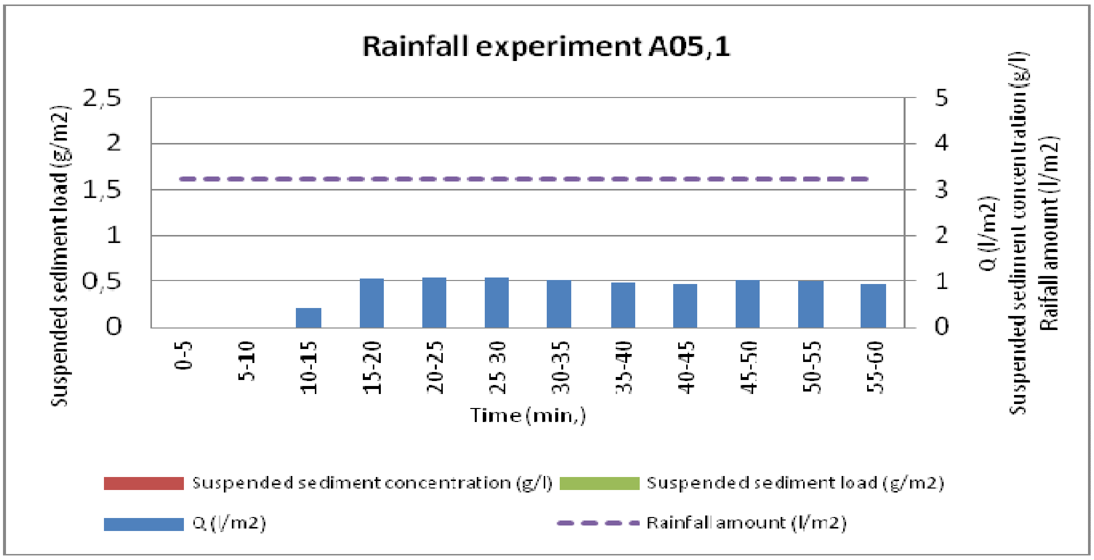


Figure 3 *Rainfall experiment site A05,1.*

In Figure 3 water runoff generation is observed from the minute 10 of the Rainfall experiment. There were no suspended sediment concentrations neither load values registered.

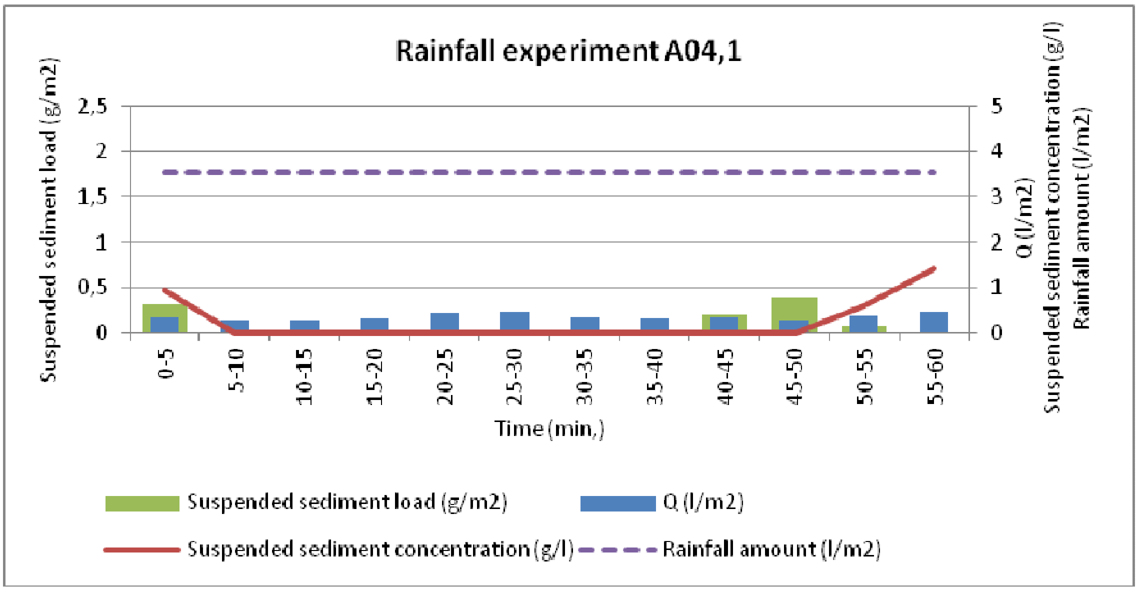


***Figure 4** Rainfall experiment site A04.1.*

In Figure 4 same trend of water runoff generation could be observed. In this case some suspended sediment release was registered at the first 5 minutes of the experiment and at the minute 45 of the rainfall experiment.

Both figures are examples of one of the three main trends on the Rainfall experiments carried out in the field. Water runoff generation was registered almost from the beginning of the experiment. However, sediment release is 0 or very low during the duration of the rainfall experiment (see Annex 1: Figure 1.7-A05.2, Figure 1.8-A06.1 and Figure 1.9-A06.2).

Type 2

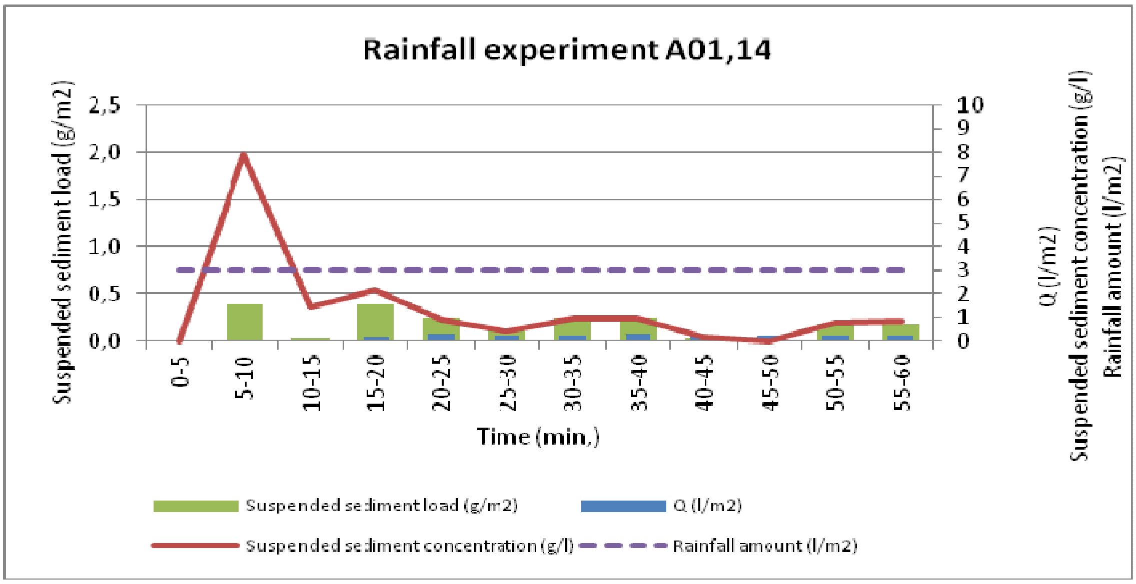


***Figure 5** Rainfall experiment site A01.14.*

In Figure 5 suspended sediment concentration values were registered since minute 5. During all the rainfall experiment these values were higher than water runoff generation. Water runoff values were registered since the minute 15, however these values were not so high.

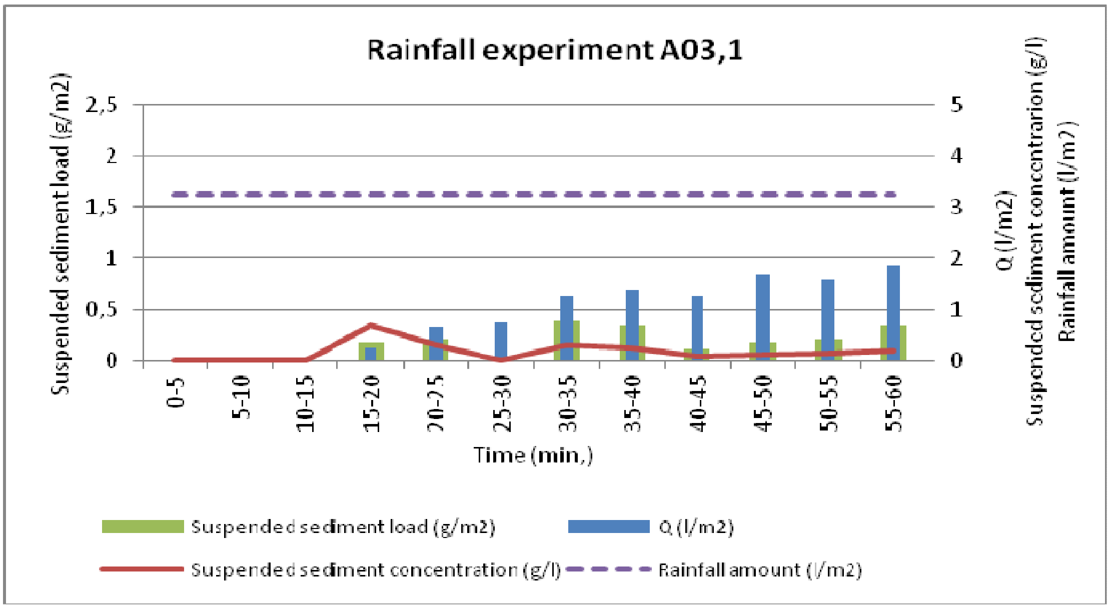


Figure 6 *Rainfall experiment site A03.1.*

In Figure 6, sediment release started on minute 15 until the end of the experiment. In this case water runoff generation values were also registered. However these values were higher than suspended sediment concentration values. Anyway, in both cases sediment release decreses in time during the experiment.

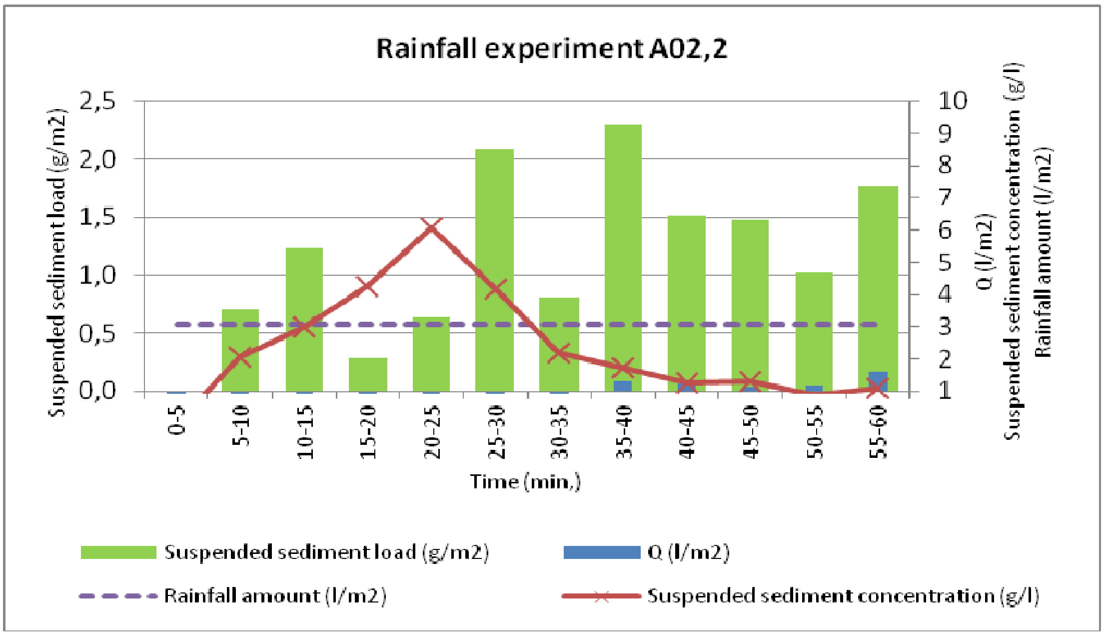


Figure 7 *Rainfall experiment site A02.2.*

Finally, figure 7 is an example of suspended sediment release on water runoff on steep topography. Sediment release started on minute 5, as showed in figure 5. During the experiment sediment concentration values were higher than water runoff values, with a peak value on minute 20. From that moment, sediment release decreases until the end of the experiment.

Figures 5 and 6 describe decreasing sediment release during the rainfall experiment. Figure 5 show higher values of sediment concetration than water runoff generation and figure 6 shows higher values of water runoff generation than sediment concentration values.

Figure 7, has similar trend as figure 5 but sediment release reaches a peak value on minute 20 (see annex 1: Figure 1.1-A01.13, Figure 1.11-A07.2, Figure 1.10-A07.1,Figure 1.6-A04.3 and Figure 1.2-A02.3).

Type 3

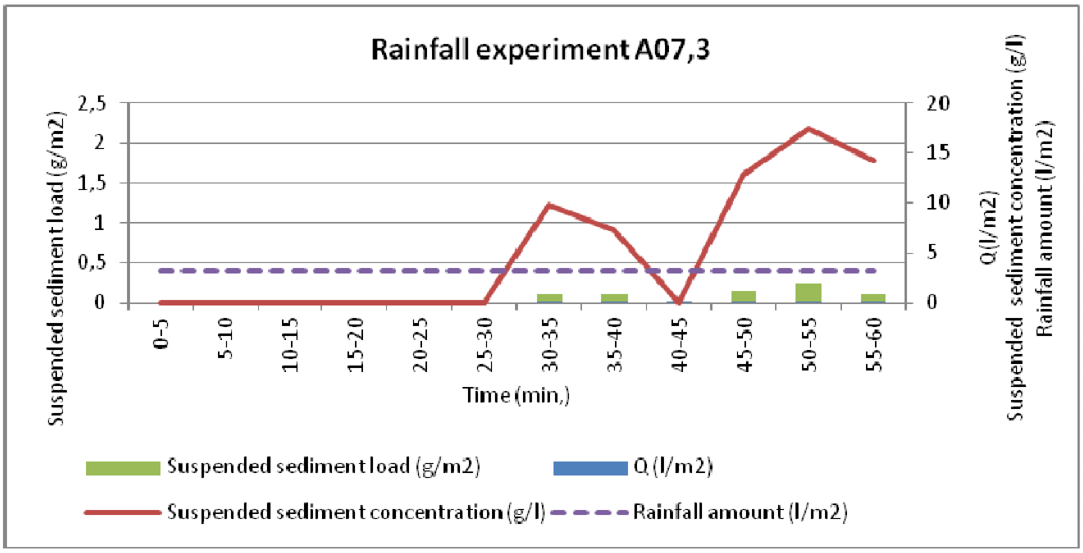


Figure 8 *Rainfall experiment site A07.3.*

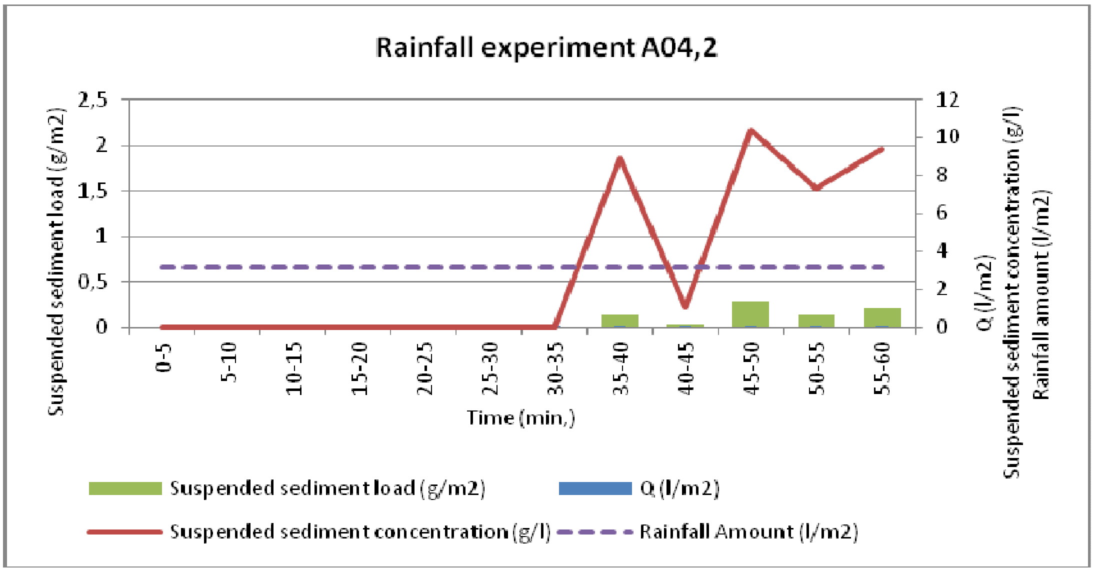


Figure 9 *Rainfall experiment site A04.2.*

In figures 8 and 9 a similar trend was observed. No water runoff generation was registered. However, suspended sediment concentration and load values were registered. The behaviour of these values is caracterized by peak values during the experiment but no constant values (see annex 1: Figure 1.3-A02.4, Figure 1.5-A03.4 and Figure 1.4-A03.3).

Wdpt and volumetric soil moisture

On each Rainfall experiment site WDPT was carried out as well as soil samples were taken in order to measure the volumetric moisture content of the Humus layer and mineral soil layer. On the charts below some of the most relevant water repellency values and volumetric moisture content values are represented.

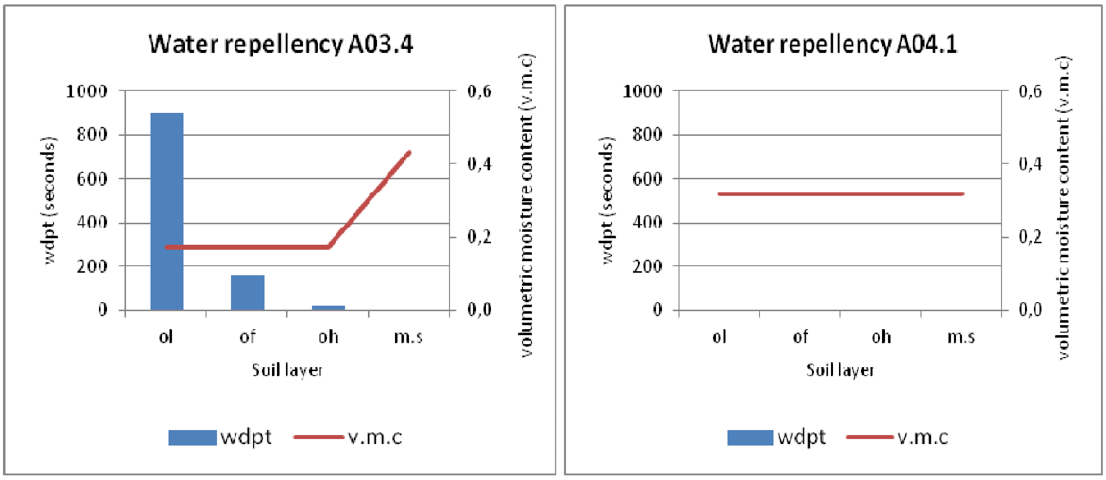


Figure 10 *WDPT and v.m.c for site A03.4 site A04.1.*

In figures 10 and 11 most representative moisture and repellency behaviours have been chosen. (See annex 2). For the study site A03.4 its possible to see that there is water repellency in all the humus layers. Moisture level is ranked as 0.2. On the mineral soil layer there is no water repellency registered. Moisture content of mineral soil layer is ranked as 0.4. In the site A04.1, there was not any water repellency registered neither in the humus layer nor in the mineral soil layer. Moisture content didn´t change through the different layers.

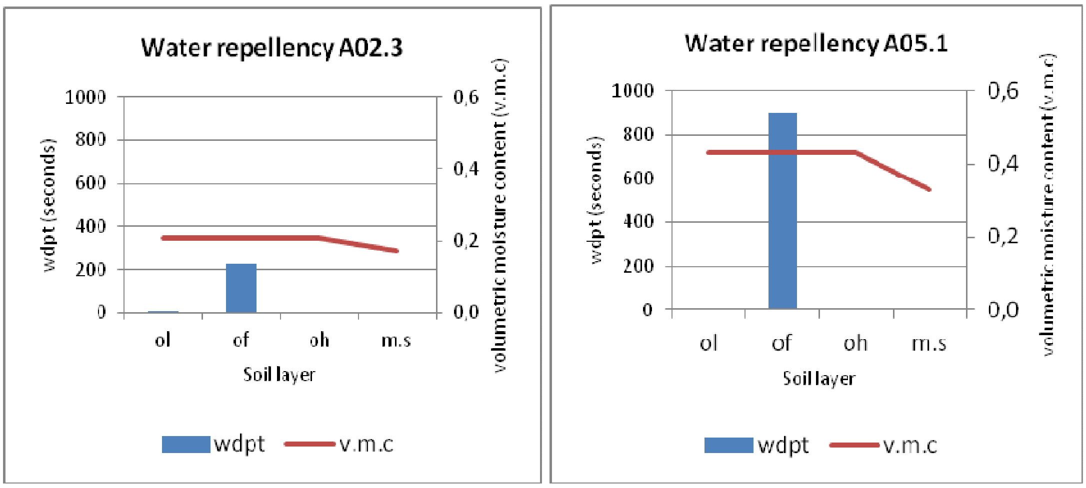


Figure 11 *WDPT and v.m.c for site A02.3 and site A05.1.*

On the other hand, figure 11 shows two examples of different behaviour. In site A02.3 water repellency was registered for humus layer but not for mineral soil layer. However, moisture content decreased in the mineral soil layer.

In site A05.5 similar behaviour was observed. Water repellency was registered in the humus layer. Mineral soil layer didn´t show repellent behaviour. However, mineral soil moisture content went down (See annex 2.).

Generally, qualitative relation between water repellency and volumetric soil moisture could be observed. However, this fact its not always possible to demostrate with the data statistically analyzed in this thesis research.

Temporal variation of water repellency and volumetric moisture content of the soil

Temporal variation of water repellency and moisture content of the studied area has been evaluated with data obtained from the rainfall experiment sites. First, graphs representing the variation of the two parameters already mentioned were made. Secondly, using the data obtained in two different dates, regarding the wdpt test data and v.m.c data of each study site, a statistical analysis was done, in order to see whether there were significant differences between both dates.

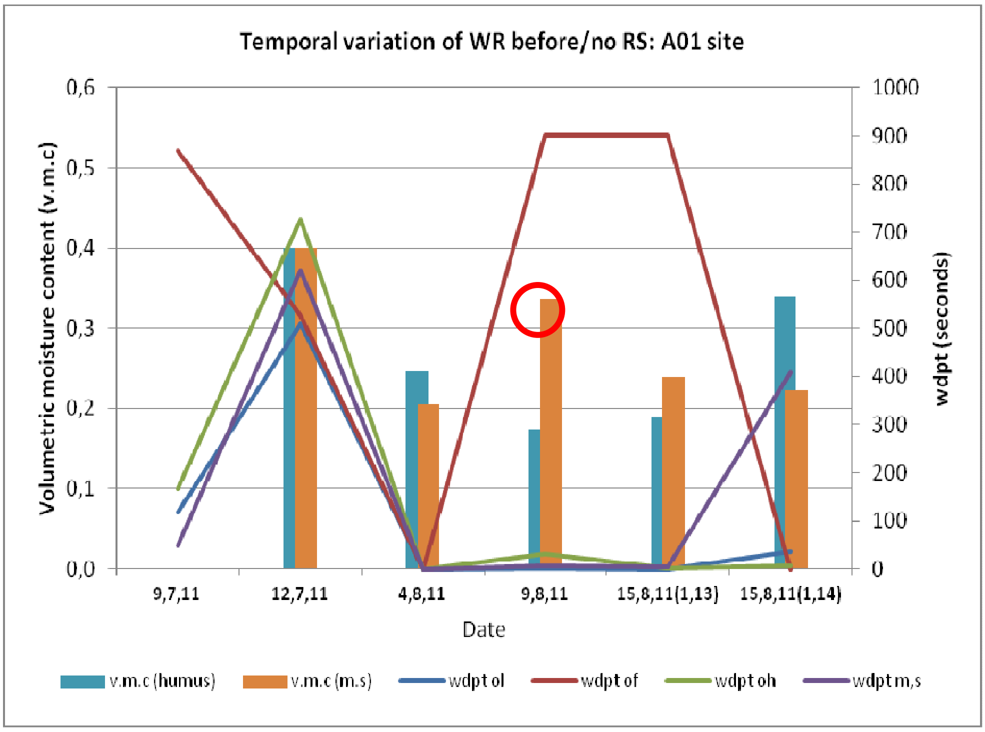


Figure 12 *Temporal variation of water repellency and v.m.c for site A01*.

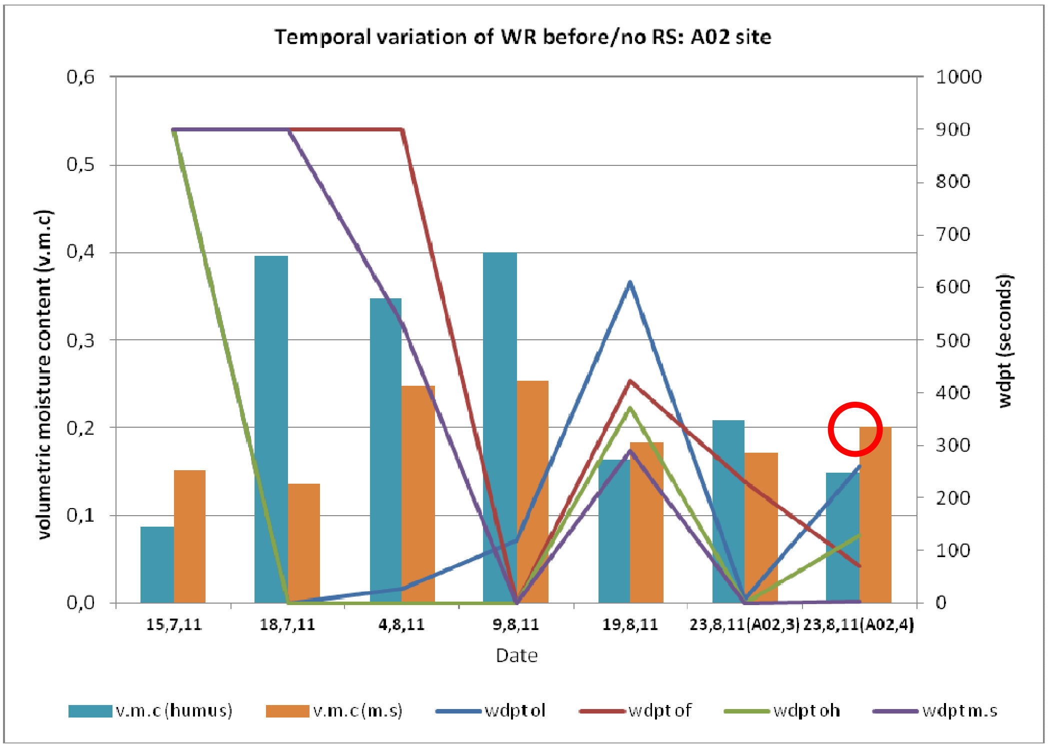


Figure 13 *Temporal variation of water repellency and v.m.c for site A02.*

On figure 13 its possible to see that there is a related behaviour of water repellency with the moisture content of the humus and the mineral soil layer. Its possible to observe that the effect of moderate repellency of all the humus layers (ol, of and oh) is higher than the isolate effect of one of the humus layers, although the water repelency of that layer is high. Thus, as we can see on the date 18.7.11, water repellency of OF is severe but water repellency of OH goes down influencing entirerly on the moisture content of Humus layer.

However, on figure 12 this is not very obious. Moderate values of water repellency showed higher values of moisture content on both layers , humus and mineral soil, comparing with other dates. Whereas for the same date data, we can observe same moisture content in the mineral soil layer with different water repellency values in the mineral soil layer.

It seems to be that the moisture content on both layers for each date cannot be interpreted as continuous variable in time with always the same moisture ranges in order to say whether we have low or high moisture content changing during time. For each date the values are independent, and spatially it could be that those values are influenced by different values of repellency on different sampling points.

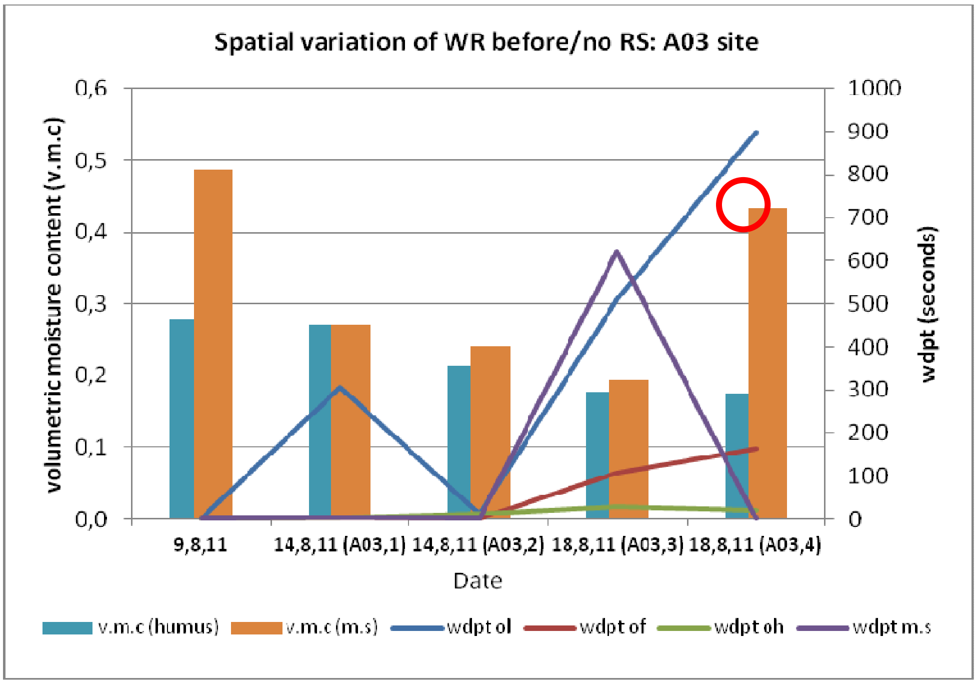


Figure 14 *Temporal variation of water repellency and v.m.c for site A03.*

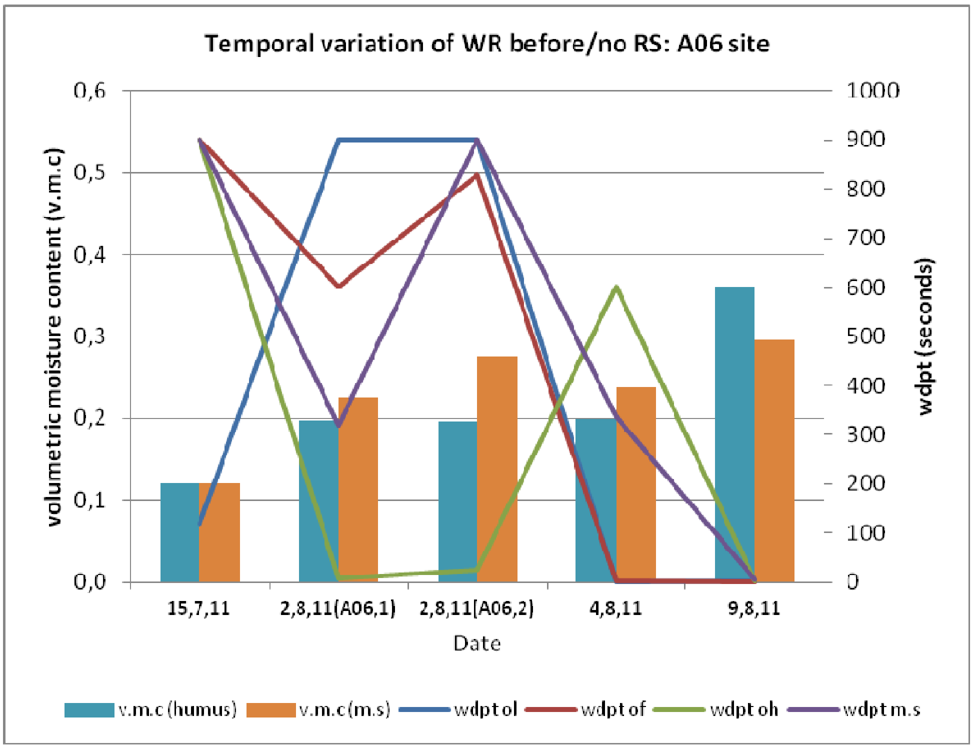


Figure 15 *Temporal variation of water repellency and v.m.c for site A06.*

On site A03 its also possible to observe the higher influence of repellency of all humus layers at the same time, influencing more on the moisture content of the Humus layer, than the isolate influence of the repellency of one humus layer. On site A06 it is also possible to see same behaviour.

Simetry in the variation of volumetric moisture content of humus and mineral soil layers could be observed, except from the highlighted dates with a red circle. Generally, if the moisture content from one of the layers goes up, also the moisture content of other layers goes up and viceversa.

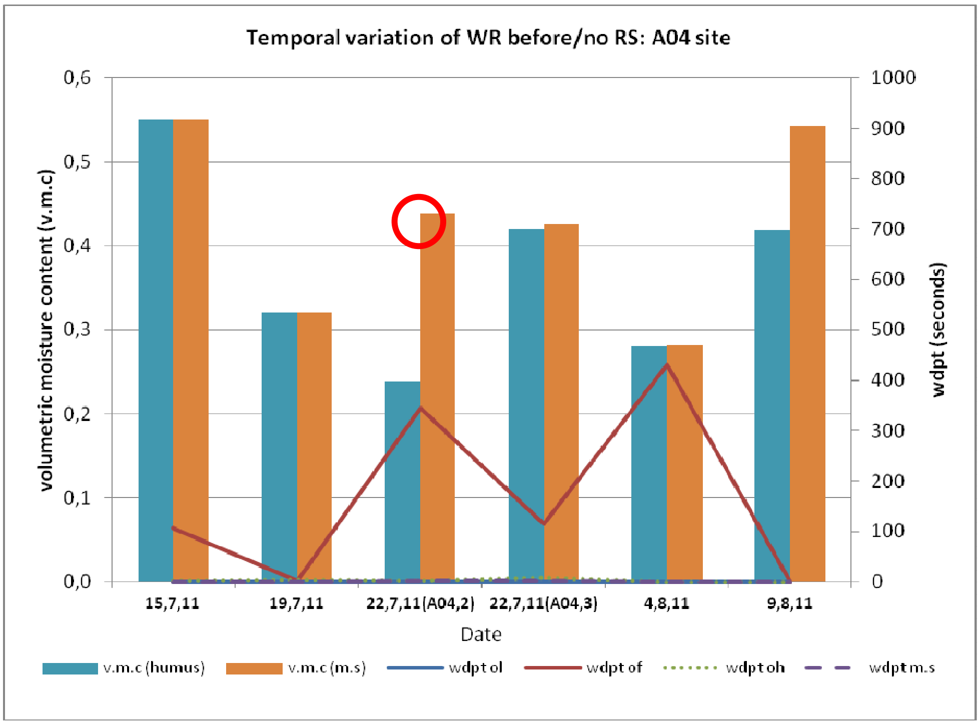


Figure 16 *Temporal variation of water repellency and v.m.c for site A04.*

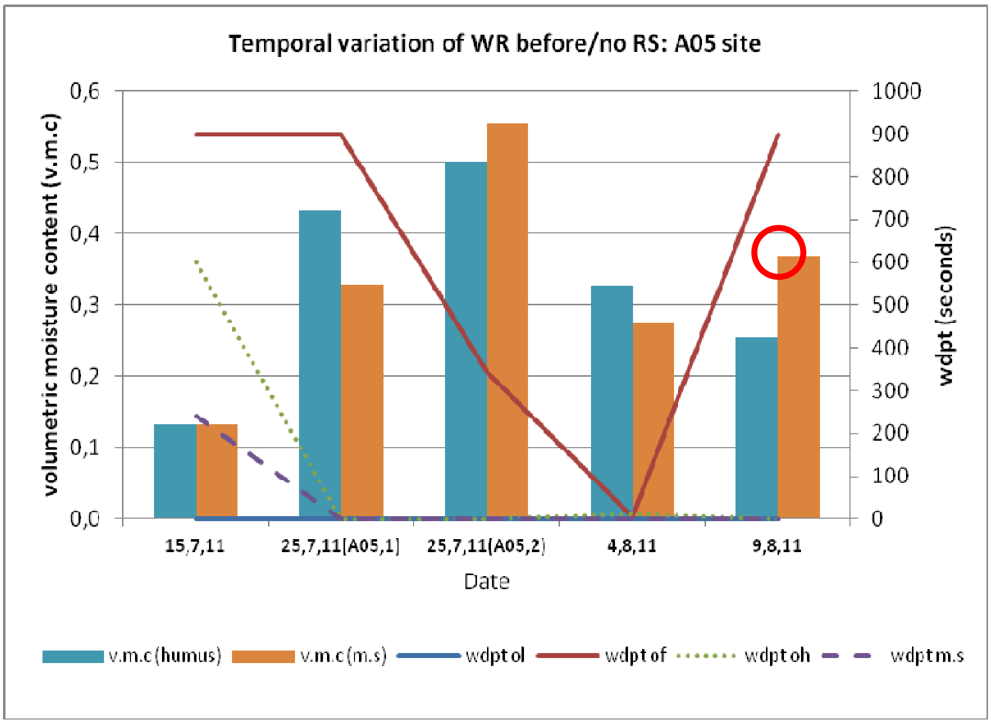


Figure 17 *Temporal variation of water repellency and v.m.c for site A05.*

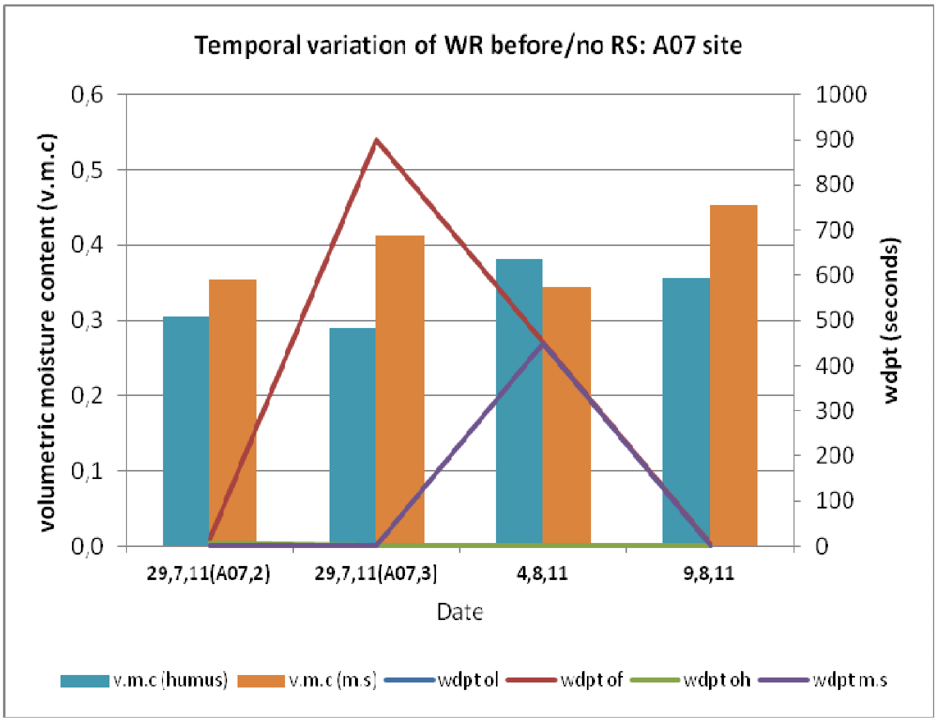


Figure 18 *Temporal variation of water repellency and v.m.c for site A07.*

For the beech forest, the v.m.c simetry in both studied layers, humus and mineral soil layers is not clear. For the A04 and A05 study sites that simetry could be observed, but still not in all the dates. In site A04 water repellency of OF layer is influenced by the v.m.c of Humus layer (see figure 16). In the site A07 on the last date there is no simetry between both v.m.c values. Moisture content of Humus layer is lower instead of increasing as the moisture content of the mineral soil does. Although the water repellency of OF humus layer decreases. On site A05 is also no simetry on moisture content of both layers for the last date. It seems to be influenced by the increase of the OF layer repellency from one date to another.

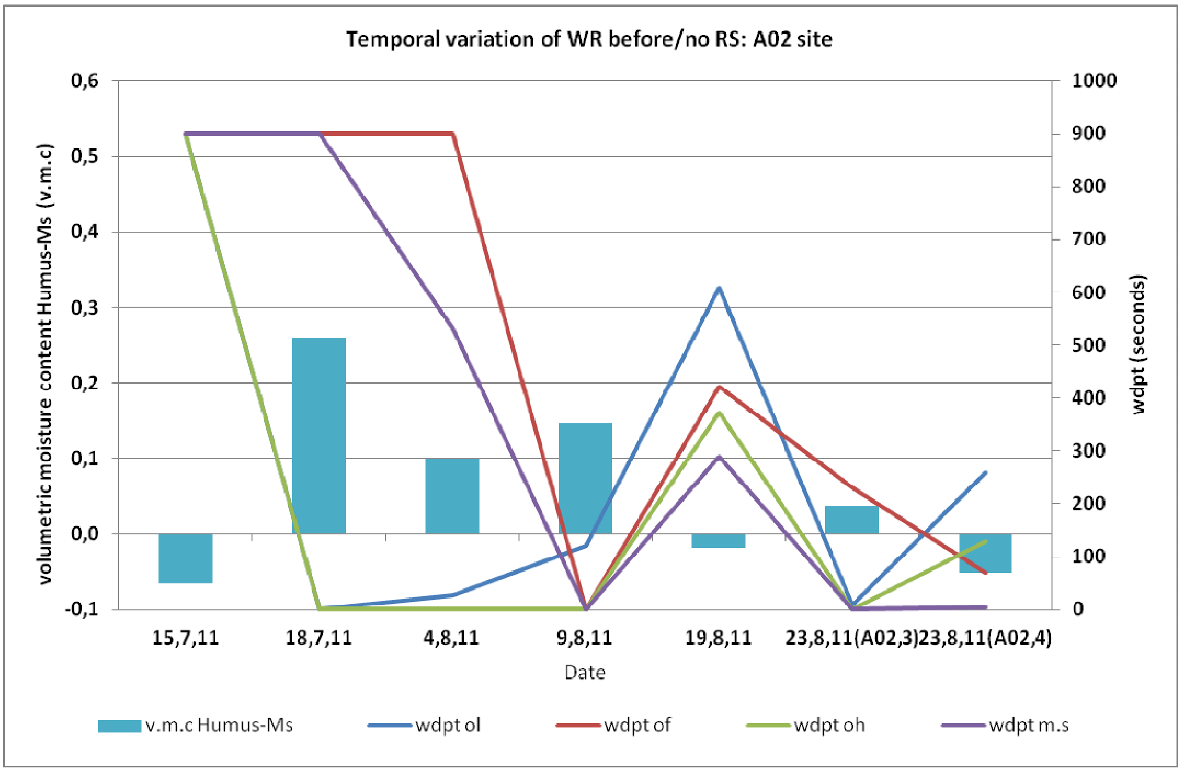


Figure 19 *Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A02.*

Regarding to the observed simetry of volumetric soil moisture on Humus and Mineral soil layers, the moisture difference between both layers has been represented. In figure 19 we can see moisture content changing in time, related to water repellency changing in time as well. When moisture values are positive, v.m.c in Humus layer is higher than in the mineral soil. When moisture values are negative, moisture content in the mineral soil is higher than in the Humus layer. Regarding figure 19, it could be possible to mention a qualitative relation between both parameters. When the moisture content is higher in the Humus layer, water repellency is low in the same layer. Whereas, when the moisture content is higher in the mineral soil the water repellency values in this layer are low. However, this behaviour was not observed in all cases. In figure 20 example of no clear qualitative relation between both parameters can be observed.

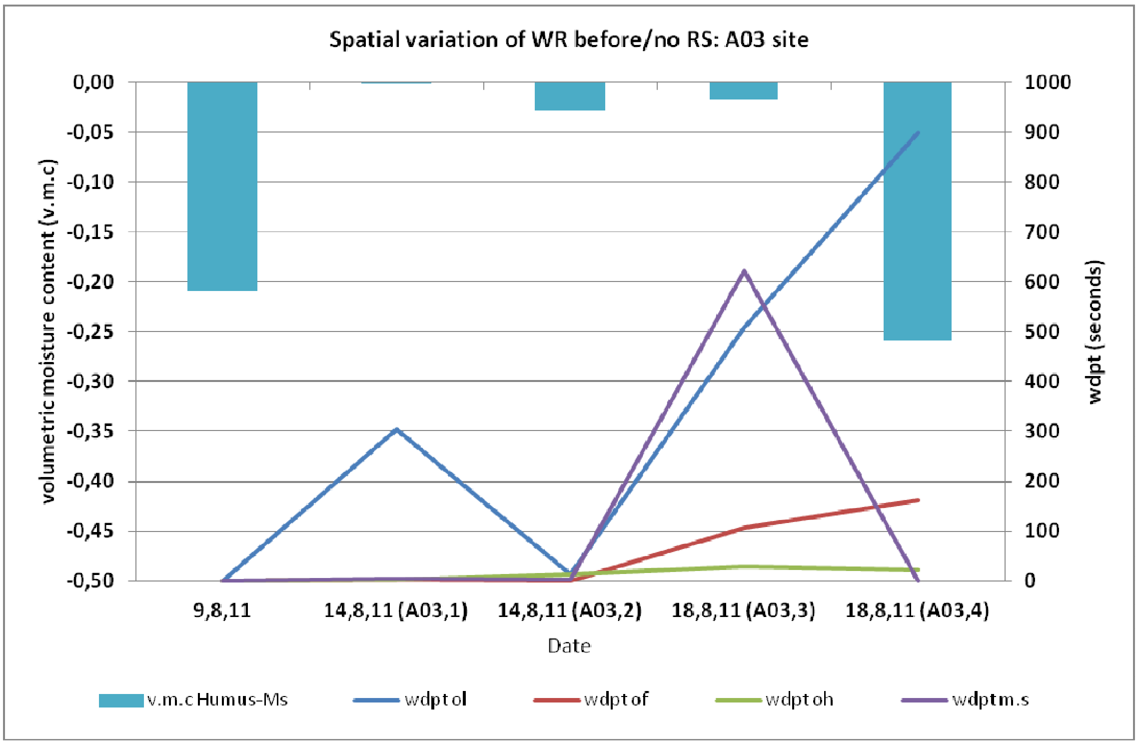


Figure 20 *Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A03.*

As we can see in figure 20, qualitative relation between water repellency and moisture content is not very clear. On the 18.8.11(A03.3) rainfall experiment point, moisture content on Humus layer is less than on Mineral soil. However, repellency on Mineral soil is classified as moderate.

Statistical analysis

With the data obtained in the field and in the laboratory work a statistical analysis was carried out. First, significant differences were studied: 1º between two different dates regarding water repellency values and volumetric moisture content values and 2º within different grouping variables were analyzed, such as rainfall experiment site, forest type and topography. Secondly, possible significant correlations between measured variables were analyzed. Finally, multiple regression analyses were done in order to determine the degree of correlation between significantly correlated variables and between not significantly correlated variables (input variables, see figures 24 and 25) that are significantly correlated with a common dependent/output variable.

Significant differences

Temporal variation

Regarding the statistical anlysis of the water repellency and volumetric moisture content data obtained in two different dates, only signifficant differences were observed for the v.m.c of Mineral Soil variable (See annex 4. Figure 4.23). But any signifficant differences were found for the wdpt of the mineral soil.

Spatial variation

In order to analyze possible significant differences depending on different grouping variables Kruskal Wallis test was used. Data obtained in the field and laboratory work were not normally distributed, therefore a non-parametric statistical analysis was chosen.

Significant differences were found when using as grouping variable forest type. The significant differences between the both forest types were found in the following variables: Wdpt ms, v.m.c ms, v.m.c humus, start runoff and roughness. (See annex 4).

In conclusion it is possible to observe that Beech forest is more wettable than Spruce forest. Volumetric moisture contents are higher in the beech forest than in the Spruce forest. Finally, runoff generation is later registered in beech forest than in Spruce forest.

Correlation analysis

In order to see possible significant correlations between the studied different variables a bivariate correlation analyses were done. First the correlation analysis was done without any grouping variable. However, after a general analysis a second correlation analysis was done with the forest type-grouping variable. In this second analysis the results were different regarding the first correlation analysis. Therefore, the significant correlations observed in the first analysis could be rejected. Significant correlations observed in the second analysis were taken as valid and as final results in all the cases were the significant correlations differed from the first analysis.

According to the research questions and sub-questions only the most interesting significant correlations are shown (see annex 4 for all the significant correlations), which can answer the main research questions and sub-questions.

Spruce forest

Table 2 *Studied significant correlations in Spruce forest.*

Variables	Correlation coefficient	Sig.
WdptOL-wdptOH	*0.646*	*0.023*
WdptOL-Susp.sed.conc.max	*-0.678*	*0.026*
wdptOL-Susp.sed.conc.mean	*-0.729*	*0.045*
WdptOH-susp.sed.load	*-0.750*	*0.020*
v.m.cHUMUS-susp.sed.load	*0.895*	*0.001*
v.m.cHUMUS-runoff coef.	*0.854*	*0.003*

Beech forest

Table 3 *Studied significant correlations in Beech forest.*

Variables	Correlation coefficient	Sig.
wdptOF-wdptOH	*-0.844*	*0.017*
v.m.cHUMUS-susp.sed.conc.mean	*-0.955*	*0.001*
v.m.cHUMUS-susp.sed.conc.max	*-0.919*	*0.003*
Qmean-start runoff	*-0.762*	*0.028*
Susp.sed.load.mean-topography	*-0.802*	*0.017*
Start runoff-runoff coef.	*-0.762*	*0.028*

In order to show these significant correlations, data obtained in the field and laboratory were typified using a logarithmic function (see annex 4). In Figure 21 example of significant correlation is shown.

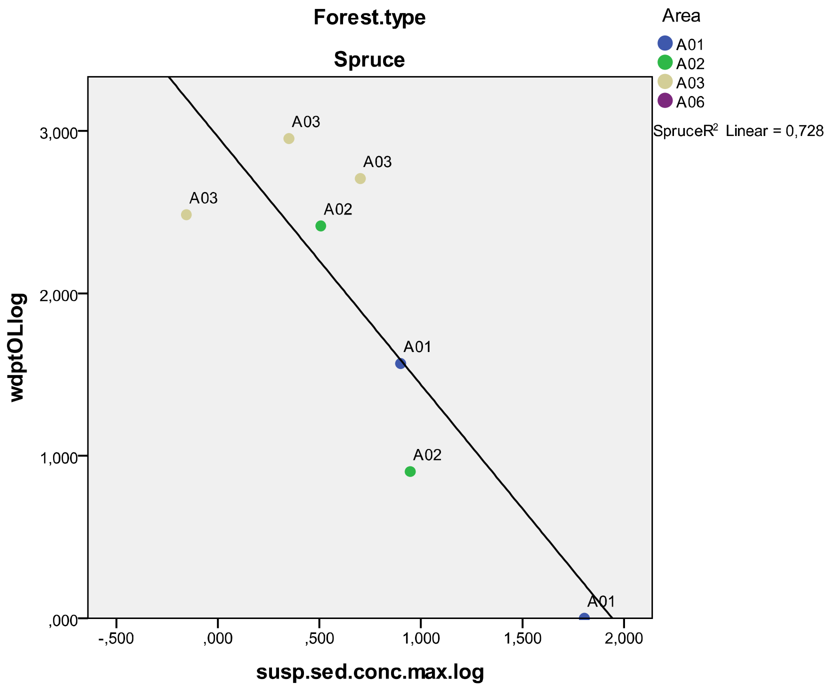


Figure 21 *Significant correlation between wdptOLlog and Suspended sediment concentration max.log in Spruce forest.*

In Figure 21, significant correlation between wdptOL and Suspended sediment concentration max. is represented. R2 value is 0.728.

Correlations found in Beech forest were not really fitting with a linear function. Lack of enough data and influence of morphologic variables on the collected data (e.g. leaf surface in the beech forest soil) didn´t allow having good statistical outputs (see annex 4).

On the other hand, non-linear correlation of moisture content and water repellency values of the studied sites were represented by dot plots using row data. The aim of doing this was to look for a transition zone within the moisture ranges, which would explain the lack of significant correlations on the statistical analysis between already mentioned both variables. (see annex 4)

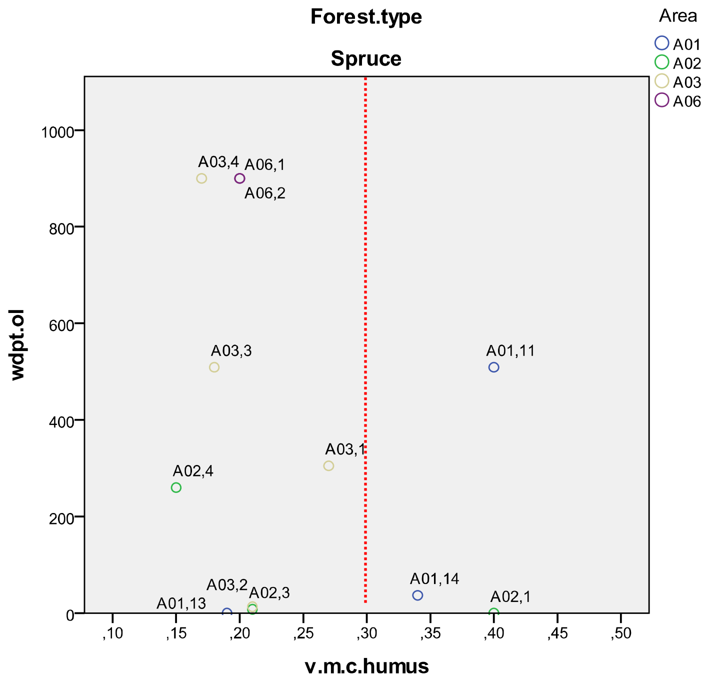


Figure 22 *wdpt.ol and v.m.c humus relationship in Spruce forest.*

In Figure 22 it is possible to see a threshold value at 30% of volumetric moisture content in the Humus layer. Under this moisture content most of the water repellency values are classified from slight to severe water repellency except from one value in site A01.13. Above 30% of moisture content water repellency values go down except from site A01.11. This trend can be observed also in the other figures that show the relation between water repellency and the volumetric moisture content for the Humus layer and for the mineral soil (see annex 4). It might be important to metion that the moisture content of the humus layer is being related to water repellency of each Humus layer. In other words, same value of moisture content is being related to each value of water repellency on each humus layer.

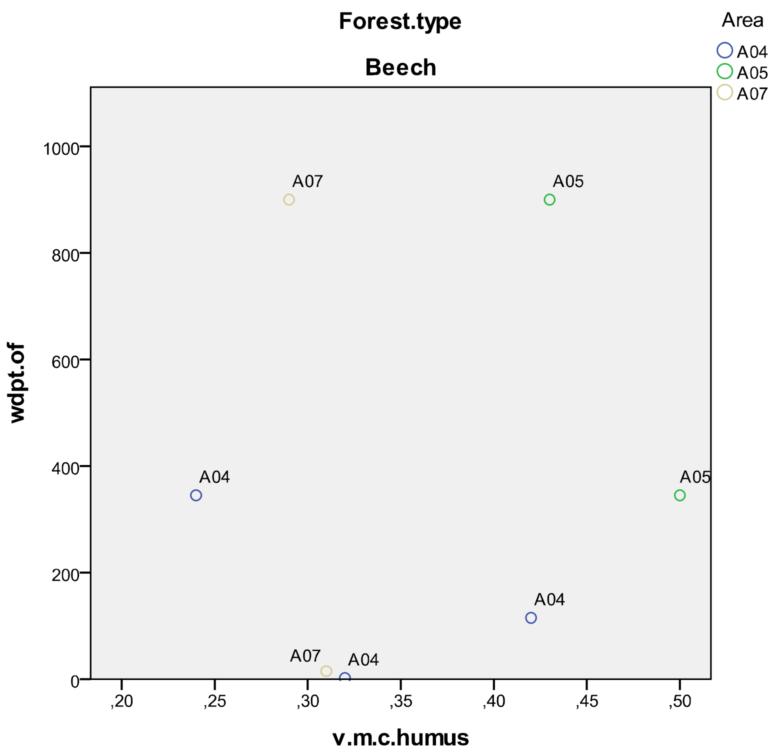


Figure 23 *wdpt.of and v.m.c humus relation in Beech forest.*

In case of Beech forest, it is not possible to observe any thereshole value. The data which had been obtained are not enough to observe clear trends. Also the variables observed in this forest were not the right ones in order to stablish a pattern on the water repellency and soil moisture content values (see annex 4).

Multiple regression

Multiple regressions were done in order to see the degree of correlation between three variables, when two of them were correlated to the same common variable. In the chart below the obtained functions and degree of correlations are mentioned.

Spruce forest

Multiple regression, method:ENTER, correlated variables

First, Enter method was used in order to analyze the degree of influence of independent/input variables on the dependent/output variable. Each variable was entered in one block; in total two blocks were defined. The procedure was done twice, changing the position of the independent/input variables from one block to the other block. The aim of this action was to see if the independent/input variables had the same influence when entering in the first position or in second position within each block.

***Table 4** Models and correlation degree of independent/input variables regarding dependent/output variables. Percentages marked in red have significant influence when adding that variable to the model.*

Model		Correlation degree (R2 adjusted)	
1. wdptOHlog *2. vmcHumuslog*	*Susp.sed.load.log=1.320-0.447wdptOHlog+3.377vmcHumuslog*	*wdptOHlog* *46.9%*	*vmcHumuslog* *18.7%*
1. vmcHumuslog *2. wdptOHlog*		*wdptOHlog* *11%*	*vmcHumuslog* *54.6%*
1. wdptOLlog *2. wdptOHlog*	*Susp.sed.conc.max.log=1.597-0.666wdptOLlog+0.395wdptOHlog*	*WdptOLlog* *67.3%*	*WdptOHlog* *10%*
1. wdptOHlog *2. wdptOLlog*		*wdptOLlog* *77.3%*	*wdptOHlog* *0%*
1. wdptOHlog *2. wdptOLlog*	*Susp.sed.load.log=-0.736-0.788wdptOH-0.029wdptOL*	*wdptOHlog* *59.7%*	*wdptOLlog* *0%*
1. wdptOLlog *2. wdptOHlog*		*wdptOHlog* *28.1%*	*wdptOLlog* *21.7%*
1. vmcHumus.log *2. Roughness.log*	*Runoff.coef.log=1.480+4.131vmcHumus.log-10.485roughness.log*	*vmcHumuslog* *42.8%*	*Roughness.log* *0%*
1. Roughness.log *2. vmcHumus.log*		*vmcHumuslog* *36.79%*	*Roughness.log* *0.003%*

Regarding to the data in the table above, every independent/input variable seems to be related to the dependent/output variable when its analyzed as the only variable in the model. When adding a second variable, the influence of both variables on the dependent/output variable is not significant (see annex 6). When changing the entering order of the variable, same behavior is observed.

Multiple regression, method: steep-wise, correlated variables:

Table 5 *Variables with significant influence in the dependent variable.*

Model	Variable with sig.influence (R2 adjusted)
1. Susp.sed.load.log=1.905+4.865vmcHumus.log	vmcHumus.log 54.6%
2. Susp.sed.conc.max.log=1.610-0.477wdptOL.log	WdptOL.log 67.3%
3. Susp.sed.load.1.log=-0.763-0.818wdptOHlog	WdptOHlog 59.7%
4. Runoff.coef.log=1.393+4.434vmcHumus.log	vmcHumus.log 42.8%

By using stepwise method, independent variables were added in the model step by step that are part of the significant correlations studied. This procedure only shows the variable, which has significant influence on the dependent/output variable. For models 1 and 4 the most influencing variable is vmc Humus. For model 2 wdptOL is the most influencing. Model 3 was singnificantly influenced by wdptOH.

Multiple regression, method: steep-wise, correlated variables and wdptOL, wdptOF, wdptOH and vmcHUMUS variables:

Table 6 *Variables with significant influence in the dependent variable, taking into account the influence of WDPT of Humus layer and v.m.c Humus.*

Model	Variable with Sig.influence (R2 adjusted)
Susp.sed.load.log=1.891+5vmcHumus.log	vmcHumus.log 61.6%
Susp.sed.conc.max.log=1.610-0.477wdptOL.log	wdptOL.log 67.3%
Susp.sed.load.1.log=1.891+5vmcHumus.log	vmcHumus.log 61.6%
Runoff.coef.log=1.389+4.472vmcHumus.log	vmcHumus.log 56.2%

The same steps as in the previous analysis were made, but in this case all water repellency variables and volumetric moisture content Humus variable were added.

For all cases studied, the variable that most influences is vmcHUMUSlog, except for susp.sed.conc.max.log that was influenced significantly by wdptOLlog.

Multiple regressions were only done for Spruce forest data. Significant correlations found in the beech forest didn´t have two variables significantly correlated to one common different variable. In other words, correlations of two variables with one common variable can be found, as we can see in the scheme below. However these correlations are not adding extra knowledge for the research questions of this thesis research.

SPRUCE FOREST

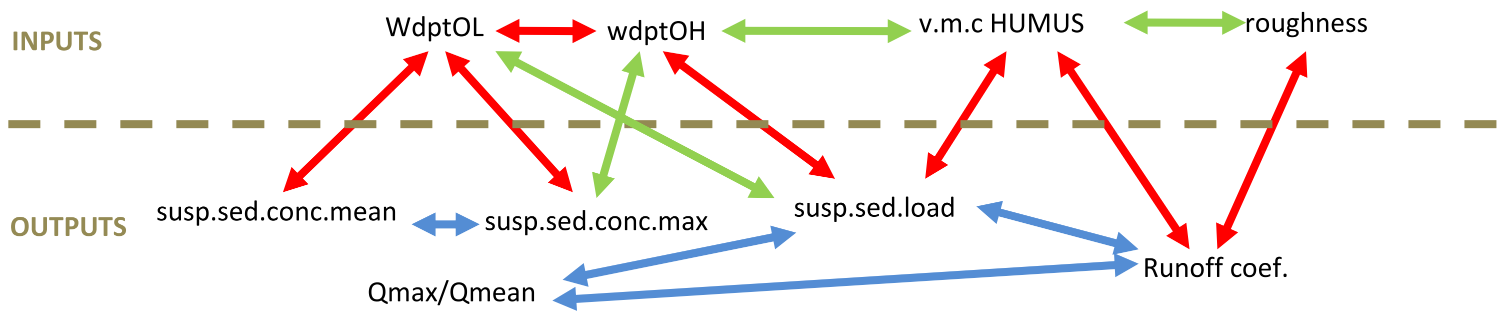


Figure 24 *Significant correlations studied, significant correlations and unknown correlations The inputs are the variables measured in the field. The outputs are the variables obtained from the variables measured in the field.*

BEECH FOREST

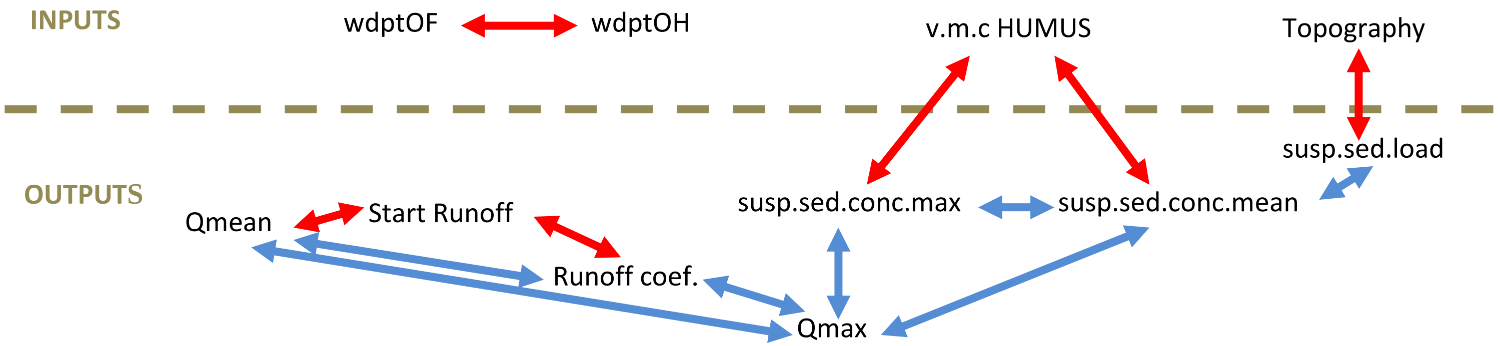


Figure 25 *Significant correlations studied, significant correlations and unknown correlations The inputs are the variables measured in the field. The outputs are the variables obtained from the variables measured in the field.*

7. Discussion

Temporal variation of water repellency and volumetric moisture content

According to the statistical analysis done with water repellency and volumetric moisture content data, significant variations between studied both dates were observed on the v.m.c of the mineral soil variable. However, as it was already mentioned in the results, no significant differences on the wdpt of the mineral soil were observed. It could be assumed that there is no clear linear relationship between both variables because they didn´t change in a similar way in time. On the other hand, lack of data, weather variability and influence of not measured other variables could have provoked non significant statistical results in the other variables.

Temporal variation of water repellency and moisture content data in the rainfall experiments sites were studied as well. Regarding the graphs of each rainfall experiment site, qualitative relation between water repellency and moisture content could be assumed (e.g. see figure 13) but this relation is not observed in all cases (e.g. see figure 12). Contrary to Keizer et al. (2008) findings, in this research it is not possible to support with obtained results a clear relation between moisture content variation and water repellency variation within time. Temporal variation trend of moisture content is not the same as the temporal variation trend of water repellency. Same observations were described in Doerr et al. (2006) where is argued that there is no clear relationship between water repellency and moisture content or any trend between both variables. It is only observed a trend of symmetry between moisture content of humus layer and moisture content of the mineral soil (e.g. see figures 13 and 15). This trend again is not observed in all cases (e.g. see figure 18). However, Keizer et al. (2008) found that moisture content is related to temporal variation in water repellency, opposite to the findings in this thesis research as mentioned before. Furthermore, Keizer et al. (2008) explains that soil moisture content is one of the key variables that affects the temporal variability of water repellency in short term periods of time (days or weeks). On the other hand, after exploring soil moisture content and antecedent rainfall as key variables for the temporal variability of water repellency the conclusion of Keizer et al. (2008) was that soil moisture content was more relevant than antecedent rainfall but not the only variable influencing temporal variability of water repellency as it has been found in this thesis research.

In addition, in qualitative terms, the influence of water repellency of a single humus layer type seems to be lower than the influence of the sum up of more than one humus layer type. Regarding the correlation analysis, correlations between different humus layers were significant. In the Spruce forest, water repellency on Ol and Oh layer were positively correlated and in the Beech forest, water repellency of Of and Oh layers were negatively correlated. Here again, qualitative observations of the influence of v.m.c on water repellency are not supported by statistical analyses. However, influence of Humus layer and its compounds, such as fungal and micro-biological organisms, in water repellency has been studied in several times (DeBano et al. 1973, Jex et al. 1985 and Bond et al. 1964) suggesting links between moisture content and development of flora and fauna within the Humus layer.

It seems to be that the time variable not only depends on the studied variables such as water repellency and moisture content. Final variability in time of these factors might also be influenced by not studied variables, such as, precipitation in the study area, moisture content in the atmosphere, evapo-transpiration, biological factors, such as organic matter content or biological activity in the humus layer as it is explained in Leighton-Boyce et al. (2005), Doerr et al. (2000) and Jonge (2010).

Therefore it is not possible to observe a clear relationship between studied both parameters in time, due to the shared influence of a group of variables that were not included in the research.

Spatial variation of water repellency

High horizontal variability of water repellency was observed at micro-scale level within the study area. Within same study site from slight to severe water repellency conditions could be found over the same studied soil layer (see annex 5). This variability could even be found in few centimeters distance with opposite water repellency conditions (see annex 5). Dekker et al. (1999) also found high degree of variability within a horizontal distance of centimeters to decimeters.

High vertical variability in water repellent conditions was also observed (see annex 2). In the literature is argued that this variability could be mainly linked with the distribution of the amount of organic matter within the soil profile but that this variability is also depending in other variables such as root channels, animal burrows and so on. Therefore, distribution of repellency cannot be described as a simple linear system of several variables but as a non-linear system of variables including feedback mechanisms (Doerr et al. 2004).

High variability in water repellency was also recorded in Dekker et al. (1994). Further research is needed in order to study whether spatial distribution is randomly distributed or is following any trend and which are the variables that lead to that distribution.

Significant differences were found between the two forest types. Beech forest showed more wettable mineral soil and higher values of volumetric moisture content in the humus layer as well as in the mineral soil. To finish, runoff started later in beech forest than in the spruce forest and roughness was higher in the beech forest than in the spruce forest.

In qualitative terms and regarding different researches that support direct relation between water repellency and moisture content of the soil and runoff water generation such as Leighton-Boyce et al. (2005), Dekker et al. (2000), Dekker et al. (1994), Doerr et al. (2004) and Doerr et al. (2003) it could be possible to say that there is a later generation of runoff water in Beech forest due to its higher wettability that was provoked by high moisture content values. Once again, qualitative results in this research are not supported by quantitative results obtained in the statistical analysis.

Correlation analysis of studied variables was done. Significant correlations between water repellency variables and rainfall experiment output variables were found in Spruce forest but not between water repellency and moisture content variables. The beech forest showed significant correlations between volumetric moisture content variables and rainfall experiment output variables. Therefore it is not possible to confirm that there is a direct link between moisture content and water repellency as it is also found in Jonge (2010) regarding data obtained in this research.

Regarding Spruce forest, a multiple regressions were carried out in order to see the degree of influence of the variables that were significantly correlated in the statistical analysis. The used data was normalized using logarithmic functions.

Suspended sediment load and runoff coefficient were mainly influenced by the volumetric moisture content of the Humus layer whereas suspended sediment concentration is mainly influenced by water repellency of the OL layer; when water repellency of the each Humus layer and the moisture content of the humus layer were taken into account for the multiple regression apart from the significantly correlated input variables.

When analyzing the two input variables that were correlated to a common output variable those input variables were independently correlated to the common output variable but not between them. Thus, the suspended sediment load is correlated to moisture content of the humus layer and to the water repellency of the OH layer. However, direct correlation between both input variables was not observed and it could be defined as non-linear correlation which is not possible to describe it only with these two variables. Non-linear behaviors have been also described in several researches: Doerr et al. (2004) Jonge (2010), Regalado et al (2005) and Jex et al (1985). Same behavior was observed in the other significant correlations described in the results (see table 4). Opposite to the results described in several researches such as Täumer et al. (2005), Soto et al. (1994), King (1981), Dekker et al. (1994), Bond et al. (1964), Witter et al. (1991) and Dekker et al (1999), this research does not support a direct relationship between water repellency and moisture content as it is explained with the several statistical analyses done in the research. Additional influencing variables which were not measured or taking in to account might be between the relationship of moisture content and water repellency that would be part of a more complex system of variables than the more simple system of variables supported in other researches such as Dekker et al. (1994), Doerr et al. (2000), Soto et al. (1994), King et al. (1981), Dekker et al. (1994) and Täumer et al. (2005).

Finally, using row data relation between water repellency in humus layer as well as in mineral soil and moisture content of both layers was represented by dot-plots.

In the Spruce forest threshold value at 30% of moisture content value was observed. Under this value from slight to severe water repellency values were registered in most of the sampling and measuring sites. Regarding to the lowest values of water repellency at low moisture content values, there is no clear inverse relationship between water repellency and moisture content opposite to findings in many researches as Soto et al. (1994), King (1981), Dekker et al. (1994) and Täumer et al. (2005) and Doerr et al. (2006). Furthermore, similar behavior was mentioned in Doerr et al. (2006) with a threshold value of 28% of moisture content, there was not any clear relationship between water repellency and moisture content (Doerr et al. 2006).

According to the results, there was not any transition zone observed. These results are supported by Jonge (2010) that also found wettable conditions at low moisture content values, opposite to many researches by Doerr et al. (2006), Täumer et al. (2005), Ziogas et al. (2005), Lichner et al (2006), Keizer et al. (2008) and Czachor et al. (2010).

Leighton-Boyce et al. (2005) suggest a distortion of the results due to the difference in the measuring area regarding water repellency and moisture content (moisture content is measured in 100cm3 soil cylinders whereas WDPT is measured over a thin humus or mineral soil layer) that could provoke a wider distribution of the results in the dot-plot and describe a transition zone. As explained before, any transition zone was described in the results. However, Leighton-Boyce et al. (2005) suggestions also could explain such distribution of the results under 30% of moisture content in this thesis research.

Above 30% of moisture content low values of water repellency were observed except from few abnormal values in A01.11 site and A02.1 site. High water repellency values in both sites could be provoked by the presence of fungal mycelia in at least one of the Humus layers as mentioned in DeBano et al. (1973), Jex et al. (1985) and Bond et al. (1964). In addition, lack of runoff water generation in site A01.11 (see annex 5: figure 4) could be explained by the presence of moss in the OL Humus layer (Jungerius et al. 1989). Further research is needed in order to see the influence of the type of vegetation over the water runoff generation.

As mentioned above, a non-linear relation between water repellency and volumetric moisture content of humus and mineral soil layers was observed. Non-linearity in this relationship could be explained by the influence of other variables that were not taken into account neither measured in this research. It could be possible to think about biological factors that might be influenced by the moisture content of the Humus layer. Variation in moisture content of the Humus layer could influence the growing cycles of several organisms as well as the development of roots and other organic components or biological processes. In consequence these activities and processes could influence on the generation of water repellency within the humus layer and mineral soil. In addition, depending on the studied humus layer, the organic matter would be in a certain stage of the decomposition process. Depending on that the influence of organic matter on water repellency of each humus layer will be different. According to Jonge (2010), organic matter is an important driver of water repellency. Furthermore, Doerr et al. (2004) remarks that abiotic processes such as water repellency are linked to biotic processes through feedback processes that mainly are non-linear. Thus, when considering a linear relationship between water repellency and moisture content without taking into account other variables such as biotic variables, would not reflect the real process leading to water repellent conditions.

Figure 26 *non-linear relationships of water repellency and v.m.c Humus. A Biological factor as influenced variable by soil moisture content.*

Regarding data obtained from Beech forest, any multiple regressions were done. Significant correlations found didn´t include three variables which both of them were related to a common variable (See figure 25). Therefore any analysis about degree of influence of each variable was realized. In addition, lack of wdpt OL data influenced the amount of information obtained regarding beech forest. When representing normalized variables in dot-plots, they didn´t fit well in a linear function, with low accuracy values.

Regarding dot-plots done with raw data, any transition zone or threshold value was observed nor any trend of the data gathered. Beech forest soil is covered by a layer of leaf that could have influenced the moisture content, water repellency and runoff water generation in a way that it was not measured in this thesis research. Measured variables might be not the best variables to measure in order to characterize the spatial variability of water repellency and moisture content as well as the runoff generation in Beech forest. Therefore, morphologic variables that could influence once again in the measured variables should be taken into account. This is also mentioned in Jonge (2010) where is explained the probable connection of leaf morphology and microbiological activity in soil with water repellent conditions in deciduous forest.

Runoff erosion and runoff water generation in the study area

No runoff erosion was registered within the study area. Sediment release by runoff water was not big enough to consider relevant erosion processes within the study area. Sediments within the water runoff were mainly composed by organic matter released from the Humus layer (yellowish color of runoff water). Forests soil cover was fully composed by a 6 cm average thick Humus layer. Regarding the results obtained in this research and Jonge (2010) water repellency occur in the study area under both studied forest types, coniferous and deciduous forest. However, water repellency is less likely to provoke erosion problems due to the presence of Humus cover in the soil (DeBano et al. 1973).

Methodology

Field work

Regarding temporal variation of the studied variables, only data of water repellency and moisture content was measured in two different dates in all study sites within the study area. It seems to be that is not enough data to characterize the temporal variability of both variables. Data gathering of water repellency and moisture content in all rainfall experiment sites should be done periodically during a period of time. In this way, more data would be available and the statistical analysis output would be more reliable. The same idea is suggested in Keizer et al. (2008) where is considered that higher frequency of data sampling would improve the characterization of temporal variation of the studied variables. In addition, the exact point of doing the WDPT and taking the soil sample in order to measure the volumetric moisture content of the soil should be the same, due to the high variability of these variables at micro-scale level. I also would advice to do WDPT and soil sampling always in the same point in all dates. Thus, it would be advisable to mark the testing and sampling point with a marker or small flag. On the other hand, according to Doerr et al. (2004) repeated measurements in the exact point would disturb the sampling point at small spatial scale influencing in the reliability of the data obtained and influencing in the temporal variability of the results. Furthermore, Leighton-Boyce et al. (2005) suggest also possible distortions of the results due to the difference in measuring surface regarding WDPT and soil sampling cylinders for moisture content measures. Thus, further research is needed in order to figure out which would be the best methodology reflecting temporal variation of water repellency and moisture content without influencing in the accuracy of the data obtained.

Regarding the rainfall experiments the deepness of the ring should be fixed from the beginning of the experiment. In some of the experiments, the hammer was used during the rainfall experiment because the ring was not deep enough that water runoff was flowing over the ring´s “mouth”. When using the hammer, a peak of suspended sediment release is produced distorting the results of the experiments.

About the soil sampling methodology, when some stones were in the soil-sampling cylinder, these stones were removed and the gap of the stone was filled with more soil material. However, this is not the best way of doing it because when adding more soil material we were also adding more volumetric moisture content, distorting the results. Other methodology should be proposed in order to improve the accuracy of the results obtained.

Laboratory work

Sediment release was so low because most of the particles in the water runoff were part of the organic matter of the humus layer. Therefore, no erosion risk was registered. According to these observations, more accurate methodology in order to quantify the particle release and water runoff generation should be used. When using the paper filters negative values were registered when weighting the filters with the particles samples of the rainfall experiments after being 24 hours in the oven due to the extra weight of the glue and paper particles of the filters. Therefore, due to the small amount of sediments and organic matter gathered in the experiments, more accurate methodology I would advice more in line with the characteristics of the study area´s soil physical processes.

8. Conclusion

This study aimed to research the spatial and temporal variation of water repellency within the study area, relationship of water repellency with moisture content and with generation of runoff erosion.

Regarding spatial variation of mentioned variables, 21 rainfall experiments were carried out in 7 different study-sites, with 2-4 repetitions of the experiment on each site. WDPT and soil sampling with 100 cm^3 cylinders was carried out on each rainfall experiment site before and after the rainfall experiment.

Regarding temporal variation of studied variables, WDPT and soil sampling with 100 cm^3 cylinders were carried out in all 7 study sites within the study area in two different dates.

Suspended sediment load, suspended sediment concentration, water runoff (Q) and volumetric moisture content were measured in laboratory.

The observed results suggest:

Temporal variability

- No significant differences were found for the studied variables in two different dates except from wdpt in the Mineral Soil.
- No temporal trends were observed regarding water repellency and volumetric moisture content.

Spatial variability

- High spatial variability at micro-scale level has been observed, vertically as well as horizontally. Spatial variability might be influenced by time when measuring variables. Values of influencing variables change over time. Water repellency influencing variables are thought to be dynamic in time and not constant.
- Significant differences have been found between two vegetation types: Spruce and Beech forest.
- No clear direct relationship between water repellency and volumetric moisture content can be concluded from our results. No linear relationship is observed between water repellency and volumetric moisture content. Non-linear system is suggested in order to describe the relationship between water repellency and volumetric moisture content.
- Measured variables might not be the best to characterize the variable system influencing water repellency. It is suggested to include more abiotic and biotic variables as well as feedback mechanisms as part of a non-linear system.
- Significant correlations have been observed between water repellency and rainfall experiment outputs (suspended sediment load) in Spruce forest. Possible slight relationship could be suggested between water repellency and sediment release in the rainfall experiments.
- Threshold value at 30% of volumetric moisture content has been observed. Below this value, slight from severe water repellency values were registered. No transition zone was observed.

Methodology

- Methodology used in order to get the results should be considered as another influencing variable in the non-linear system leading to water repellency of soils.

As a main conclusion of this thesis research it could be said that volumetric soil moisture content might not be the only variable influencing temporal variability of water repellency. Water repellency is suggested to be a function composed by more variables than volumetric moisture content:

Water repellency=f(P,Cº,ETP,Organic Matter, v.m.c, Biological activity…)

9. Further research and recommendations

Regarding temporal variability of water repellency and moisture content higher sampling frequency is recommended in order to describe with higher accuracy temporal variation and variables affecting this variability.

High spatial variability at micro-scale level has been observed, vertically as well as horizontally. Further research on trend of water distribution is recommended in order to determine how the spatial distribution of water repellency might be influenced by abiotic as well as biotic variables and feedback mechanisms.

Significant differences in water repellency and moisture content as well as when runoff starts have been found between two vegetation types: Spruce ad beech forest. Further research is needed in order to characterize the influence of soil cover morphology in water repellency, moisture content and runoff generation depending on vegetation type.

There are no important erosion features in the study area. Linear relationship of Water repellency and volumetric moisture content has not been observed. Non-linear relationship between both variables is proposed. The influence of more variables is suggested as part of the non-linear system: Biotic variable. Further research is needed regarding influence of moisture content on biotic variables affecting water repellency.

Significant correlations have been found between water repellency and suspended sediment load in water runoff. Water repellency is likely to be linked to water runoff generation. Further research is needed in order to increase the amount of data from rainfall experiment and accuracy of the results.

Methodology used in the research might be not the best, what could be influencing the obtained data in the research. Further research is needed in order to figure out which is the less data distorting methodology.

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Annex 1 Rainfall experiment outputs

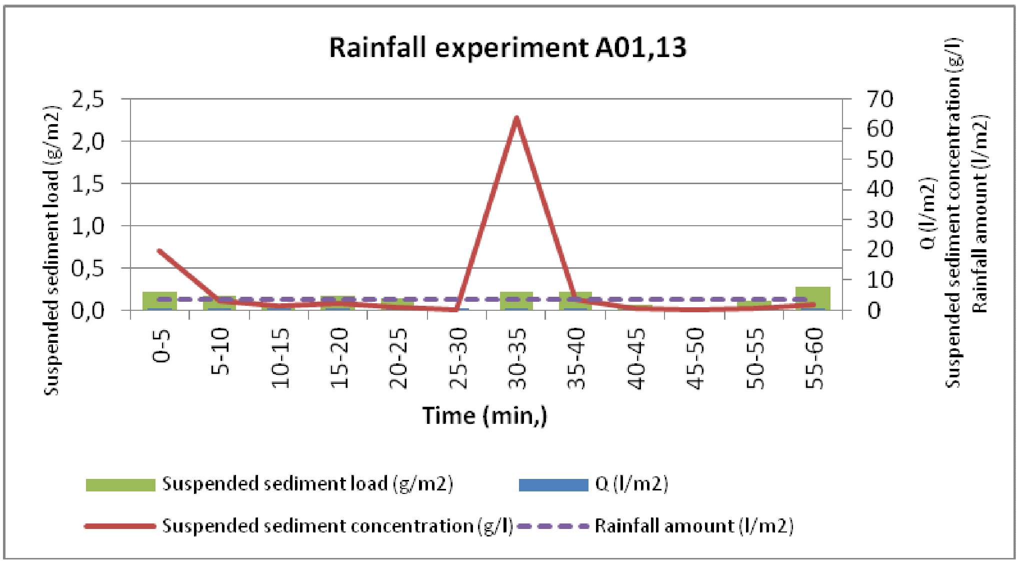


Figure 1.1 Rainfall experiment site A01,13

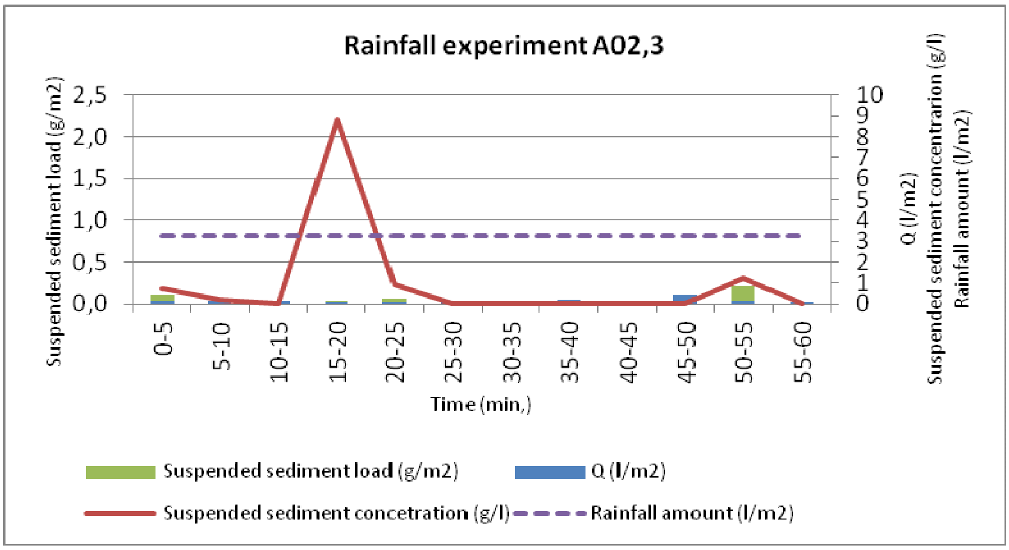
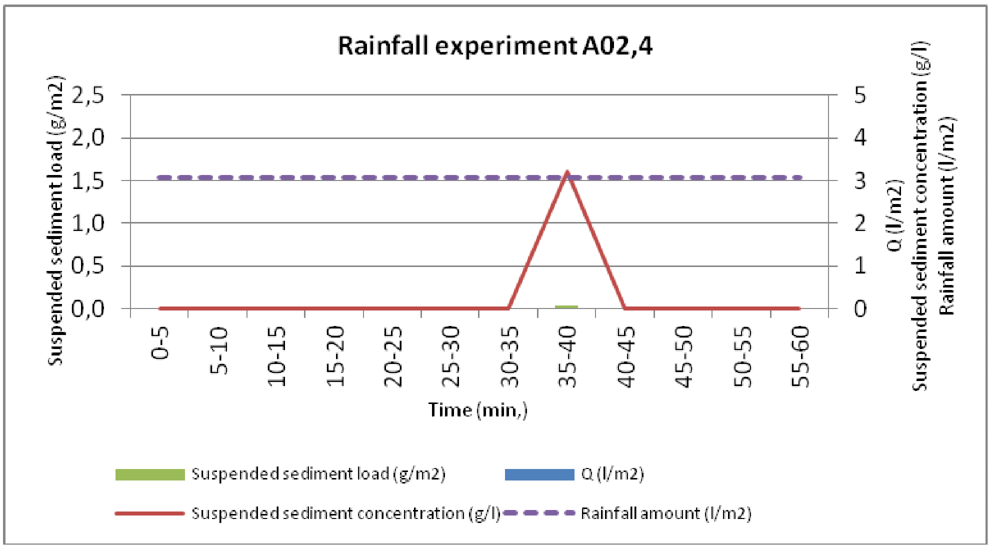


Figure 1.2 Rainfall experiment site A02.3



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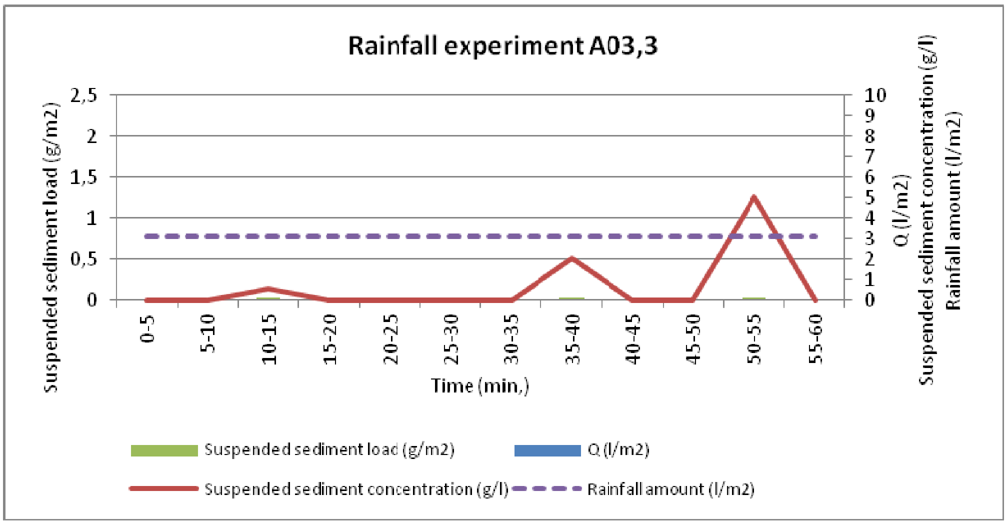


Figure 1.4 Rainfall experiment site A03.3

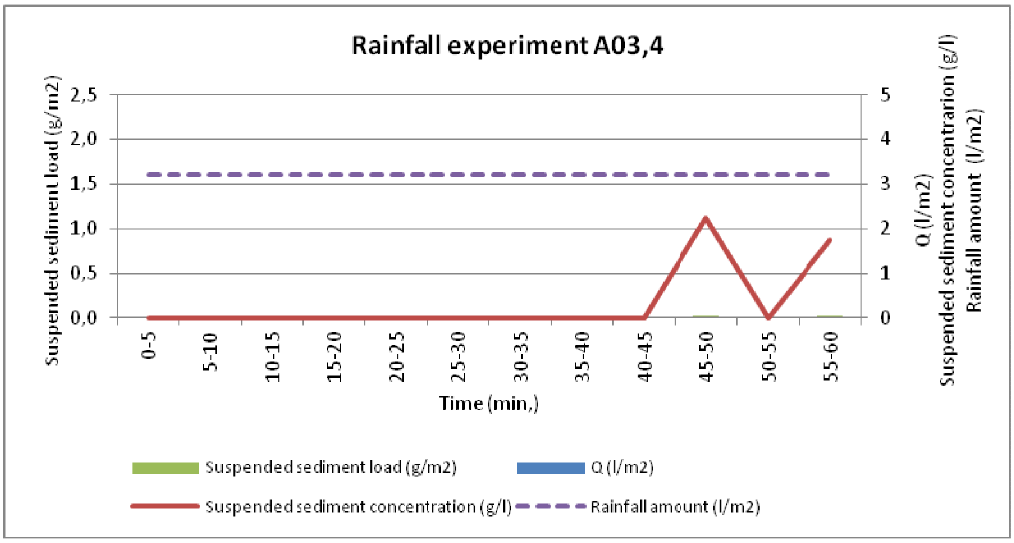
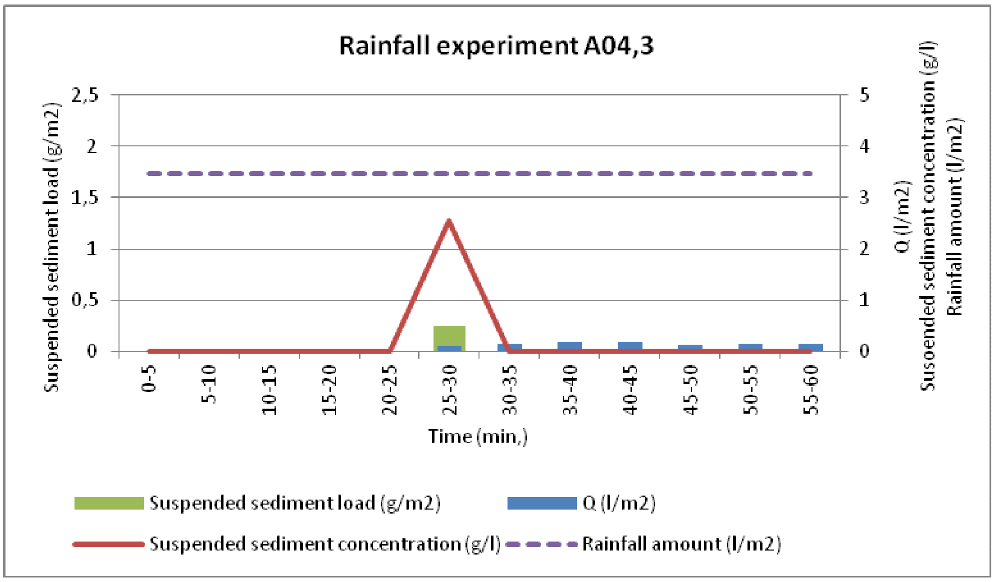


Figure 1.5 Rainfall experiment site A03.4



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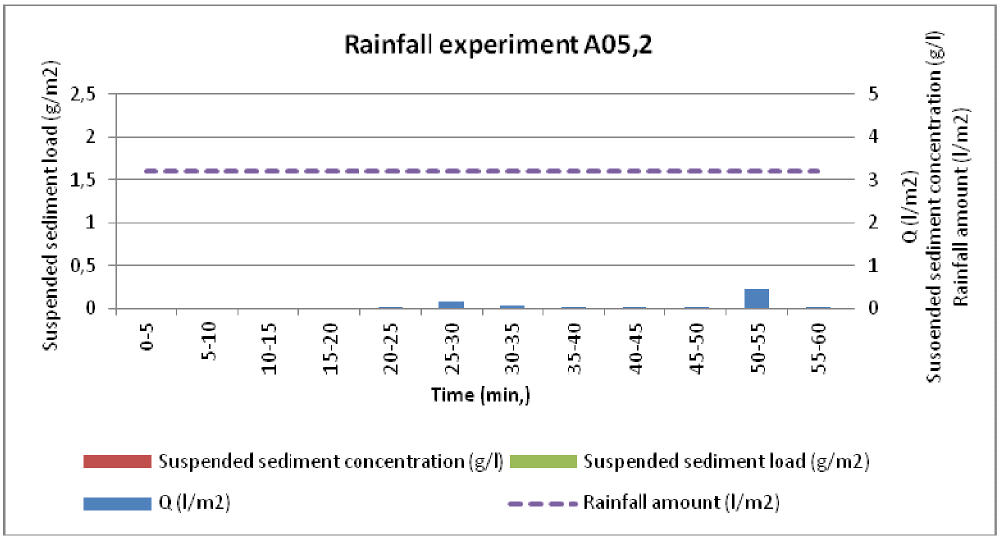

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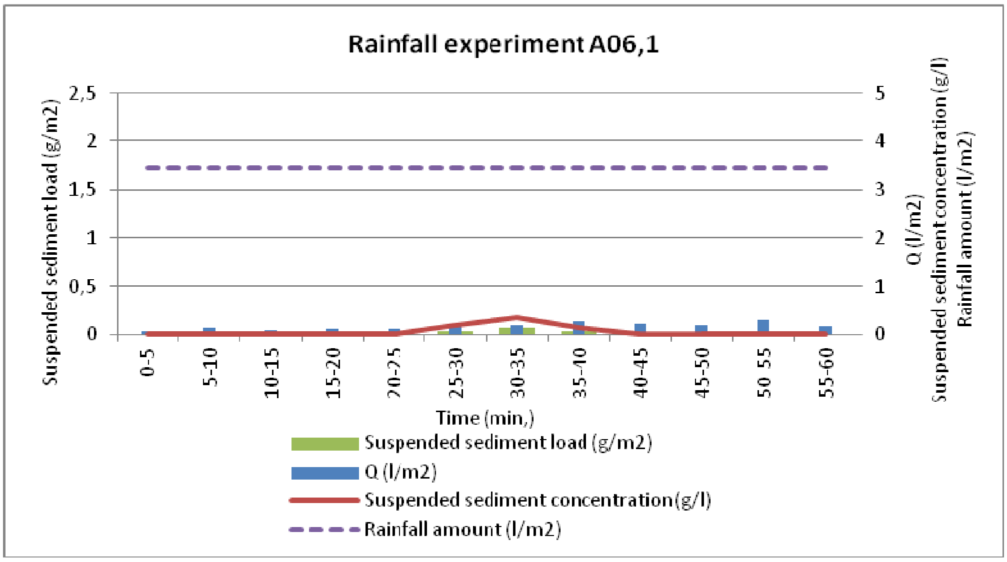
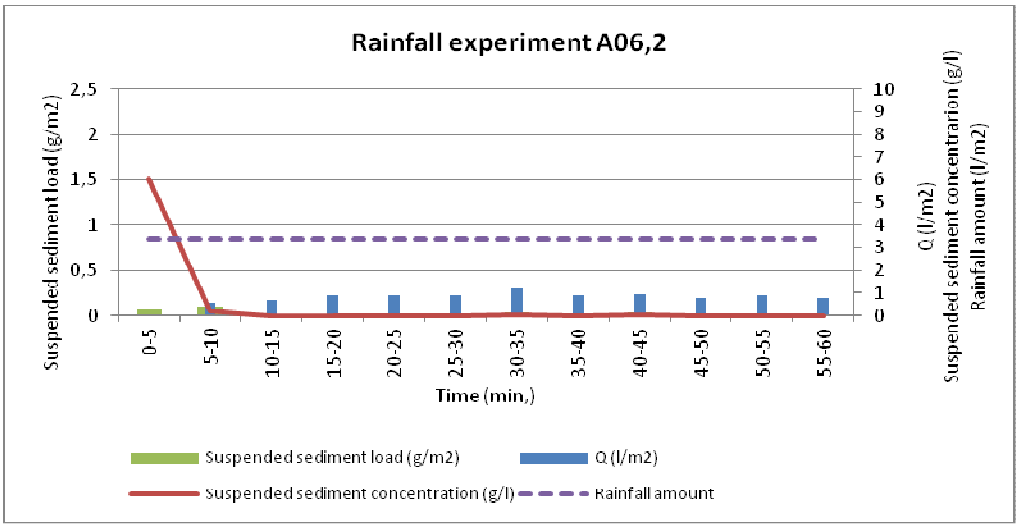


Figure 1.8 Rainfall experiment site A06.1



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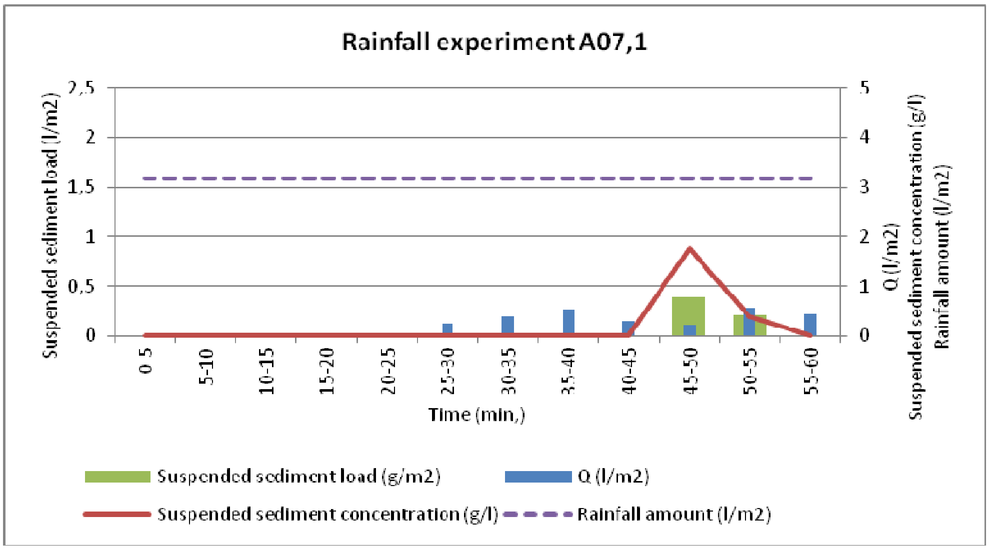

Figure 1.10 Rainfall experiment site A07.1

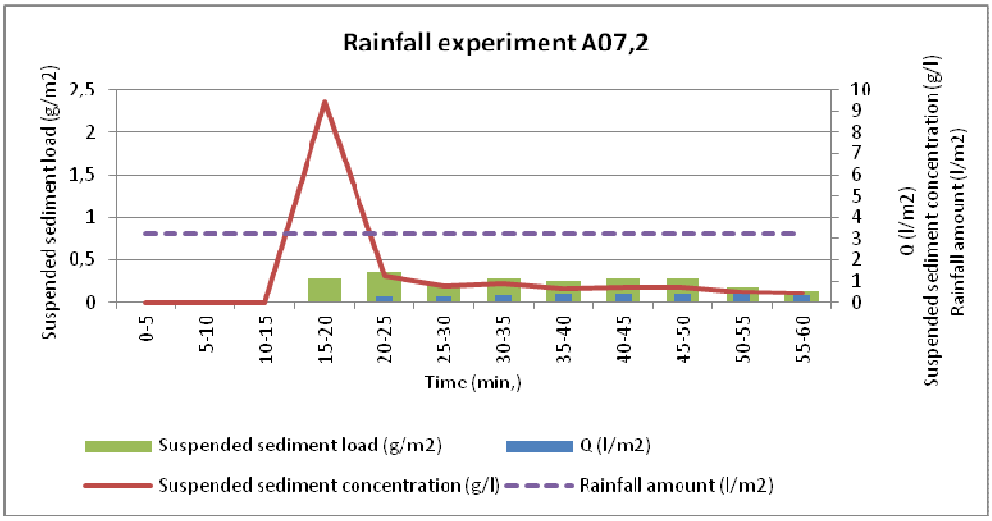

Figure 1.11 Rainfall experiment site A07.2

Annex 2 Wdpt and volumetric moisture content data

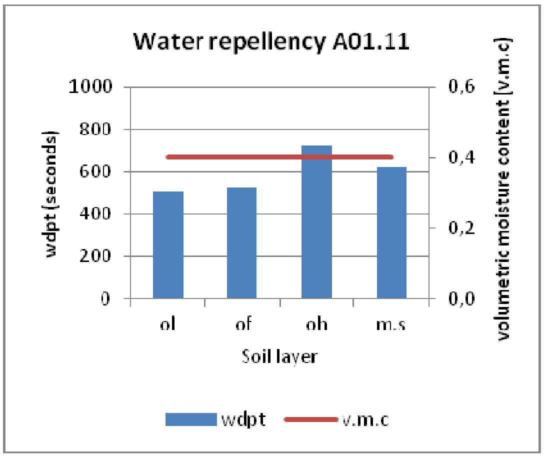

Figure 2.1 WDPT and v.m.c for site A01.11

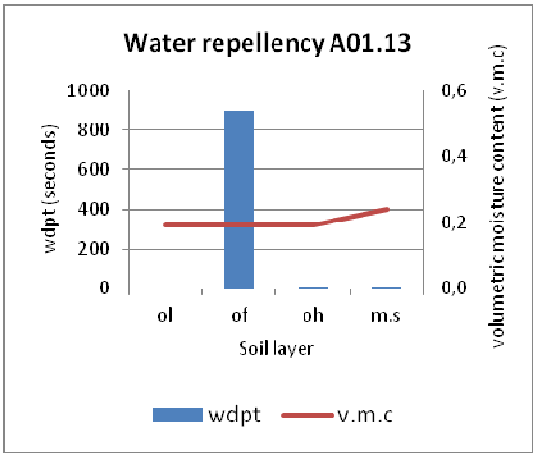

Figure 2.2 WDPT and v.m.c for site A01.13

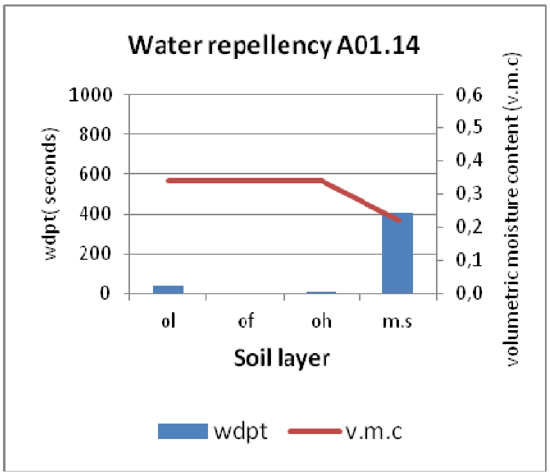

Figure 2.3 WDPT and v.m.c for site A01.14

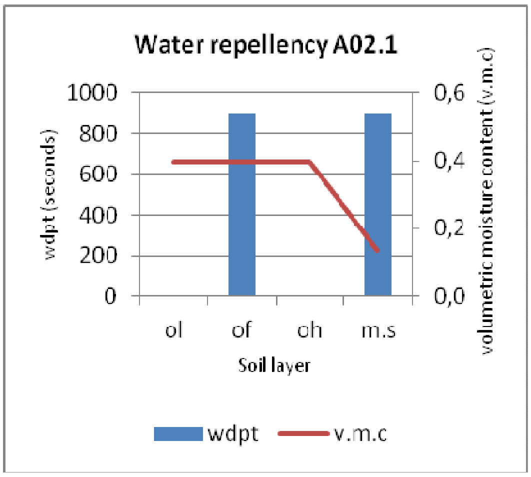

Figure 2.4 WDPT and v.m.c for site A02.1

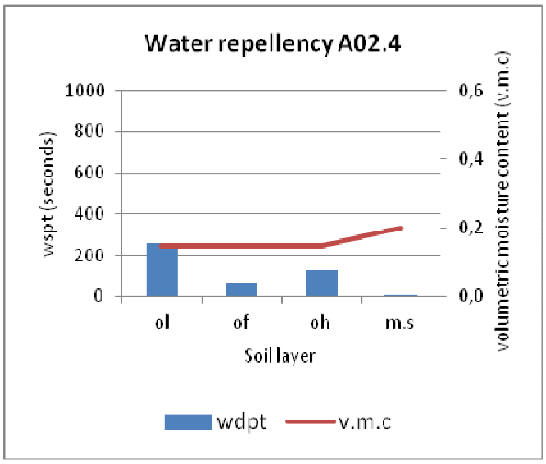

Figure 2.5 WDPT and v.m.c for site A02.4

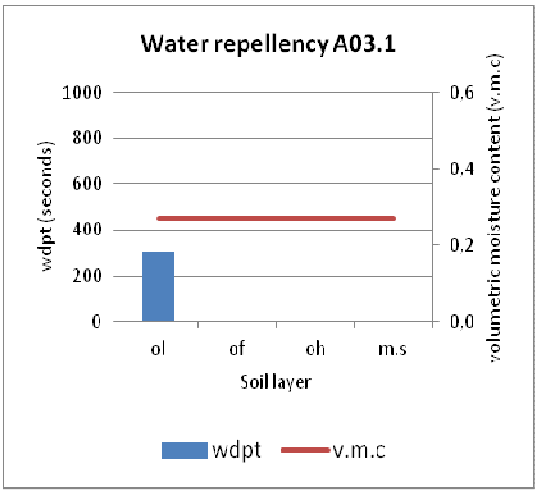

Figure 2.6 WDPT and v.m.c for site A03.1

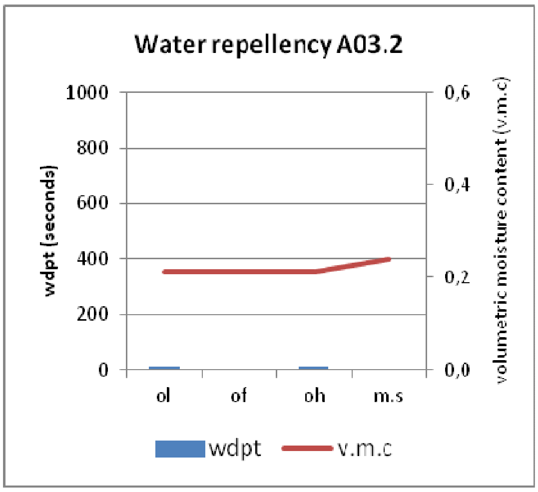

Figure 2.7 WDPT and v.m.c for site A03.2

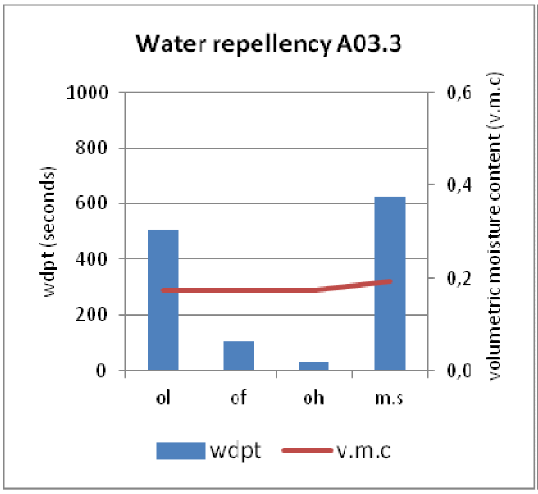

Figure 2.8 WDPT and v.m.c for site A03.3

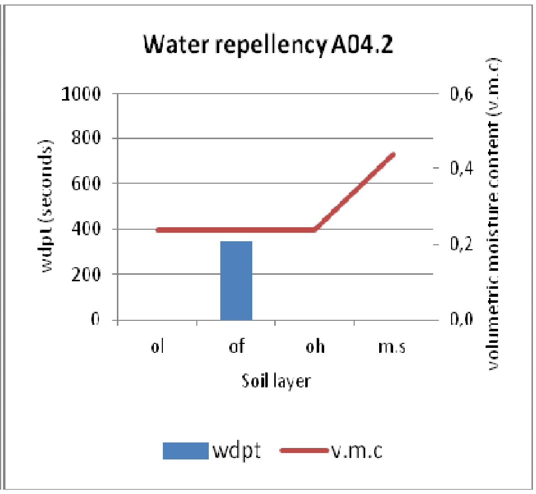

Figure 2.9 WDPT and v.m.c for site A04.2

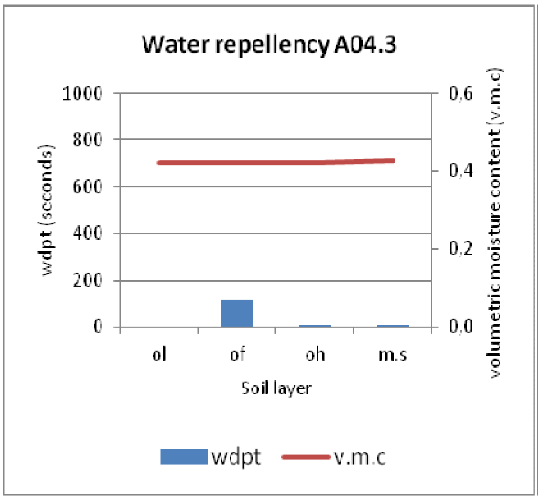

Figure 2.10 WDPT and v.m.c for site A04.3

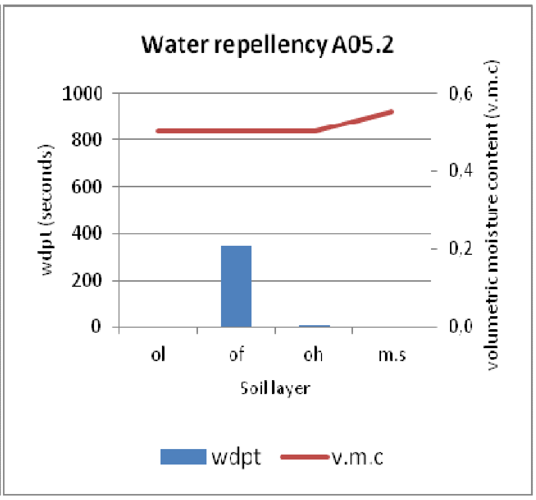

Figure 2.11 WDPT and v.m.c for site A05.2

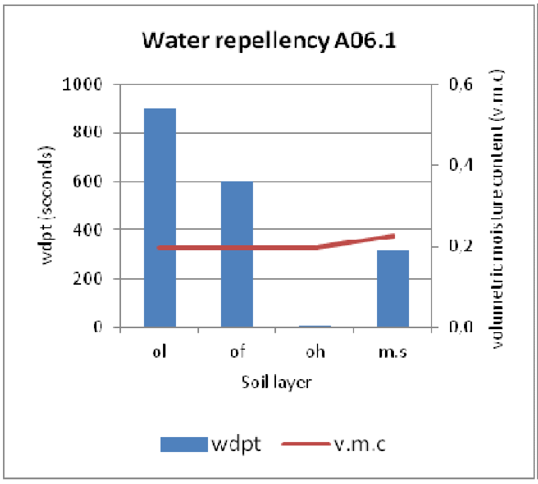

Figure 2.12 WDPT and v.m.c for site A06.1

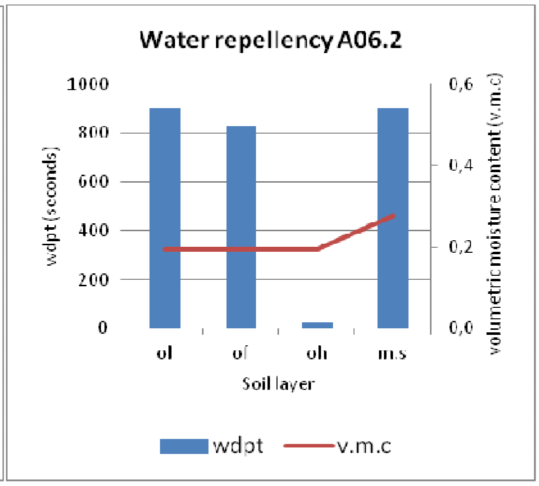

Figure 2.13 WDPT and v.m.c for site A06.2

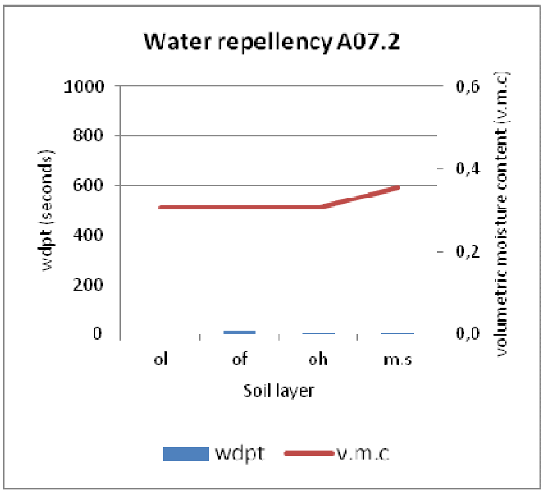

Figure 2.14 WDPT and v.m.c for site A07.2

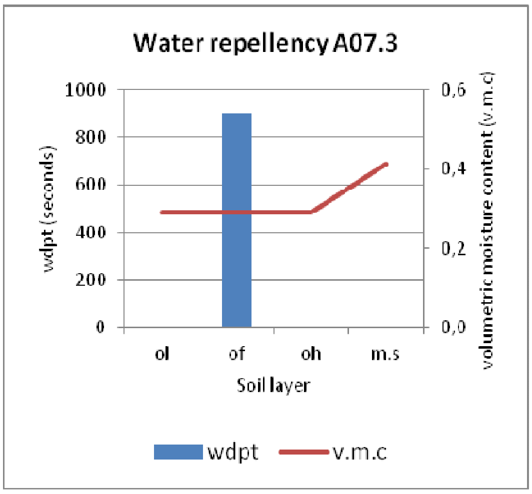

Figure 2.15 WDPT and v.m.c for site A07.3

Annex 3 Temporal variation of water repellency and volumetric moisture content

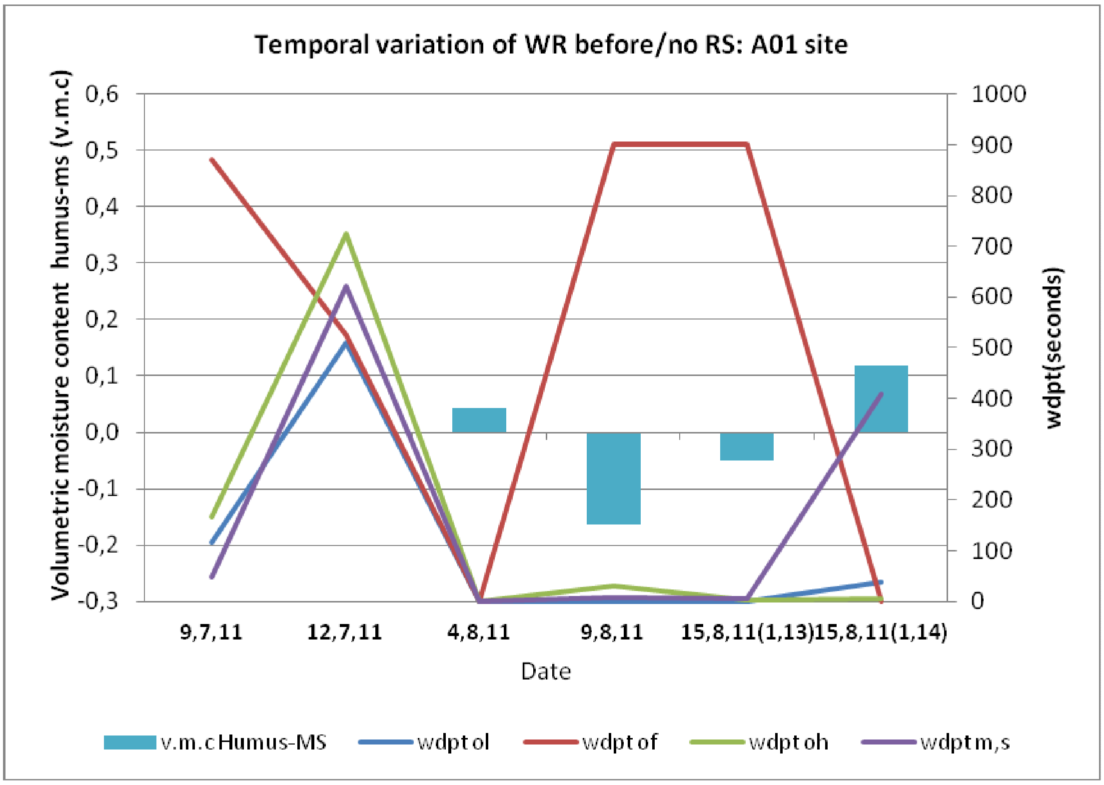

Figure 3.1 Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A01

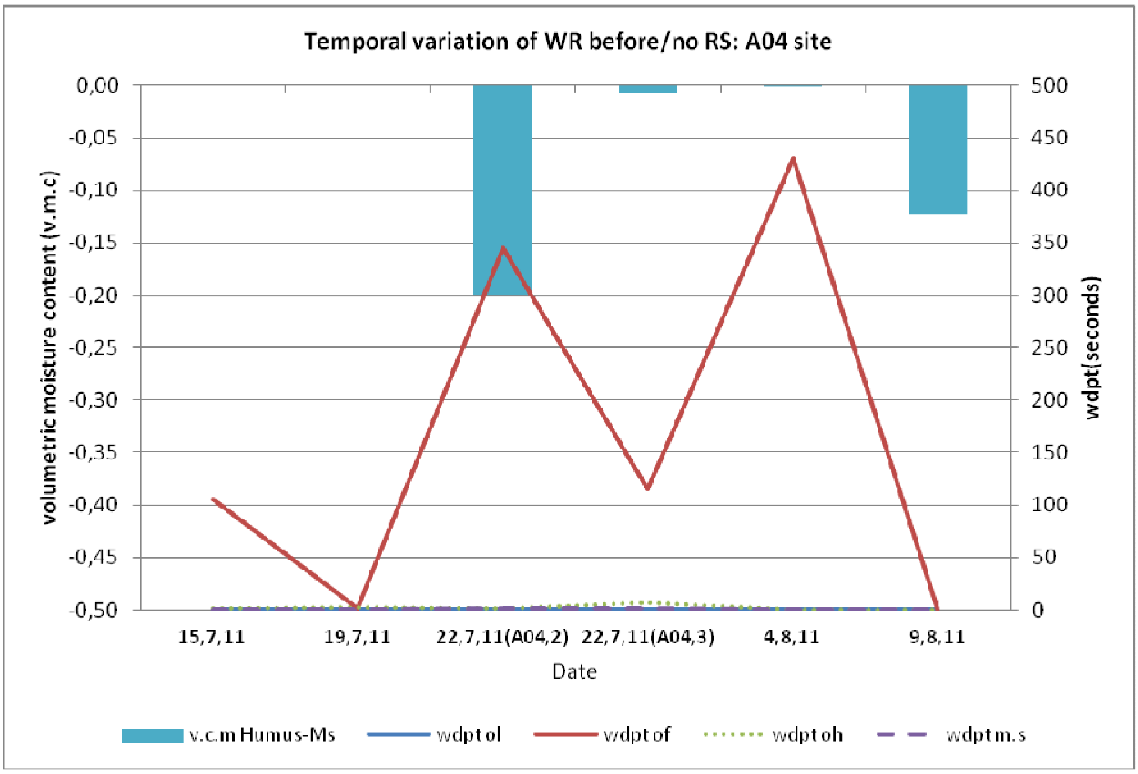

Figure 3.2 Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A04

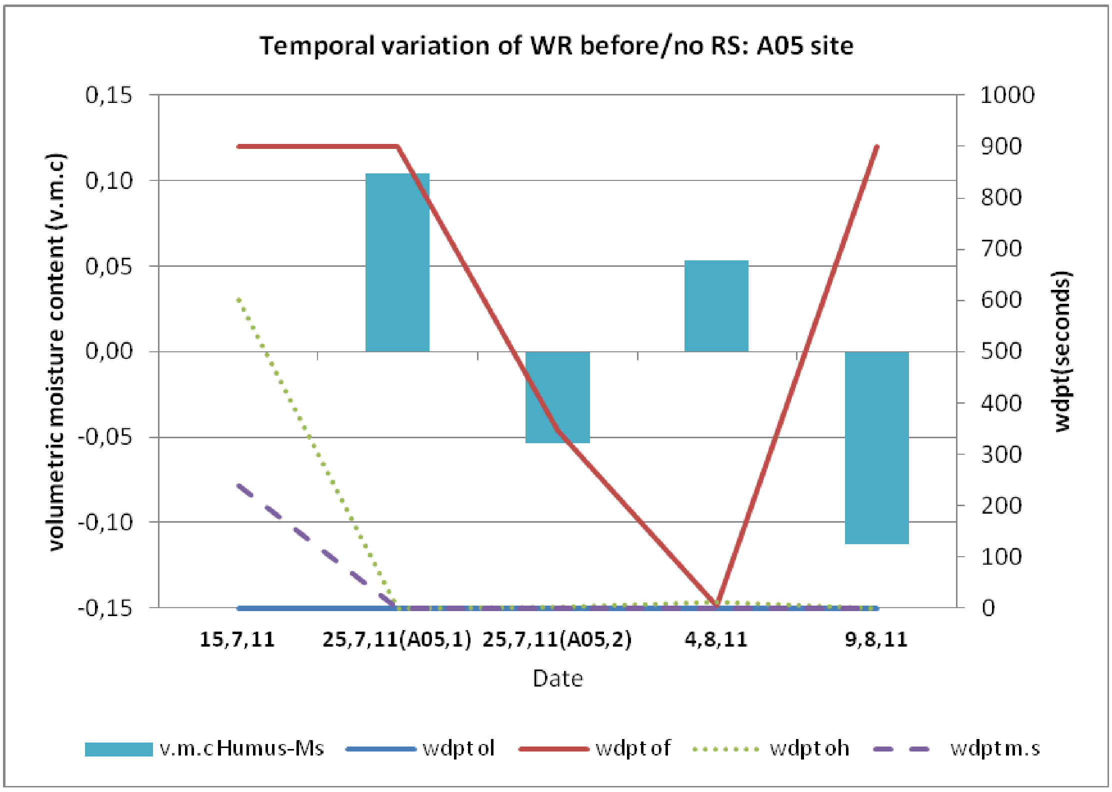

Figure 3.3 Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A05

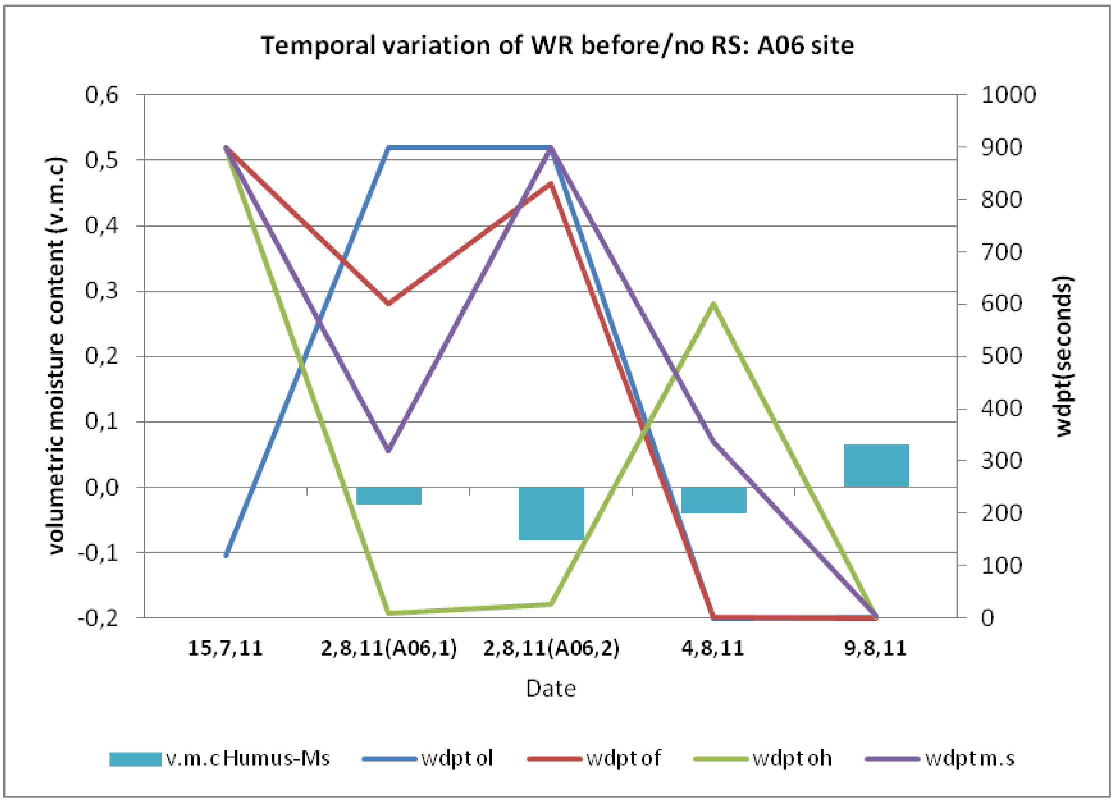

Figure 3.4 Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A06

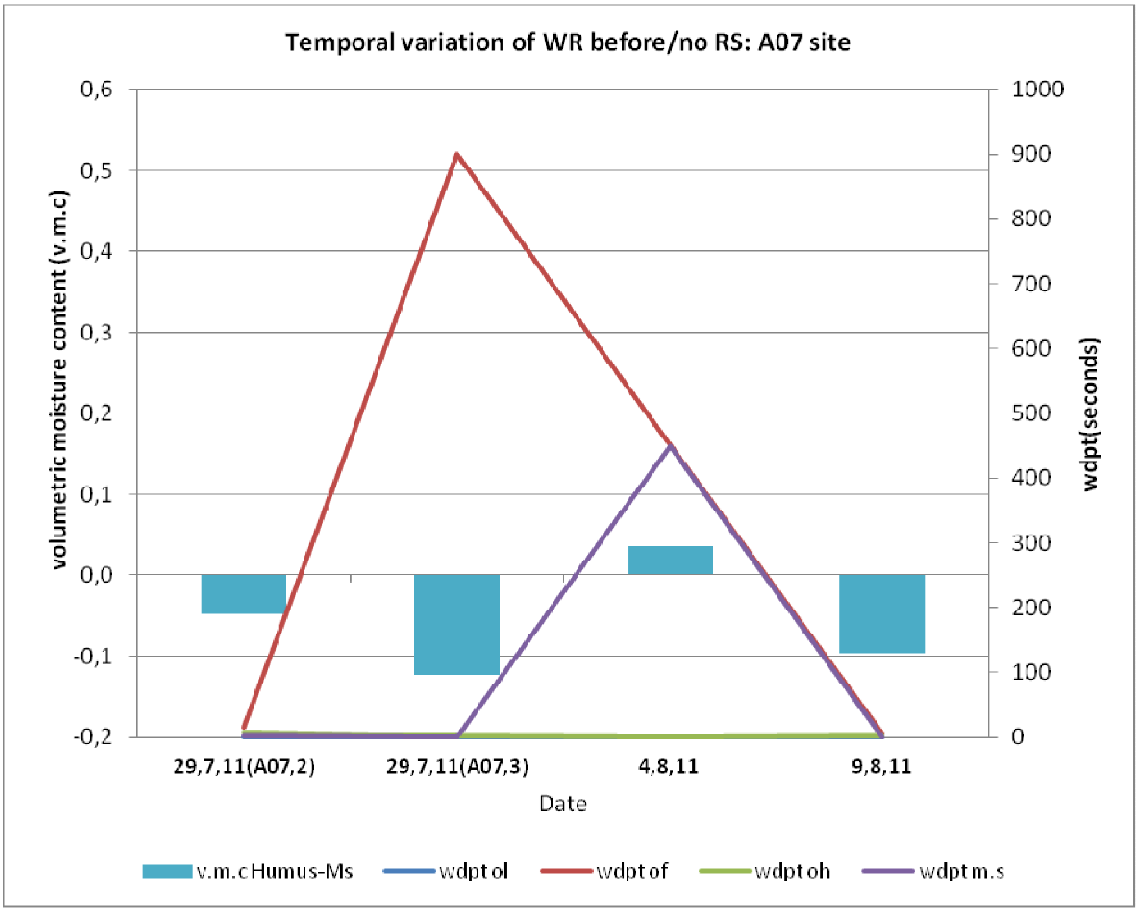

Figure 3.5 Temporal variation of water repellency and v.m.c difference between Humus and Ms layer for site A07

Annex 4: Statistical analysis output

Significant differences

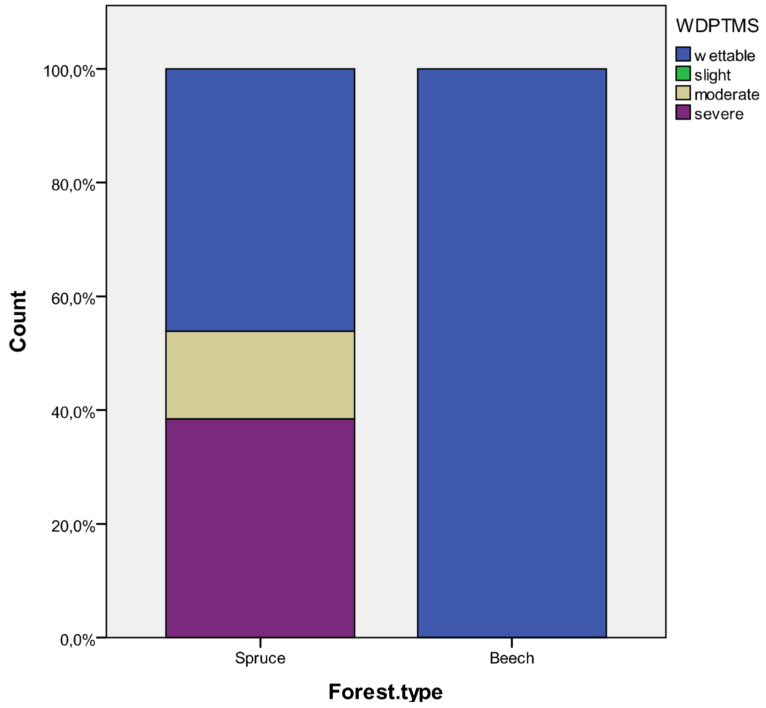

Figure 4.1 Significant differences between forest type: WDPT ms

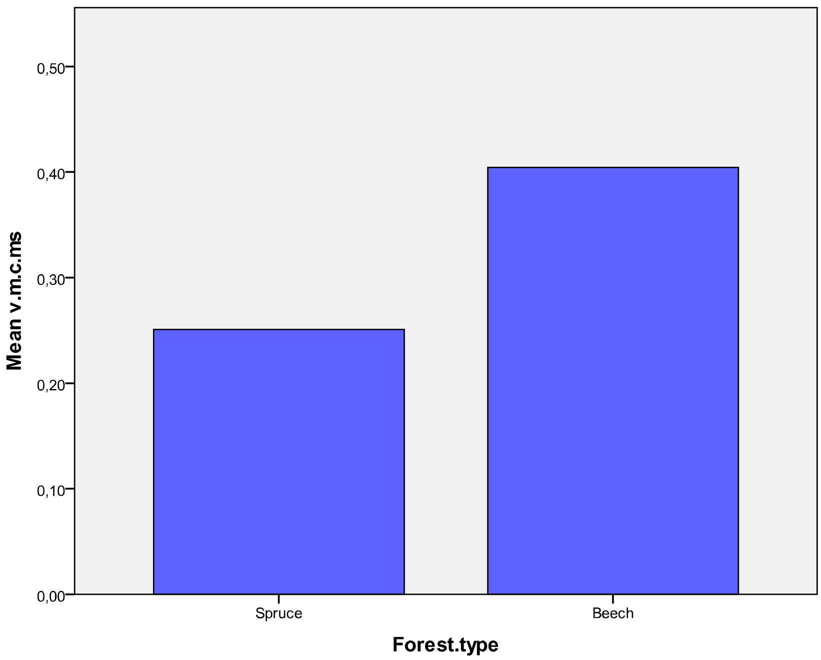

Figure 4.2 Significant differences between forest type: v.m.c ms

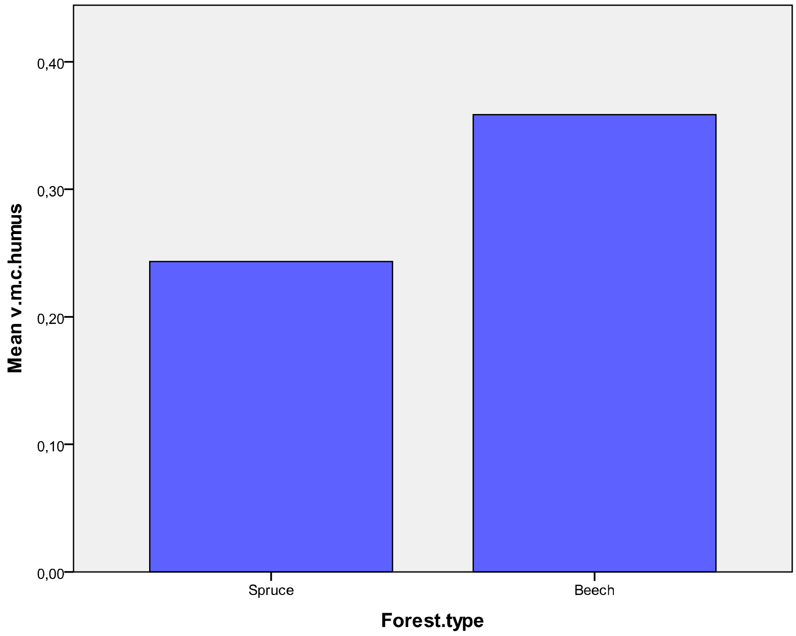

Figure 4.3 Significant differences between forest type: v.m.c Humus

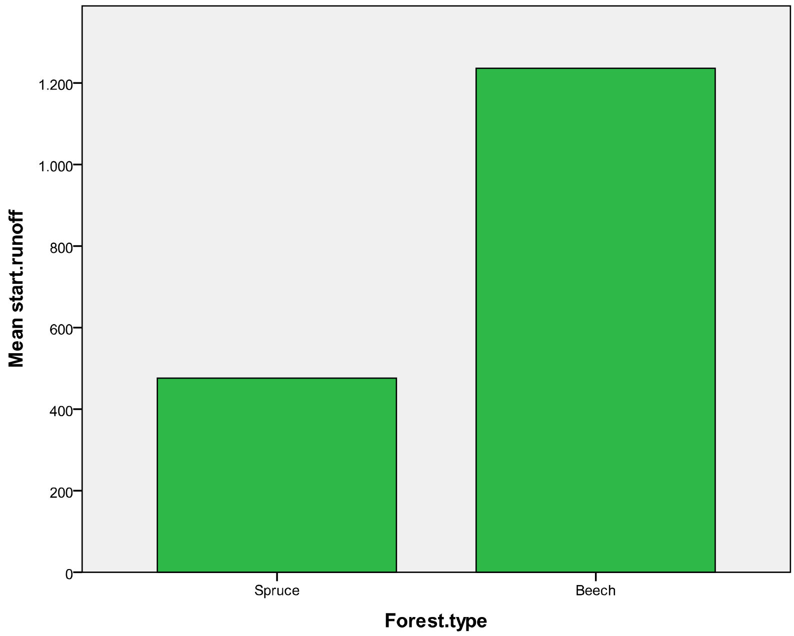

Figure 4.4 Significant differences between forest type: start runoff

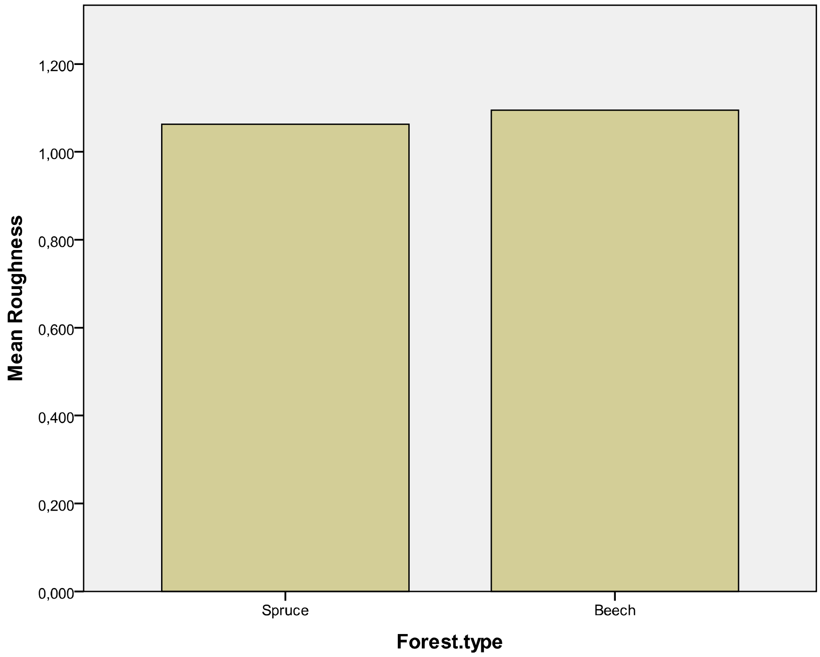

Figure 4.5 Significant differences between forest type: Roughness

Correlation analysis

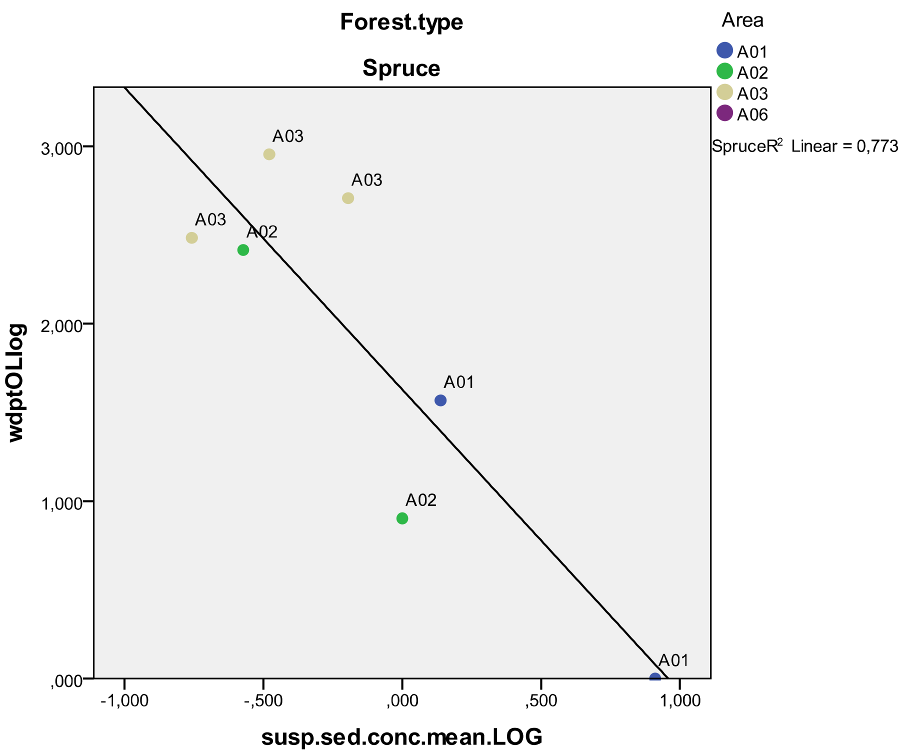

Figure 4.6 Significant correlation: wdpt OL log and Suspended sediment concetration mean log. in Spruce forest.

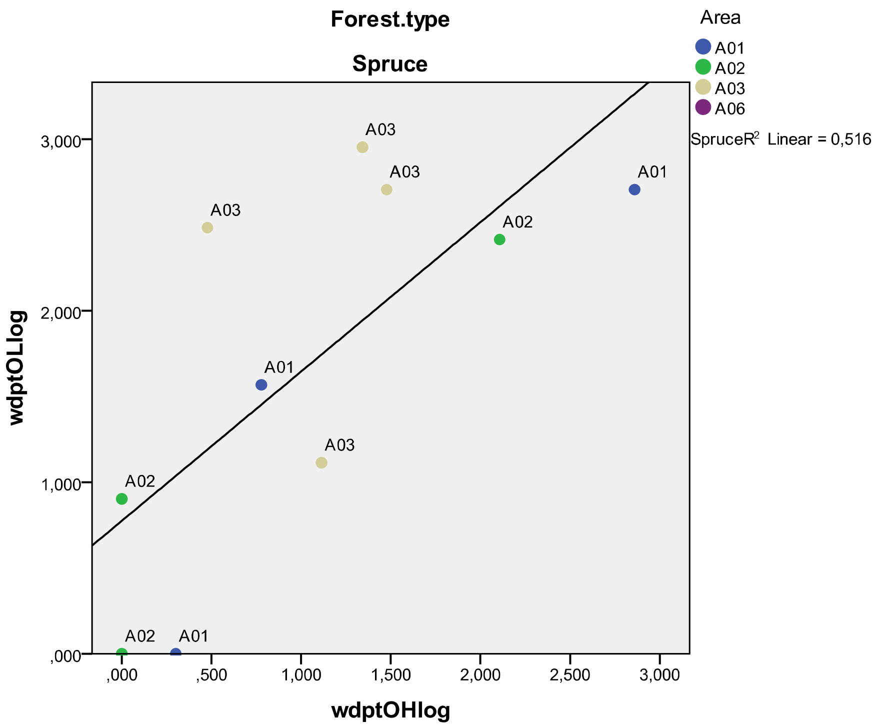

Figure 4.7 Significant correlation: wdpt OL log and wdpt OH log. in Spruce forest.

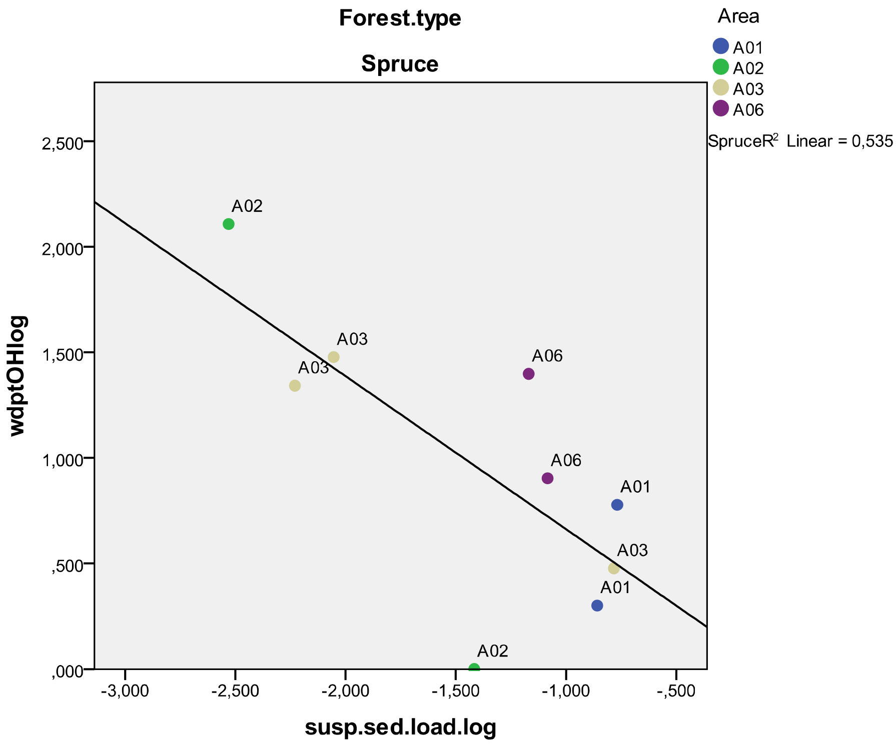

Figure 4.8 Significant correlation: wdpt OH log and Suspended sediment load log. in Spruce forest.

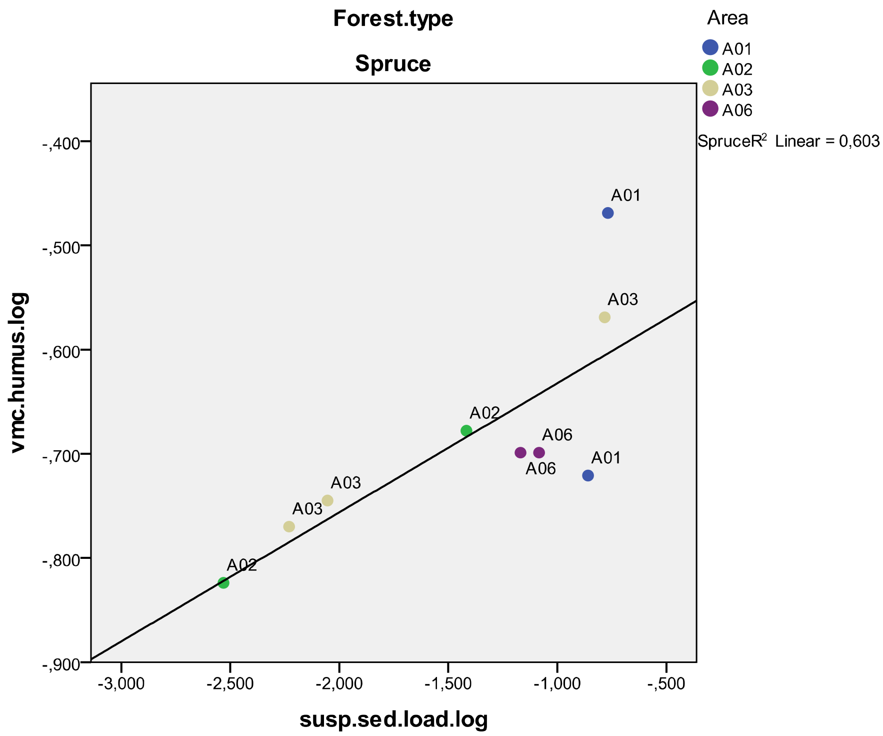

Figure 4.9 Significant correlation: v.m.c Humus log and Suspended sediment load log. in Spruce forest.

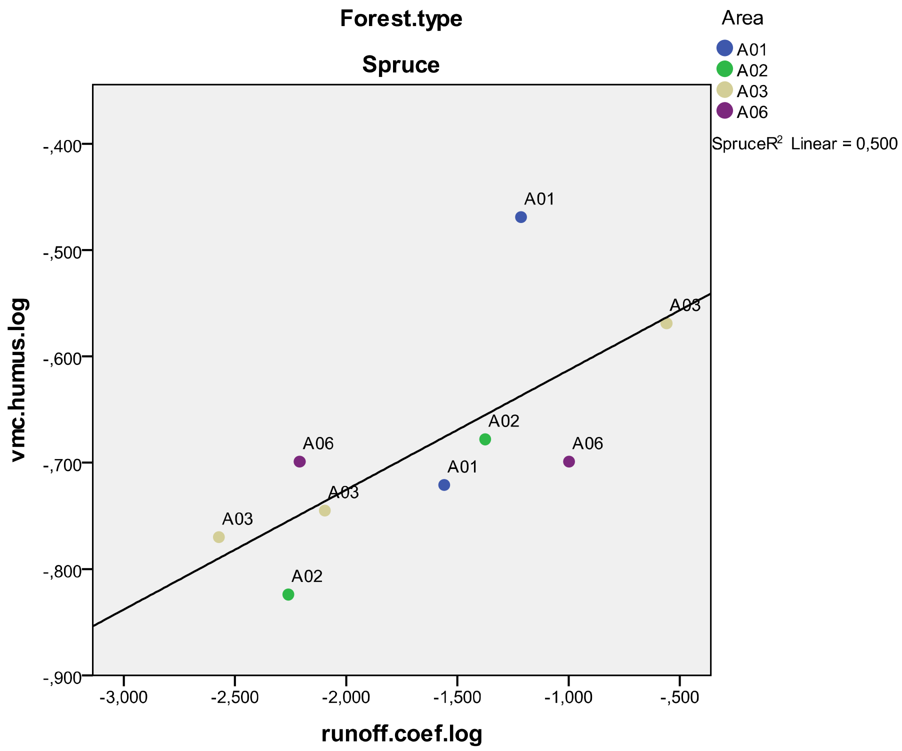

Figure 4.10 Significant correlation: v.m.c Humus log and runoff coefficient log. in Spruce forest.

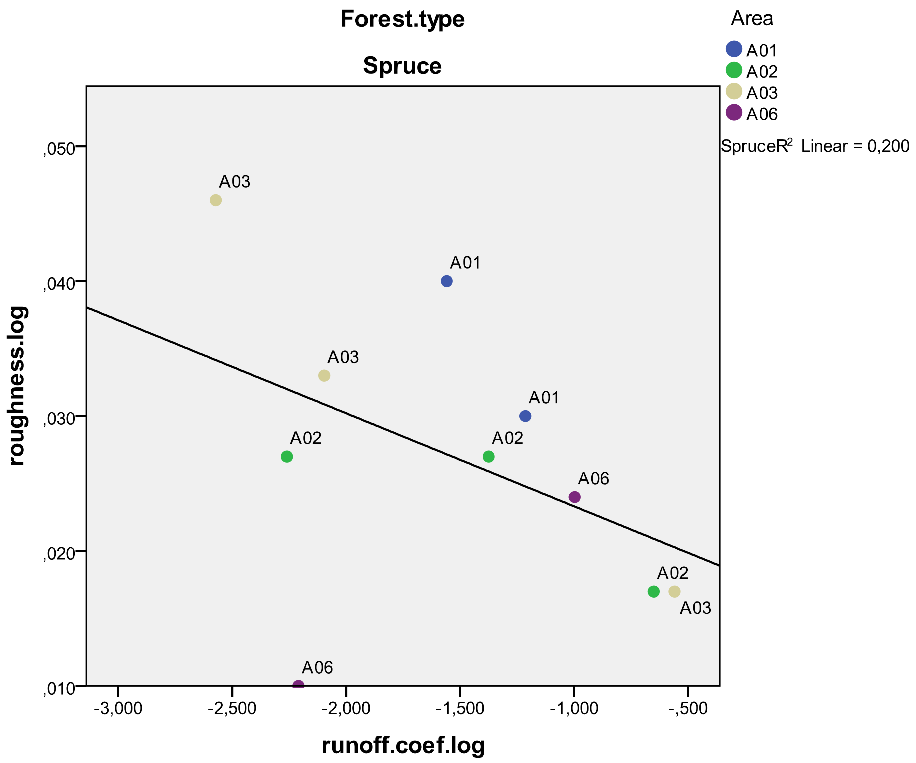

Figure 4.11 Significant correlation: roughness log and runoff coefficient log. in Spruce forest.

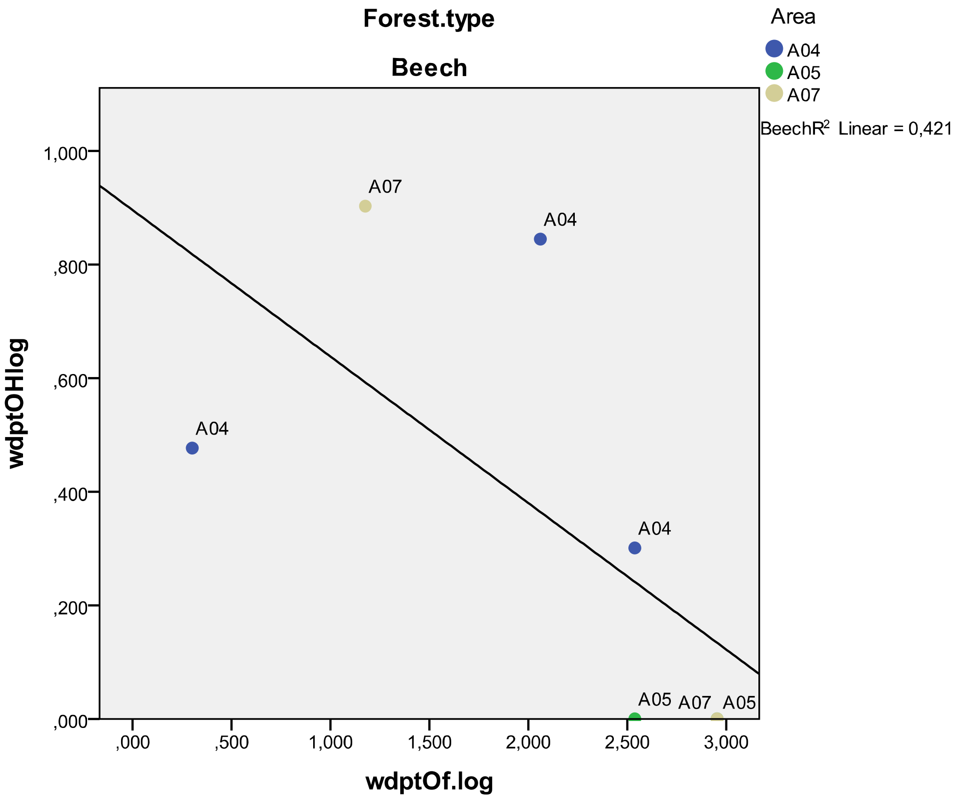

Figure 4.12 Significant correlation: wdpt OH log and wdpt OFcetration log. in Beech forest.

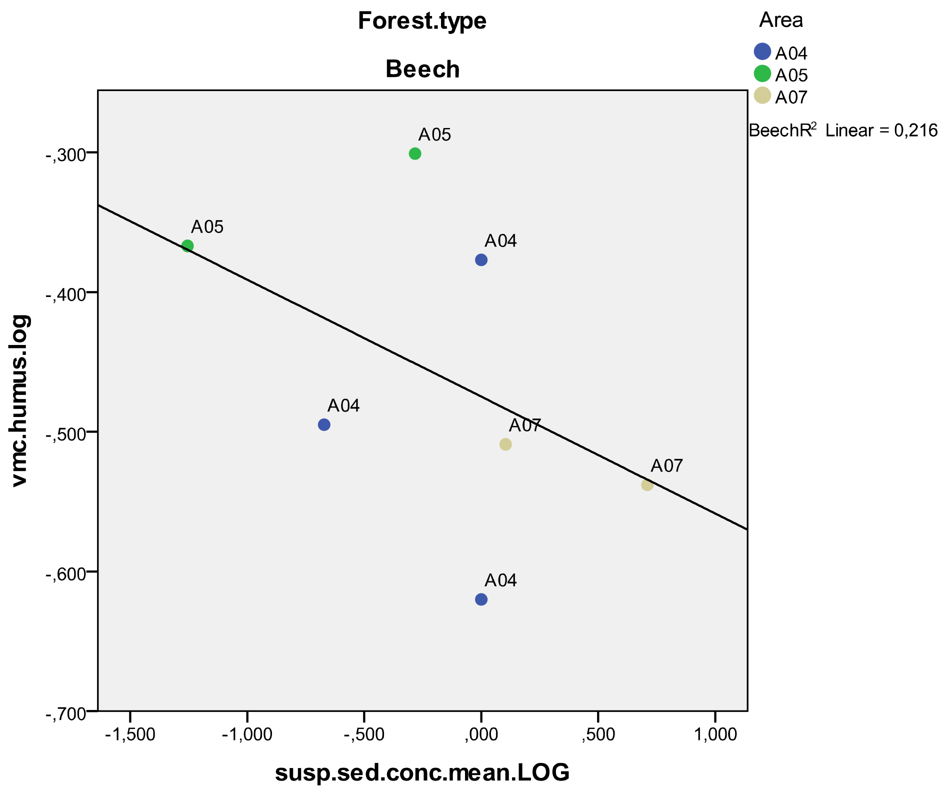

Figure 4.13 Significant correlation: v.m.c Humus log and Suspended sediment concetration mean log. in Beech forest.

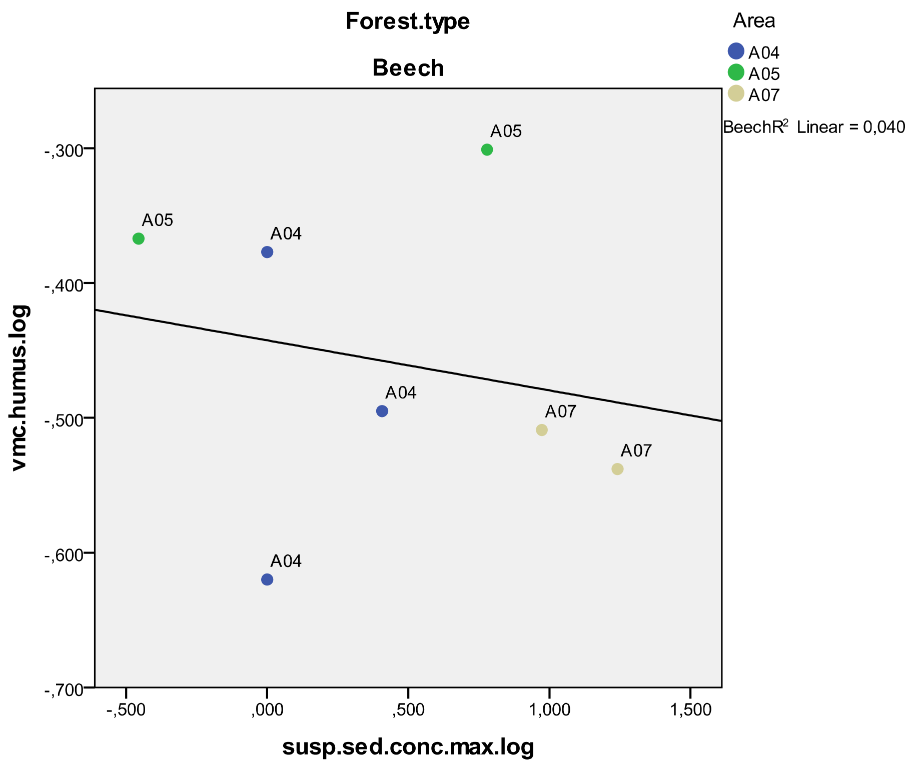

Figure 4.14 Significant correlation: v.m.c Humus log and Suspended sediment concetration max log. in Beech forest.

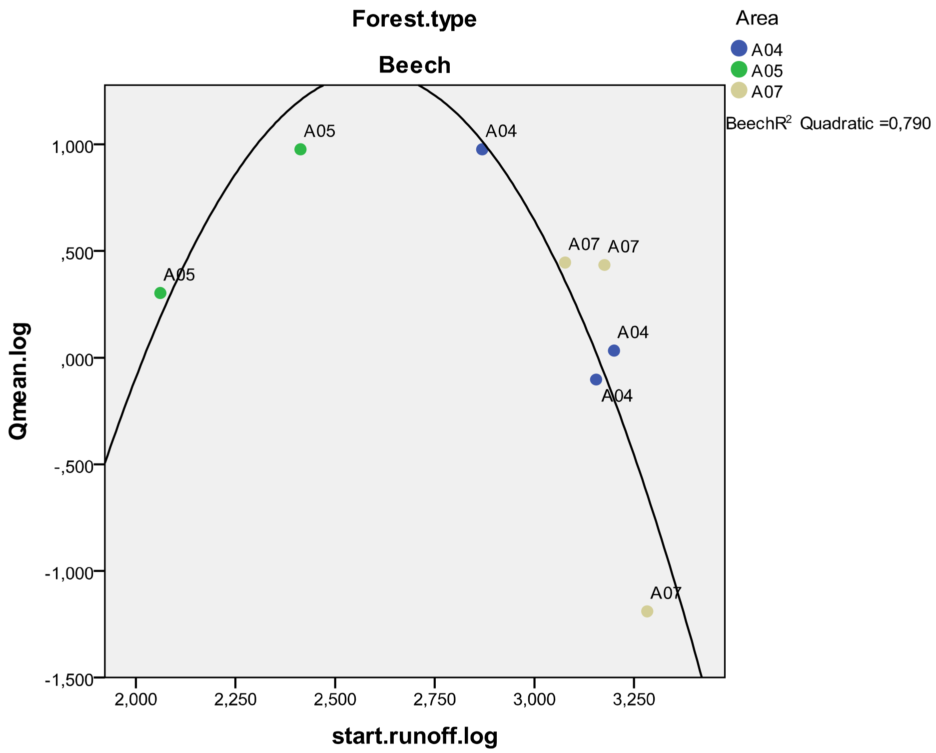

Figure 4.15 Significant correlation: Qmean log and Start runoff log. in Beech forest.

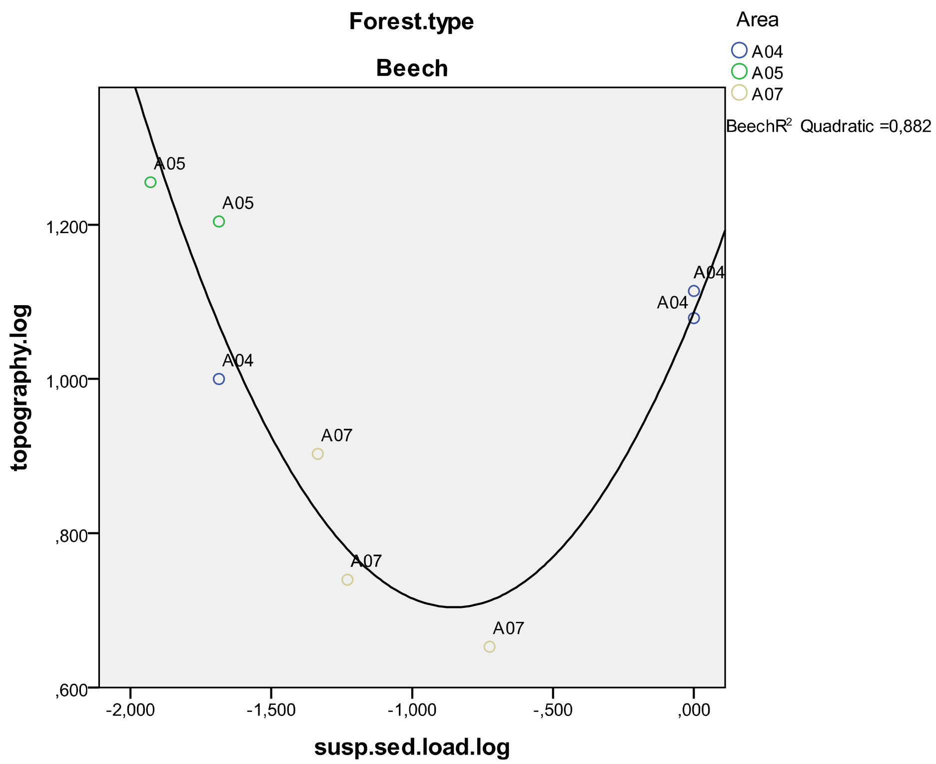

Figure 4.16 Significant correlation: topography log and Suspended sediment load log. in Beech forest.

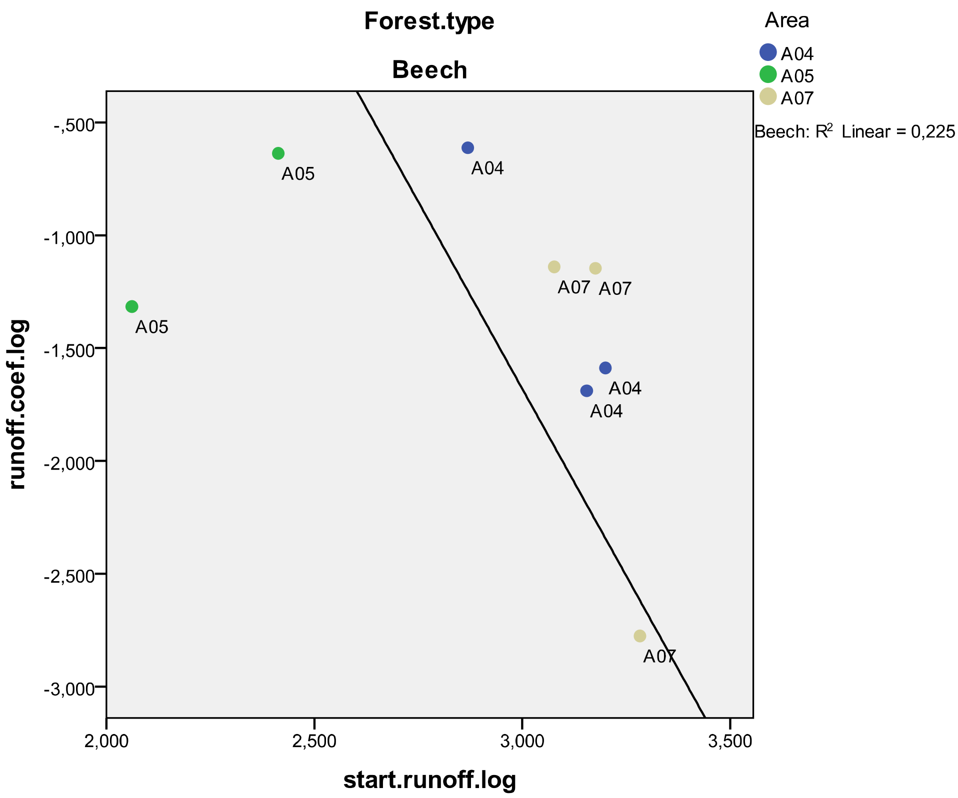

Figure 4.17 Significant correlation: runoff coefficient log and start runoff log. in Beech forest.

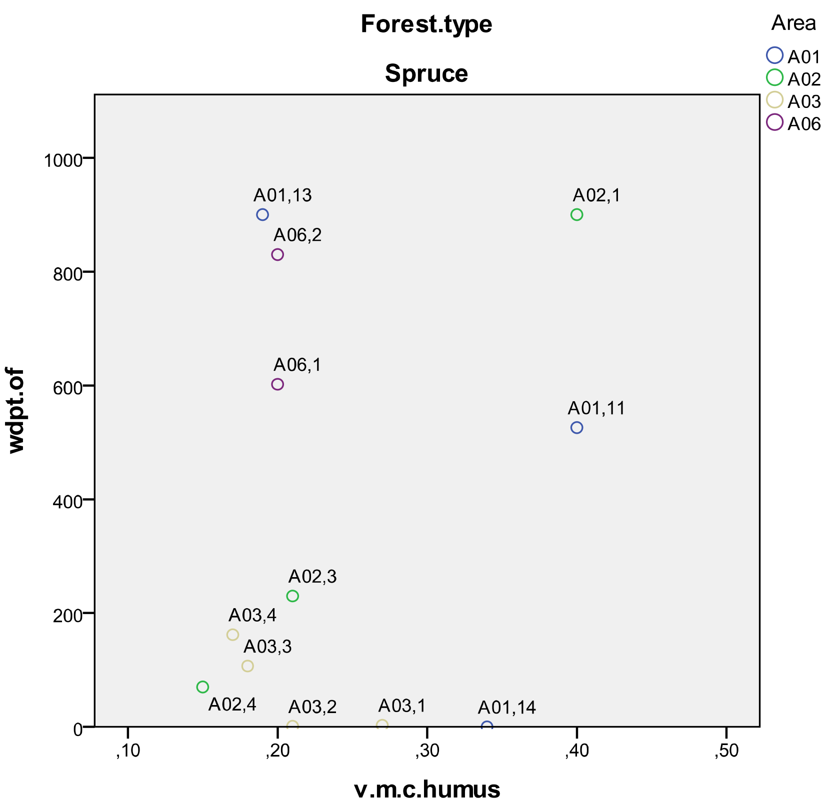

Figure 4.18 wdpt.of and v.m.c.humus correlation in Spruce forest.

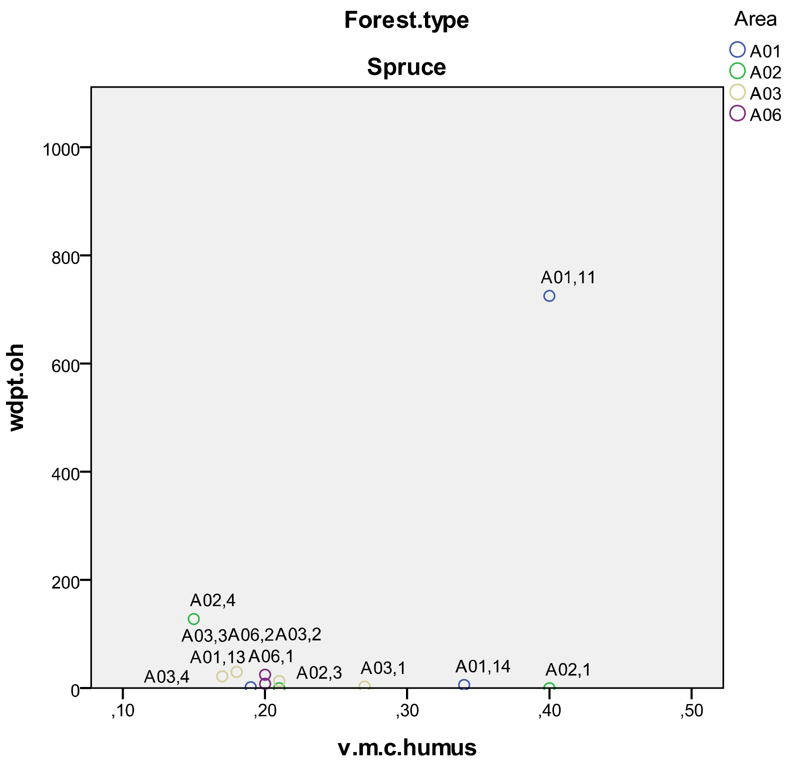

Figure 4.19 wdpt.oh and v.m.c.humus correlation in Spruce forest.

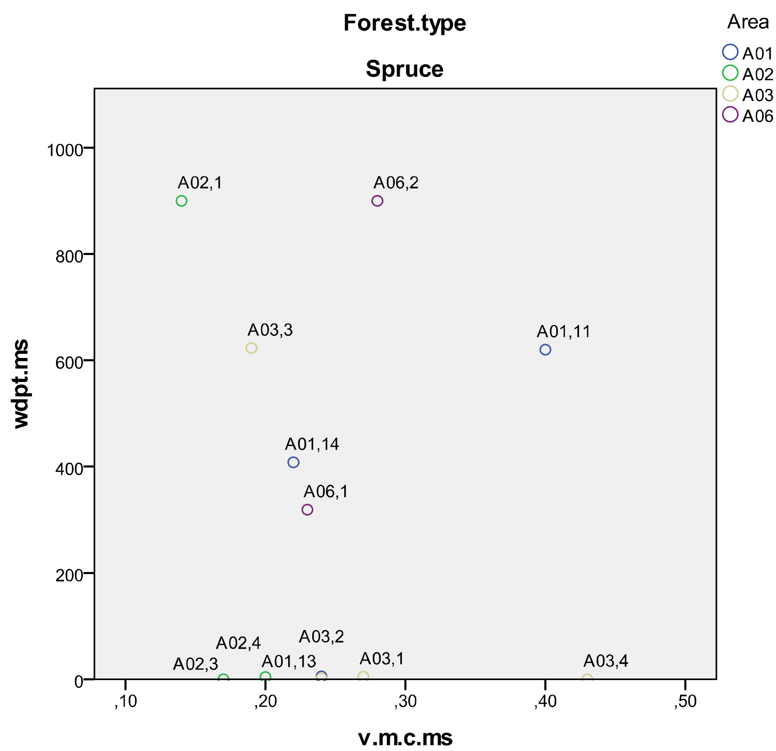

Figure 4.20 wdpt.ms and v.m.c.ms correlation in Spruce forest.

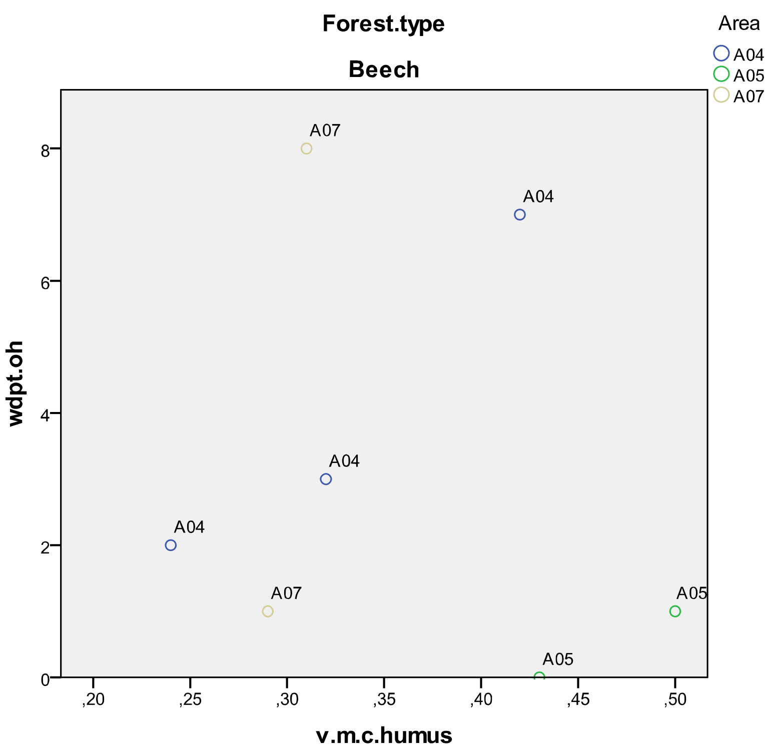

Figure 4.21 wdpt.oh and v.m.c.humus correlation in Beech forest.

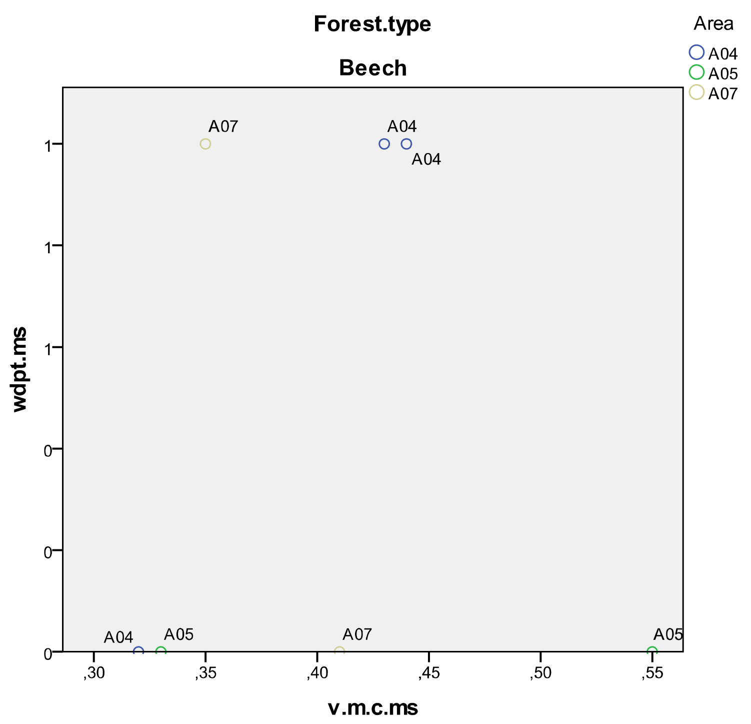

Figure 4.22 wdpt.ms and v.m.c.ms correlation in Beech forest.

Table 4.1 Correlation analysis for Spruce forest.

	Spearman's rho	wdpt .ol	wdpt .of	wdpt .oh	wdpt .ms	v.m.c. humus	v.m.c.ms	Q.mean	Q.max	susp.sed. concet. mean	susp.sed. concentr. max	susp.sed.load .mean	start.runoff	roughness	runoff.coef	Topogra.phy
wdpt. ol	Correlation Coefficient		-,057	,646	,115	-,327	,572	,085	,048	-,678	-,729	-,492	,051	-,291	,017	-,028
	Sig. (2-tailed)		,861	,023	,721	,300	,052	,803	,888	,045	,026	,179	,897	,359	,965	,931
wdpt. of	Correlation Coefficient	-,057		-,223	,413	,023	-,023	,064	,173	,167	,283	-,133	-,633	,214	-,083	,399
	Sig. (2-tailed)	,861		,486	,182	,944	,944	,852	,611	,668	,460	,732	,067	,503	,831	,198
wdpt. oh	Correlation Coefficient	0,646	-,223		,148	-,356	,432	-,515	-,569	-,383	-,400	-0,75	,267	-,262	-,383	,074
	Sig. (2-tailed)	,023	,486		,647	,257	,161	,105	,067	,308	,286	,020	,488	,411	,308	,820
wdpt. ms	Correlation Coefficient	,115	,413	,148		,354	-,141	,292	,174	,142	,092	,218	-,343	-,111	,452	,147
	Sig. (2-tailed)	,721	,182	,647		,258	,663	,383	,610	,715	,814	,574	,366	,731	,222	,648
v.m.c. humus	Correlation Coefficient	-,327	,023	-,356	,354		-,083	,195	,149	,167	,159	0,895	-,251	-,293	0,854	,088
	Sig. (2-tailed)	,300	,944	,257	,258		,798	,567	,662	,667	,683	,001	,515	,356	,003	,786
v.m.c. ms	Correlation Coefficient	,572	-,023	,432	-,141	-,083		-,148	-,203	-,267	-,317	,033	,367	-,276	,167	-,368
	Sig. (2-tailed)	,052	,944	,161	,663	,798		,663	,549	,488	,406	,932	,332	,385	,668	,240
Q.mean	Correlation Coefficient	,085	,064	-,515	,292	,195	-,148		0,972	-,006	,006	0,733	-,188	-,295	1	-,133
	Sig. (2-tailed)	,803	,852	,105	,383	,567	,663		,000	,987	,987	,016	,603	,327	.	,680
Q.max	Correlation Coefficient	,048	,173	-,569	,174	,149	-,203	0,972		,018	,042	0,721	-,273	-,301	0,939	-,007
	Sig. (2-tailed)	,888	,611	,067	,610	,662	,549	,000		,960	,907	,019	,446	,318	,000	,983
susp.sed. concet.mean	Correlation Coefficient	0,678	,167	-,383	,142	,167	-,267	-,006	,018		0,927	,552	-,127	,280	-,006	,006
	Sig. (2-tailed)	,045	,668	,308	,715	,667	,488	,987	,960		,000	,098	,726	,432	,987	,987

susp.sed. concentr.max	Correlation Coefficient	- 0,729	,283	-,400	,092	,159	-,317	,006	,042	0,927		,467	-,273	,213	,006	,127
	Sig. (2-tailed)	,026	,460	,286	,814	,683	,406	,987	,907	,000		,174	,446	,554	,987	,726
susp.sed.load. mean	Correlation Coefficient	-,492	-,133	-0,75	,218	0,895	,033	0,733	0,721	,552	,467		-,067	-,341	0,733	-,309
	Sig. (2-tailed)	,179	,732	,020	,574	,001	,932	,016	,019	,098	,174		,855	,334	,016	,385
start.runoff	Correlation Coefficient	,051	-,633	,267	-,343	-,251	,367	-,188	-,273	-,127	-,273	-,067		,268	-,188	-,224
	Sig. (2-tailed)	,897	,067	,488	,366	,515	,332	,603	,446	,726	,446	,855		,454	,603	,533
Roughness	Correlation Coefficient	-,291	,214	-,262	-,111	-,293	-,276	-,295	-,301	,280	,213	-,341	,268		-0,817	,058
	Sig. (2-tailed)	,359	,503	,411	,731	,356	,385	,327	,318	,432	,554	,334	,454		,004	,850
runoff.coef	Correlation Coefficient	,017	-,083	-,383	,452	0,854	,167	1	0,939	-,006	,006	0,733	-,188	-0,817		-,248
	Sig. (2-tailed)	,965	,831	,308	,222	,003	,668	.	,000	,987	,987	,016	,603	,004		,489
Topogra.phy	Correlation Coefficient	-,028	,399	,074	,147	,088	-,368	-,133	-,007	,006	,127	-,309	-,224	,058	-,248	
	Sig. (2-tailed)	,931	,198	,820	,648	,786	,240	,680	,983	,987	,726	,385	,533	,850	,489	

Table 4.2 Correlation analysis for Beech forest

Spearman´s rho		wdpt. of	wdpt .oh	wdpt .ms	v.m.c. humus	v.m.c. ms	Q.mean	Q.max	susp.sed.concet. mean	susp.sed. concentr.max	susp.sed. load.mean	start.runoff	Roughness	runoff.coef	Topogra.phy
wdpt. of	Correlation Coefficient		-,844	-,367	,036	,273	-,346	-,200	,000	,073	-,661	,436	,211	-,346	,418
	Sig. (2-tailed)		,017	,417	,938	,554	,448	,667	1,000	,876	,106	,328	,650	,448	,350
wdpt. oh	Correlation Coefficient	-,844		,728	-,306	-,090	,072	-,216	,282	,318	,736	-,072	,179	,072	-,613
	Sig. (2-tailed)	,017		,063	,504	,848	,878	,641	,540	,487	,059	,878	,701	,878	,144
wdpt. ms	Correlation Coefficient	-,367	,728		-,433	,289	-,144	-,433	,291	,437	,437	,144	,717	-,144	-,289
	Sig. (2-tailed)	,417	,063		,332	,530	,758	,332	,526	,327	,327	,758	,070	,758	,530
v.m.c. humus	Correlation Coefficient	,036	-,306	-,433		,036	,500	,714	-,955	-,919	-,703	-,143	-,158	,500	,714
	Sig. (2-tailed)	,938	,504	,332		,939	,253	,071	,001	,003	,078	,760	,736	,253	,071
v.m.c. ms	Correlation Coefficient	,273	-,090	,289	,036		-,714	-,500	-,018	,126	-,378	,679	,630	-,714	,250
	Sig. (2-tailed)	,554	,848	,530	,939		,071	,253	,969	,788	,403	,094	,129	,071	,589
Q.mean	Correlation Coefficient	-,346	,072	-,144	,500	-,714		,833	-,515	-,635	,012	-,762	-,464	1,000	,190
	Sig. (2-tailed)	,448	,878	,758	,253	,071		,010	,192	,091	,978	,028	,247	.	,651
Q.max	Correlation Coefficient	-,200	-,216	-,433	,714	-,500	,833		-,802	-,850	-,347	-,571	-,491	,833	,381
	Sig. (2-tailed)	,667	,641	,332	,071	,253	,010		,017	,007	,399	,139	,217	,010	,352
susp.sed. concet. mean	Correlation Coefficient	,000	,282	,291	-,955	-,018	-,515	-,802		,928	,759	,228	,110	-,515	-,707
	Sig. (2-tailed)	1,000	,540	,526	,001	,969	,192	,017		,001	,029	,588	,796	,192	,050
susp.sed. concentr. max	Correlation Coefficient	,073	,318	,437	-,919	,126	-,635	-,850	,928		,590	,491	,384	-,635	-,683
	Sig. (2-tailed)	,876	,487	,327	,003	,788	,091	,007	,001		,123	,217	,347	,091	,062
susp.sed. load. mean	Correlation Coefficient	-,661	,736	,437	-,703	-,378	,012	-,347	,759	,590		-,275	-,247	,012	-,802

	Sig. (2-tailed)	,106	,059	,327	,078	,403	,978	,399	,029	,123		,509	,555	,978	,017
start.runoff	Correlation Coefficient	,436	-,072	,144	-,143	,679	-,762	-,571	,228	,491	-,275		,518	-,762	-,190
	Sig. (2-tailed)	,328	,878	,758	,760	,094	,028	,139	,588	,217	,509		,188	,028	,651
Roughness	Correlation Coefficient	,211	,179	,717	-,158	,630	-,464	-,491	,110	,384	-,247	,518		-,464	,245
	Sig. (2-tailed)	,650	,701	,070	,736	,129	,247	,217	,796	,347	,555	,188		,247	,558
runoff.coef	Correlation Coefficient	-,346	,072	-,144	,500	-,714	1,000	,833	-,515	-,635	,012	-,762	-,464		,190
	Sig. (2-tailed)	,448	,878	,758	,253	,071	.	,010	,192	,091	,978	,028	,247		,651
Topogra.phy	Correlation Coefficient	,418	-,613	-,289	,714	,250	,190	,381	-,707	-,683	-,802	-,190	,245	,190	
	Sig. (2-tailed)	,350	,144	,530	,071	,589	,651	,352	,050	,062	,017	,651	,558	,651	

Test Statistics[a,b]

	wdpt.ol	wdpt.of	wdpt.oh	wdpt.ms	v.m.c.humus	v.m.c.ms
Chi-Square	,538	,333	,000	1,492	,621	5,253
df	1	1	1	1	1	1
Asymp. Sig.	,463	,564	1,000	,222	,431	,022

a. Kruskal Wallis Test
b. Grouping Variable: date

Figure 4.23 Significant differences between two different dates. v.m.c Mineral Soil is the only variable significantly different.

Annex 5 Spatial variation of water repellency: field observations

Figure 5.1 Spatial horizontal variation of water repellency in Beech forest in site A05.

Figure 5.2 Spatial horizontal variation of water repellency in Beech forest site A05

Figure 5.3 Spatial horizontal variation of water repellency in site A07

Figure 5.4 No runoff water generation neither infiltration of rainfall in the soil in site A01.11

Annex 6 Multiple regression: ENTER method.

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	vmc.humus.log	.	Enter
2	roughness.log	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: runoff.coef.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	,707[a]	,500	,428	,508793	,500	6,987	1	7	,033	
2	,725[b]	,526	,368	,534648	,027	,339	1	6	,581	2,844

a. Predictors: (Constant), vmc.humus.log
b. Predictors: (Constant), vmc.humus.log, roughness.log
c. Forest.type = Spruce
d. Dependent Variable: runoff.coef.log

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	roughness.log	.	Enter
2	vmc.humus.log	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: runoff.coef.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,357[a]	,128	,003	,671710	,128	1,025	1	7	,345
2	,725[b]	,526	,368	,534648	,399	5,049	1	6	,066

a. Predictors: (Constant), roughness.log
b. Predictors: (Constant), roughness.log, vmc.humus.log
c. Forest.type = Spruce
d. Dependent Variable: runoff.coef.log

Figure 6.1 Multiple regression for the output variable runoff coef. Input variables: Roughness.log and v.m.c Humus.log.

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	wdptOHlog[a]	.	Enter
2	vmc.humus.log	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.load.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,732[a]	,535	,469	,489707	,535	8,063	1	7	,025
2	,861[b]	,742	,656	,394069	,207	4,810	1	6	,071

a. Predictors: (Constant), wdptOHlog
b. Predictors: (Constant), wdptOHlog, vmc.humus.log
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.load.log

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	vmc.humus.log	.	Enter
2	wdptOHlog[a]	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.load.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,776[a]	,603	,546	,452775	,603	10,621	1	7	,014
2	,861[b]	,742	,656	,394069	,139	3,241	1	6	,122

a. Predictors: (Constant), vmc.humus.log
b. Predictors: (Constant), vmc.humus.log, wdptOHlog
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.load.log

Figure 6.2 Multiple regression for output variable suspended sediment load. Input variables: wdpt OH.log and v.m.c Humus.log.

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	wdptOLlog[a]	.	Enter
2	wdptOHlog[a]	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.conc.max.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,853[a]	,728	,673	,346829	,728	13,367	1	5	,015
2	,921[b]	,849	,773	,288843	,121	3,209	1	4	,148

a. Predictors: (Constant), wdptOLlog
b. Predictors: (Constant), wdptOLlog, wdptOHlog
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.conc.max.log

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	wdptOHlog[a]	.	Enter
2	wdptOLlog[a]	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.conc.max.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,345[a]	,119	-,057	,623929	,119	,675	1	5	,449
2	,921[b]	,849	,773	,288843	,730	19,330	1	4	,012

a. Predictors: (Constant), wdptOHlog
b. Predictors: (Constant), wdptOHlog, wdptOLlog
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.conc.max.log

Figure 6.3 Multiple regression for the output variable suspended sediment concentration max.log. Input variables: wdpt OH.log and wdpt OL.log.

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	wdptOHlog[a]	.	Enter
2	wdptOLlog[a]	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.load.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,815[a]	,664	,597	,475640	,664	9,885	1	5	,026
2	,815[b]	,665	,498	,531055	,001	,011	1	4	,922

a. Predictors: (Constant), wdptOHlog
b. Predictors: (Constant), wdptOHlog, wdptOLlog
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.load.log

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	wdptOLlog[a]	.	Enter
2	wdptOHlog[a]	.	Enter

a. All requested variables entered.
b. Forest.type = Spruce
c. Dependent Variable: susp.sed.load.log

Model Summary[c,d]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,590[a]	,348	,217	,662800	,348	2,666	1	5	,163
2	,815[b]	,665	,498	,531055	,317	3,789	1	4	,123

a. Predictors: (Constant), wdptOLlog
b. Predictors: (Constant), wdptOLlog, wdptOHlog
c. Forest.type = Spruce
d. Dependent Variable: susp.sed.load.log

Figure 6.4 Multiple regression for output variable Suspended sediment load.log. Input variables: wdpt OL.log and wdpt OH.log.