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DETERMINING SOIL HYDRAULIC PROPERTIES – PROPOSAL AND COMPARISON OF DIFFERENT SAMPLING APPROACHES

Master thesis (Double Degree Programme)
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Declaration

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1 Abstract

Soil hydraulic properties are subject to a high natural spatial variability. This makes the estimation of representative parameters, e.g. for modeling soil water balances, highly challenging. Therefore, the 1st objective of this study was to capture changes of the hydraulic properties within the depth and distinction of it regarding different soil horizons for two contrasting types of land use. The 2nd objective was to compare new sampling approach to a standard one.

To derive the unsaturated hydraulic conductivity, two contrasting land uses and soil types were analyzed: A Chernozem at the agricultural research farm in Gross Enzersdorf and a Luvisol at the forest demonstration center in the Rosalian Mountains (both Lower Austria) were sampled in steps of 5 cm down a vertical transect. The samples were measured using the evaporation method (HYPROP device, UMS GmbH Germany). The evaporation data was used to subsequently derive the hydraulic conductivity and retention functions using parameter fitting procedures. The simulation software HYDRUS was used to assess the impact of different soil hydraulic properties regarding depth, as well as, varying soil horizons on water balance components. The simulation results showed how water movement and storage in the soil is affected by the soil hydraulic parameters and climatic conditions and proved that the proposed sampling method better reflects soil profile's hydraulic properties than the standard approach.

2 Introduction and state-of-the-art

Knowledge about soil water processes within vadose zone is important as it is an integral part of hydrological cycle. This hydrologic matter influences water quality and quantity, ecosystem function and health, the connection between atmospheric and terrestrial processes, nutrient cycling, soil development, and natural hazards such as flooding and landslides (Perkins, 2011). Furthermore, hydraulic conductivity is the most important property of geological formations as the flow of fluids and movement of solutes depend on it.

It is unquestionable that soils differ in a manner of landscape and change in time as a result of intrinsic or extrinsic processes. Moreover, the reasons of high soil diversity may be random, related, periodic, or any possible mix of mentioned; what is the most important regarding this topic is scale dependency which may have significant role in soil variability. Therefore, methods that target on soil physical properties and behavior, are often tremendously variable and usually do not adjust to commonly used conventional statistical assumptions (van Es, 2002).

Geological, hydrogeological and biological factors that effect pedogenesis are the most important natural reasons of soil variety. They have a clear special section that can be called to be regionalized – it changes in space with a tendency to be comparable with adjacent areas. Nonetheless, scale dependent plays the most important role regarding those processes which function from continental scale to submeter level. Thus, it systemize and simplifies overall awareness about soil scale diversity, it has to be taken into account that in a field it does not always adhere, especially when human-made factors had occurred (van Es et al. 1999).

Sample rings are commonly used for soil science, soil physical analyses and agricultural research. To sample a soil profile there are taken few soil cores from each soil horizon to ensure its representativeness. Afterwards they are analyzed and the hydraulic properties for a whole soil horizon are derived based on the average. In this thesis is presented a new approach of soil profile sampling. Each taken sample stands for its own hydraulic properties, thus creating detailed vertical set of them. In other words, each soil horizon is characterized by a numerous individual hydraulic properties where each represents certain depth.

2.1 Measurement of hydraulic properties

Soil hydraulic properties like water retention characteristics and unsaturated hydraulic conductivity characteristics may be determined by many methods and procedures (Klute and Dirksen, 1986; Green et al. 1986). Some of the most important and common techniques are shortly reviewed further down.

2.1.1 Water retention characteristics

Water retention characteristics of a soil are important to plan irrigation schedules, determine agronomical/economical values of soil types, moreover predict or analyze growth stress problems in plants (Eijkelkamp – Agrisearch Equipment presentation, “pF values and measurements”).

Most common procedures to measure this characteristic are sandbox (hanging water column) (de Rooij et al., 2004; Cresswell et al., 2008), sand/kaolin box and pressure plate extractors (Dane and Hopmans, 2002).

2.1.1.1 Sandbox (hanging water column)

Sandbox is used in low-tension (wet) range of water retention (pF) curve and its measurement range is from 0-10 kPa. An undisturbed soil sample is placed on a homogeneous water saturated fine sand surface or porous plate and suction is applied in steps. After hydraulic equilibrium is reached, samples water content is determined gravimetrically. Its relatively cheap and easy method (Durner and Lipsius, 2005; Matula, 2011).

2.1.1.2 Sand/kaolin box

This method is generally used in a tension range of 10-50 kPa. Its working principle is the same as sandboxes. The difference lays in a surface where samples are placed. Instead of sand, sample is placed on saturated sand-kaolin clay surface. Due to higher air-entry value of this porous bed the measurement range is increased (Romano et al., 2002).

2.1.1.3 Pressure plate extractor

Pressure plate extractor is used to determine high tension in a range of 100-1500 kPa. A soil sample is positioned on a porous plate inside a pressure chamber. Air pressure is applied to the container by a compressor or any other source of pressed air, which leads to displacement of water toward and through the porous plate to the free atmosphere. When equilibrium is reached, the water content is determined gravimetrically (Dane and Hopmans, 2002; Durner and Lipsius, 2005; Matula, 2011). Although the application range is wide, it consumes a lot of time (up to few months) to reach equilibrium and it is relatively costly method (Schindler et al., 2012).

2.1.2 Unsaturated hydraulic conductivity

2.1.2.1 Tension disk infiltrometer – field method

It is a device used in situ and it is classified as the inverse methods (Hopmans et al., 2002a). In this infiltrometer either a positive or negative pressure is applied on the top of the soil sample, therefore it is used to determine both saturated and unsaturated hydraulic conductivity. Infiltrometer is placed together with Time Domain Relfectometers (TDR) and tensiometers. Analytical solution of measured data is made using Wooding's (1986) Steady-state analytical solution. Its limitations are concern mostly to top soil and low-tension range measurements (Reynolds and Elrick, 1991); additionally hydraulic conductivity is determined less accurately in comparison to other methods (Reynolds, 2000).

2.1.2.2 Hot-air method

The principle of this method is that the sample is dried under forced hot air. It enables determination of the soil water diffusivity as a function of water content D(Θ). It is possible to convert D(Θ) into hydraulic conductivity of water content function K(Θ) if the soil water characteristics of the sample are known. Advantage of this method is its rapidity and provision of D(Θ) and K(Θ) over a wide range of water content. Disadvantage is that experimental conditions remarkably vary from the natural conditions – temperature impacts on water flow; moreover experimental conditions are not firmly coherent with theoretical assumptions (Arya, 2002).

2.1.2.3 Centrifuge method

An initially saturated sample is placed in a centrifuge and spun with a specific velocity. After the centrifugal and capillary forces reach equilibrium the saturation can be determined. The method is well suited to determine residual water saturation. It also measures hydraulic conductivity. The pressure range depends on the power of the centrifuge. Advantage of this technique is simplicity and accuracy with the speed and adaptation afforded by centrifugal force. Disadvantage is cost and often a mechanical destruction of the sample under high acceleration. Furthermore, in many cases during the measurement may occur compaction that alters structure of the sample, thus influence the hydraulic conductivity and water retention (Nimmo et al., 2002; Durner and Lipsius. 2005).

2.1.2.4 One-step and Multistep outflow methods

In One-step method a saturated soil core is placed on ceramic plate. It is exposed to high air pressure from the top or to a rapid reduction in water pressure on the bottom of ceramic plate. The pressure difference causes unsaturated flow in the soil sample, with the ceramic plate underneath standing saturated. The cumulative outflow is recorded and in the end the volumetric water content is determined by oven-drying a soil core (Gardner, 1958). Kool et al. (1985) were one of the pioneers to apply the inverse approach to determine soil hydraulic functions simultaneously (Hopmans et al., 2002b). The main problem with the One-step method was that swift change of the boundary condition does not represent natural conditions thus sensitivity can be low (van Dam et al., 1992). Because of those disadvantages a Multistep method was introduced, where the pressure was increased in several small steps (van Dam, 1990). Results obtained by those methods (especially by Multistep outflow method) are reliable and widely in use (Schindler et al., 2012), nevertheless dry-end conductivity values may be too low due to porous membrane effects (Hopmans et al., 2002b).

2.1.2.5 Evaporation method

The first recorded evaporation experiment was performed by Gardner and Miklich (1962) for quantifying soil hydraulic properties from horizontally oriented soil column. Wind (1968) developed method to simultaneously measure retention curve ($\Theta(h)$) and hydraulic conductivity ($K(h)$) by placing soil column vertically, sealing bottom and letting water evaporate from its surface. Tensiometers are installed into the soil column at regular depth intervals. Measurement of weight and pressure head is done periodically. The evaporation experiment is performed under transient-flow conditions. Many modifications were developed over the years (e.g., Schindler, 1980; Klute and Dirksen, 1986; Halbertsma, 1996; Schindler and Muller, 2006). The advantage of this method is its relatively low cost and time consumption. Nonetheless, all classical evaporation methods have the same limitation, that is water cavitation in the tensiometers occur at tensions around 70-90 kPa (Schindler et al., 2010b). Unfortunately, many hydrologic and plant physiological disciplines require soil hydraulic properties at higher tensions. Schindler et al. (2010a, b) presented a new design of evaporation method which is based on improved cavitation tensiometers enable to measure tension up to 435 kPa. Moreover using the air-entry pressure of the tensimeter’s porous ceramic cup gives defined pressure value. Hence, it allows overcoming previous tensiometer’s limitation and allows the simultaneous quantification of water retention and hydraulic conductivity close to the wilting point. This experimental setup is used in this thesis to determine hydraulic properties of the samples. More about this technique can be found in “Materials and methods” chapter.

3 Materials and methods

3.1 Experimental sites

Two experimental sites were chosen which refers to different land use and different soil type: A Chernozem at the agricultural research farm in Gross Enzersdorf and a Luvisol at the forest demonstration center in the Rosalian Mountains (both Lower Austria). Samples were taken from 3 soil profiles – once from the research farm and twice from the forest. Horizons of the profiles were marked on Figure 3-1. Additionally, from soil profile A and C a 5 cm of top soil was separate and considered as a single layer (0 horizon). It was done to avoid falsification of horizons hydraulic properties because top soil properties highly differ from the rest in a horizon.

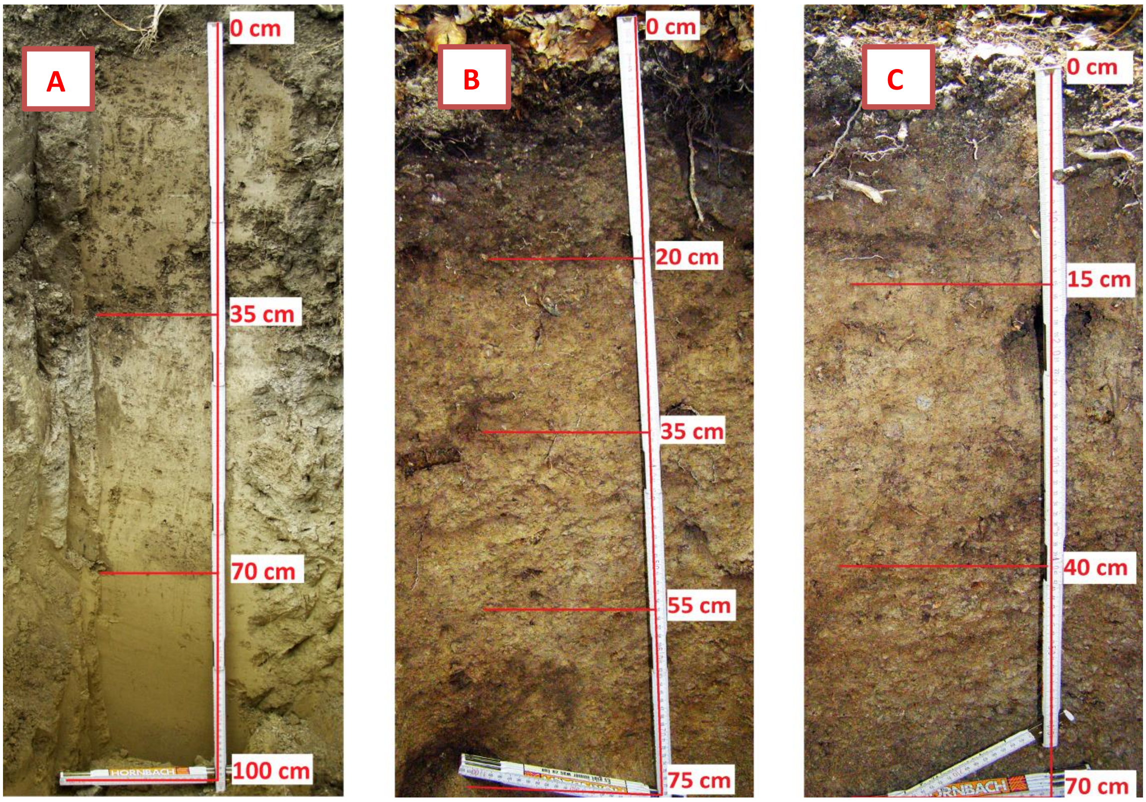

Figure 3-1. Vertical transects of soil profiles: a) Gross Enzersdorf; b) Rosalian Mountains profile 1; c) Rosalian Mountains profile 2.

While soil profiles were created in the forest the maximum depth was determined by bedrock. Coarse material (> 2mm) in soil profiles from the forest demonstration center was between 20-52% of the sample's total mass; 0% was in soil profile from Gross Enzersdorf.

3.2 Field sampling

To collect samples were used soil sampling rings of 250 cm^3 volume, 5 cm high. Samples were taken vertically beginning from the surface of soil in 5 cm steps to create a continuous integral.

Ring was hammered by using a proper knock-on handle and a hammer. Overlapping soil was removed along the ring's rim with a sharp knife. Collected sample was covered with protective cups for transportation.

3.3 Unsaturated hydraulic conductivity and retention curve measurement

Hydraulic properties of analyzed soil samples were obtained by UMS HYPROP® device. It is a simplified technique of Wind's (1968) method proposed by Schindler (1980) – more information about historical background was mentioned in "2.1.2.5 Evaporation method". This evaporation method was chosen because it is fast, accurate and reliable method to determine soil hydraulic properties in the measurement range (Peters and Durner, 2008a).

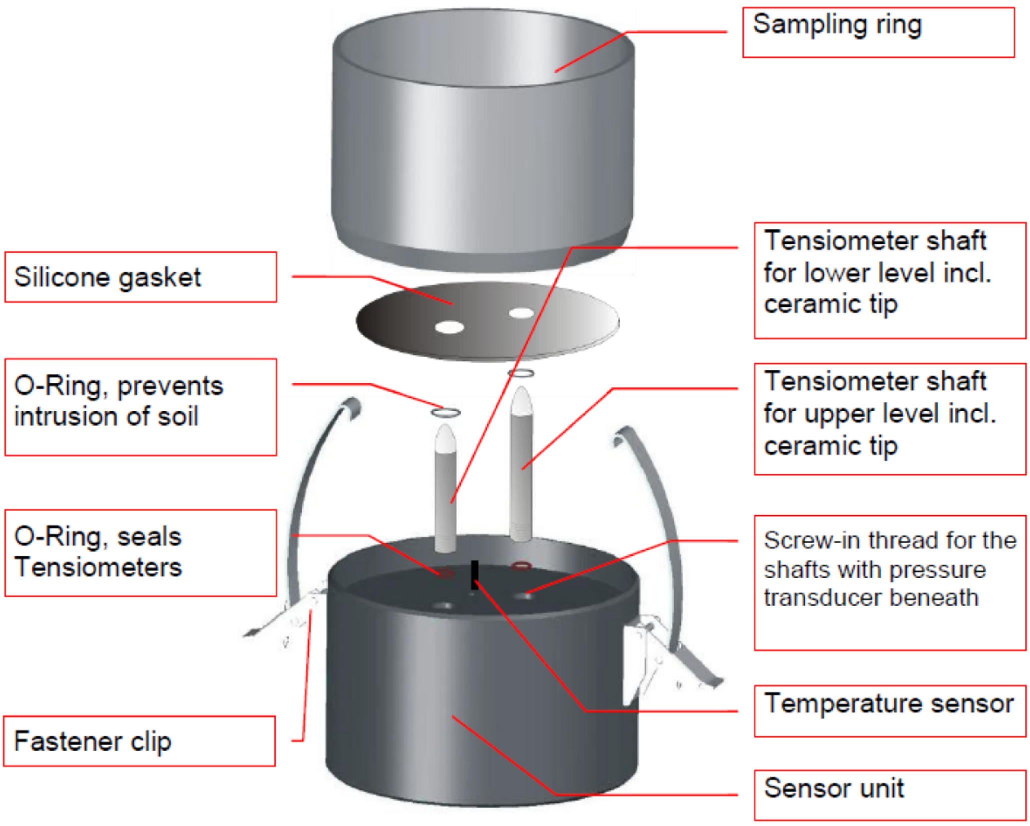

Figure 3-2. HYPROP measuring device according to HYPROP User Manual.

The measurement procedure started with preparation of the equipment: saturation of soil samples from the reverse side and degassing of sensor units together with tensiometers shafts (Figure 3-2). Perfectly degassed shafts measure tension in the soil sample much above bubble point through special manufacturing process of tensiometers and fill with deaerated deionized or distilled water. For a deaerating process a vacuum pump was used. Applied negative pressure was in a range of -500 to -700 hPa. Time duration of that process vary until water in shafts and sensor units was air-bubble-free. In the same time soil samples underwent a process of saturation.

When preparation was done two holes were drilled into a soil sample using auger positioning tool and tensiometer auger; tensiometers were carefully screwed in into the screw-in thread. Sample was attached to the sensor unit. Attached samples were kept oversaturated until all 5 devices were prepared. Measurement campaign was started when hydraulic equilibrium was obtained which means the difference in tensions at two levels in the each individual sample do not exceeded 1-2 hPa.

Tension (Ψ) is recorded in 10 min intervals (every minute for the first hour of the measurement) and sample mass (*m*) is recorded two times per day (one time per day during the weekends) because of multi-device campaign and one scale. The hydraulic gradient (i_m) is determined from the tension readings. The flux (*v*) is derived from the soil water volume difference Δ*V* (where: 1 cm^3 of water = 1 g) per surface area (*A*) and time interval (Δ*t*). Points creating water retention curve are based on water loss (volumetric water content Θ) at time *t* and mean value of the tension in the soil sample at this time. The hydraulic conductivity (*K*) is estimated according to the Darcy-Buckingham law:

$$\mathrm{K}(\Psi_{mean}) = \frac{\Delta \mathrm{V}}{2A\Delta t i_m} \qquad [1]$$

where Ψ_{mean} (for K) is the mean tension estimated from values of the upper (positioned at z_1 = 3.75 cm above the bottom) and the lower (z_2 = 1.25 cm above the bottom) Tensiometers, and averaged across the time interval Δ*t*, Δ*V* is the total evaporated water volume, *A* is the area of sample's cross-section, and i_m is the mean hydraulic gradient in the time interval, given by:

$$i_m = \frac{1}{2}\left(\frac{\Psi_{t1,upper} - \Psi_{t1,lower}}{\Delta z} + \frac{\Psi_{t2,upper} - \Psi_{t2,lower}}{\Delta z}\right) \qquad [2]$$

where $\Psi_{ti,upper}$ and $\Psi_{ti,lower}$ are the values of the upper and lower Tensiometer at time *ti*, $\Delta z = z_1 - z_2$ is the vertical distance between the Tensiometers.

For the validity of the equation 1 is assumed that water tension and water content are distributed linearly along the sample, and that changes in water tension as well as in the sample weight are linear between two evaluation points.

3.3.1 Hydraulic property models

Hyprop Data Evaluation Software offers wide range of retention function models: the unimodal constrained model of van Genuchten (1980); the unimodal unconstrained model of van Genuchten (1980); the bimodal van Genuchten model (Durner, 1994); the model of Brooks and Corey (1964); the model of Kosugi (1996); the Fayer and Simmons (1995) model; the model of Ross and Smettem (1993); and 4 conductivity function models: Mualem (1976); Burdine (1953); Peters-Durner I (2008b); Peters-Durner II (2008b). In all retention functions, the water content is expressed through the effective saturation, S_e, given by:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad [3]$$

where Θ [cm^3/cm^3] is the volumetric water content, Θ_r is the residual water content, and Θ_s is the saturated water content.

After a consultation with HYPROP developers the bimodal van Genuchten model and Peters-Durner II model were chosen. Thus, those models had the best fitting to measured data points. Akaike information criterion (AICc, Akaike, 1974) indicates the most appropriate model for given data points, hence it confirmed the assumptions in each fitting as can be seen in the example below - Table 3-1.

Table 3-1. Comparison of more appropriate hydraulic property model by Akaike information criterion. Example – sample from Gross Enzersdorf (5-10 cm).

Hydraulic property model	AICc
van Genuchten bimodal – Peters-Durner II	-1826
van Genuchten bimodal – Peters-Durner I	-1749
van Genuchten bimodal - Mualem	-1798
van Gen constrained - Mualem	-1663
van Gen constrained – Peters-Durner II	-1737
Brooks & Corey - Burdine	-1683
Kosugi - Mualem	-1650
Fayer-Simmons – Peters-Durner I	-1754
Fayer-Simmons – Peters-Durner II	-1803
Ross-Smettem – Peters-Durner II	-1812

The bimodal van Genuchten model could be expressed as:

$$S_{e(h)} = \sum_{i=1}^{2} w_i \left[\frac{1}{1+(\alpha_i|h|)^{n_i}}\right]^{1-\frac{1}{n_i}} \quad [4]$$

This model is a weighted superposition of two van Genuchten functions, where the weights w1 [-] and w2 [-] add up to unity, w1 + w2 = 1. Each of the sub-functions has now its own shape factors α_i [cm^{-1}] and n_i [-]. This seven-parameter function is much better suitable than the unimodal models to describe the retention functions of structured soils, but due to its overall flexibility it is also better suited to fit data of loamy or sandy soils that just do not follow perfectly the van Genuchten unimodal shape.

Peters and Durner (2008b) presented a new model that combines conductivity prediction models and film flow as the commonly used hydraulic conductivity functions models of porous media are based only on pore bundle concept which neglects film flow. Their experiment proved importance of film flow in the medium to dry moisture in unsaturated porous media. Furthermore, this model performed the best of all cases according to Akaike information criterion. Additionally, comparison of different models with all UNsaturated SOil hydraulic DAtabase (UNSODA) data sets showed that 75% of all data sets are best described by the new model. Peters-Durner's model can easily be coupled to any water retention function. Moreover, due to its mathematical simplicity, it can easily and efficiently be implemented in existing codes for the numerical solution of unsaturated flow problems. Peters-Durner II model is given by:

$$K_r(S_e(h)) = (1-\omega)S_e^{\tau 1}\left[\frac{\int_0^{S_e} h^{-1} dS_e(h)}{\int_0^1 h^{-1} dS_e(h)}\right]^2 + \omega S_e^{\tau 2} \quad [5]$$

where $K_r(h)$ is relative conductivity; τ is an additional fitting parameter, called tortuosity parameter; ω is one additional parameter, as compared to the original Mualem model, which expresses as weighing factor the contribution of the film flow component to the total conductivity; τ_2 [-] is an additional parameter for the film-flow part.

3.4 Bulk density and porosity

Measurement of hydraulic properties made by HYPROP device allows obtaining bulk density (mass of a dry soil per soil volume) and porosity (calculated from bulk density) data. This simple calculation is done by the HYPROP Data Evaluation Software when oven-dried mass of the soil is filled in for calculation of initial water content.

3.5 Soil particle size distribution

Soil particle size distribution was analyzed by using pipette method for silt/clay particles and wet sieving for sand particles. Samples were softly grinded and sieved through a 2mm (in diameter) mesh sieve. Then samples were treated for a 1 day with dispersion agent Tetrasodium pyrophosphate and after left for another day for shaking. Pipette method was automatized and its grain measurement ranges were 0.063 – 0.020 mm; 0.020 – 0.0063 mm; 0.0063 – 0.0020 mm; <0.0020 mm. Material left after pipette method was used in wet sieving. Soil was sieved under water current through 2mm, 1mm, 0.63mm, 0.20mm, 0.125mm and 0.063mm sieves. All 10 grain seizes were oven dried in 105 ^{o}C and weighted.

However, before starting the regular procedure the samples from demonstration forest center were initially dry sieved by 1mm sieve. The objective was to separate course material which was exceeding even 50% of a sample's total weight. Separated grain size fraction of 1mm and 2mm were sieved under water current, dried and weighted.

3.6 Organic carbon content

Organic carbon content was obtained from a difference between total carbon measured by Elementar Vario MAX and carbonate content measured by Scheibler method. Grinded and sieved through 2mm sieve soil samples were prepared for both methods.

3.7 Data analysis

3.7.1 Models parameter estimation

HYPROP Data Evaluation Software (HYPROP-DES) was used to determine soil hydraulic parameters of all samples. In this work, 3 criteria which combined together provided the best possible fitting of used models and gathered data were chosen: 1. Statistical analysis of the water content and logarithmic hydraulic conductivity. 2. The difference between 2.5% and 97.5% quintile for the uncertainty bandwidth of the parameter. 3. Graphically presented uncertainty bandwidth – shadow area. Statistical analysis provides root mean square error for retention (RMSE_Theta) and conductivity (RMSE_logK) curve, and Akaike Information Criterion (AICc). Root mean square error (water content and hydraulic conductivity) represents fit quality. The uncertainties of the individual parameters are indicated by 95% confidence limits for the parameter values (expressed by the 2.5% quantiles and the 97.5% quantiles in the two following columns) – the smaller the difference between 2.5% and 97.5% the lower the uncertainty. Parameters' minimum and maximum values were kept as default.

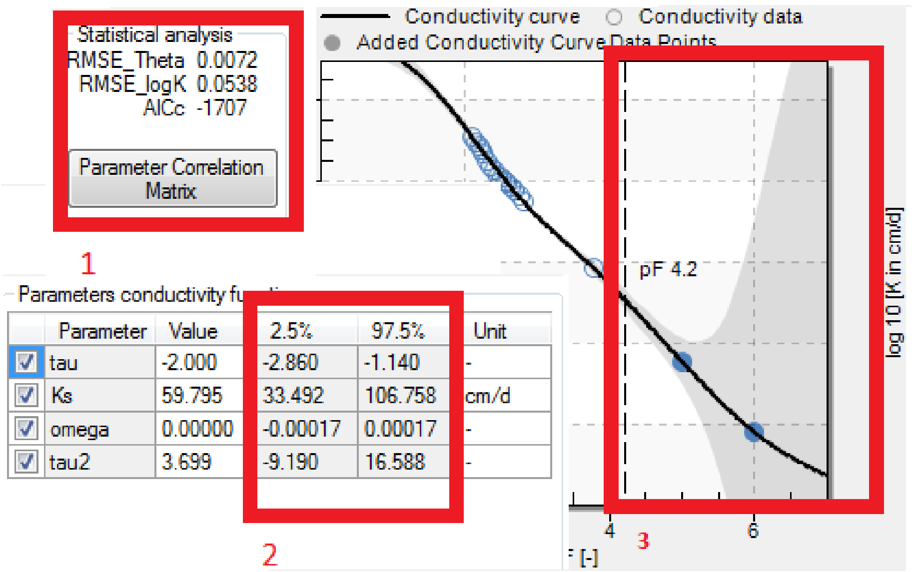

Figure 3-3. Chosen criteria for the best models fittings from HYPROP DES.

The fitting algorithm minimizes the sum of squares deviations between data points and fitted functions. Conductivity data are fitted on a log K scale, because otherwise the large conductivity data would completely dominate the fitting result. Fitting both data types simultaneously is a multi-objective problem, and improving the fit for the retention data sometimes can be only accomplished by a worse fit for the conductivity data, and vice versa (HYPROP Data Evaluation Software manual).

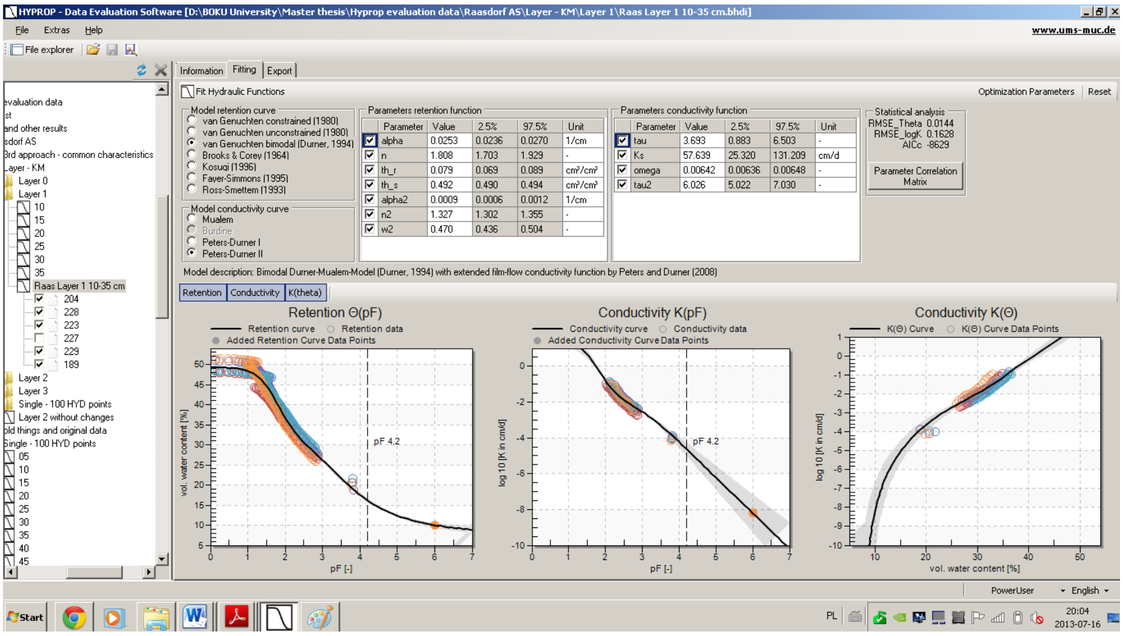

Figure 3-4. Example of combined data set from HYPROP Data Evaluation Software.

Additionally, HYPROP Data Evaluation Software allows assembling individual data sets into multiple data sets - Figure 3-4. This is of particular use if multiple data sets are to be fitted with a single hydraulic function.

3.7.2 Correlations

Parameter correlation was made to find any relationship between important soil physical and chemical parameters e.g. saturated hydraulic conductivity, bulk density, organic carbon content, clay content, etc. The aim was to find such a parameters dependence that would allow for an easy characterization of soil hydraulic properties by a quick measurement of other related physical and/or chemical factors.

3.8 Soil water simulations

For water flow simulations was used a public free software Hydrus-1D developed by PC-Progress for analysis of water flow and solute transport in vadose zone. It numerically solves Richards's equation for variably-saturated water flow and Fickianbased advection-dispersion equations for heat and solute transport. Hydrus offer many well-known and widely used soil hydraulic models (e.g. single porosity - van Genuchten – Mualem; dual-porosity – Durner, dual van Genuchten – Mualem).

Hydrus-1D was used to simulate water behavior in soil profiles and compare differences in water storage between two approaches which vary in hydraulic properties. Each soil profile was investigated for three consecutive years using real climatic data gathered by meteorological stations. For Gross Enzersdorf, I have chosen years 2009-2011, since those years vary in precipitation thus wet (2010 – 717.2 mm), moderate (2009 – 535.2 mm) and dry (2011 – 385.4 mm) period was distinguished; for Rosalian Mountains years 2004-2006, since data from those years were complete; Wet and moderate period was distinguished: year 2004 – 681 mm, 2005 – 908 mm, 2006 – 728 mm. A 30 days simulation was done for each studied soil profile to establish initial conditions for a first year of pertinent simulations. To keep continuity in the following years an initial condition were taken from the last day of a previously simulated year. Meteorological data were consisted of: precipitation (cm/day), net radiation (MJ/m^2/day), air temperature (^oC), humidity (%), and wind speed (km/day).

Hydrus software was used only for simulating water flow within a soil profile. Additionally root water uptake and root growth were implemented because the transpiration is the dominating process and cannot be neglected. Since was chosen the Peters-Durner II model for conductivity curve, which is not supported by Hydrus-1D software, the look-up tables were used to provide data information about hydraulic properties of the soil layers. Look-up tables were created by Hyprop DES. Each look-up table consist a set of a 100 hydrological points for each soil material used in a simulation where each point is represented by water content, tension and hydraulic conductivity values. Gross Enzersdorf soil profile's upper boundary condition was set as "atmospheric boundary conditions with surface layer". This condition permits water to build up on the surface. The height of the surface water layer increases due to precipitation and reduces because of infiltration and evaporation. Upper boundary condition of both soil profiles from Rosalian Mountains was set as "atmospheric boundary conditions with surface run off". In this condition the potential water flux across the upper boundary is controlled by external conditions. However, the actual flux depends also on the prevailing (transient) soil moisture conditions. Lower boundary condition for Gross Enzersdorf's soil profile was 'free drainage" since this lower boundary condition is most appropriate for situation where the water table lies far below the domain of interest, and 'seepage face' for both soil profiles from Rosalian Mountains since the condition assumes that the boundary flux will remain zero as long as the pressure head is negative like in case of impervious bedrock. In each soil profile were set up 5 observation points to mainly capture changes of water content in time. Root water uptake and root growth parameters were taken from BOKU data base. In all cases was used Feddes root water uptake model. Root growth parameter was implemented only to soil profile from Gross Enzersdorf since it is an agricultural area where different crops were sowed and harvested during that time (2009 – corn; 2010 – wheat; 2011 – wheat).

4 Results and discussion

Soil-water simulations through three soil profiles were divided on two approaches: (i) Single Layers (SL) and (ii) Pedological Layers (PL).

(i) Single Layers approach is characterized by well-defined hydraulic properties for every 5 cm step down a vertical transect. Thus, retention and conductivity data were obtained for each step forming thin soil layers, e.g. 20 layers for 100 cm deep soil profile.

(ii) Pedological Layers approach is based on visual characterization of soil horizons (layers) and defining soil hydraulic properties for each of them. HYPROP-DES was used to create multiply data set for each layer (horizon) and fit a single hydraulic function to it.

4.1 Agricultural research farm in Gross Enzersdorf

4.1.1 Retention and hydraulic conductivity curves

There was noticed a difference in measured retention curves as well as in unsaturated hydraulic conductivity curves between the samples. Figure 4-1, Figure 4-2 and Figure 4-3 show water retention curve of every sample in pedological layer 1, 2 and 3, respectively. The difference is up to 14% in water content and is especially noticeable at close to saturation point as well as at pF = 2.5 and 3.8.

Soils which are next to each other nonetheless still remaining in the same horizon may vary significantly, e.g. sample 55 cm and 60 cm in Figure 4-2 or 95 cm and 100 cm in Figure 4-3.

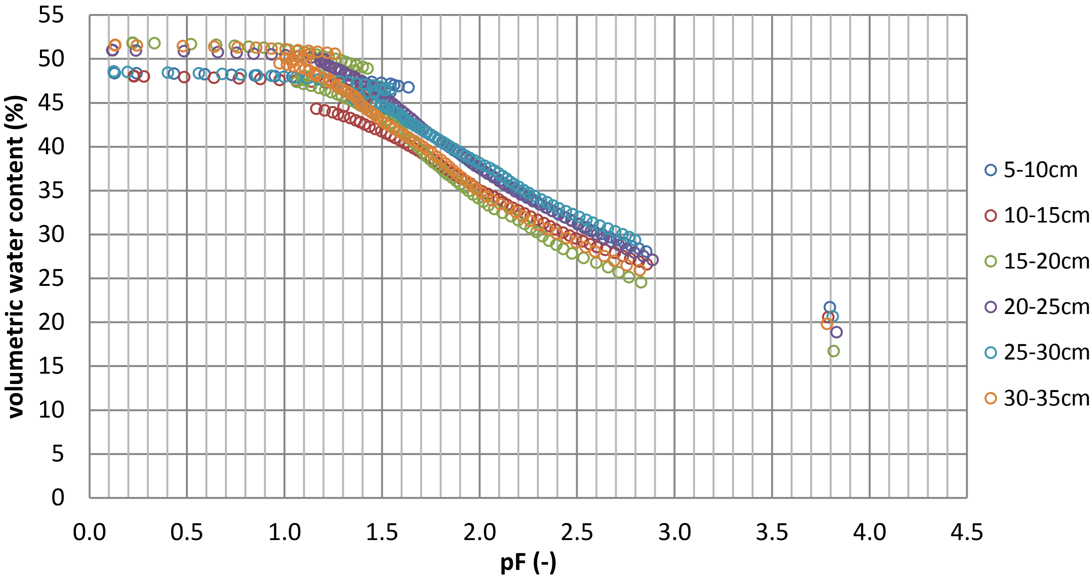

Figure 4-1. Retention curves of Gross Enzersdorf's pedological layer 1 at depth 5 - 35 cm.

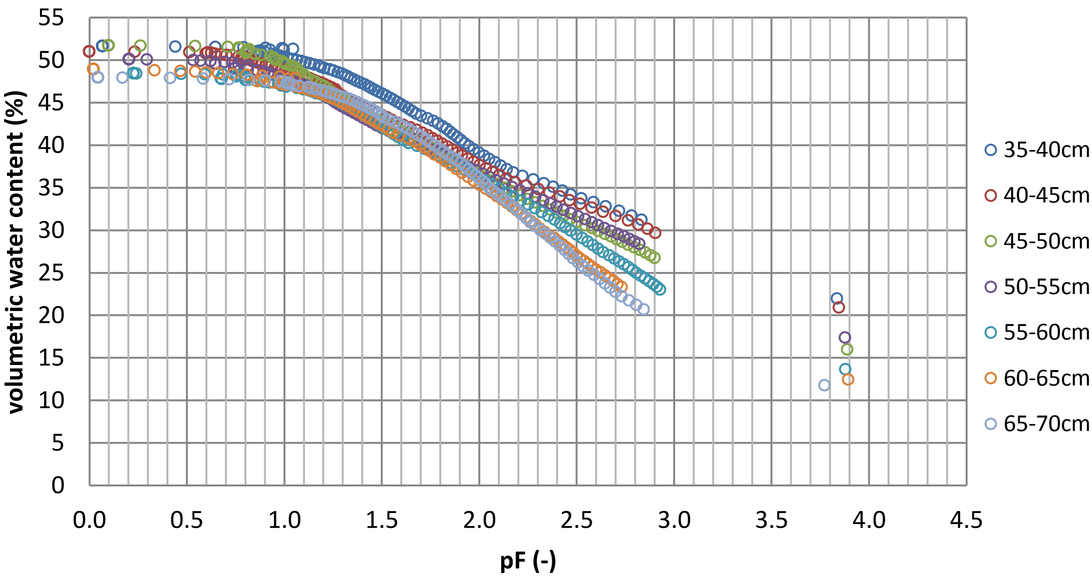

Figure 4-2. Retention curves of Gross Enzersdorf's pedological layer 2 at depth 35 - 70 cm.

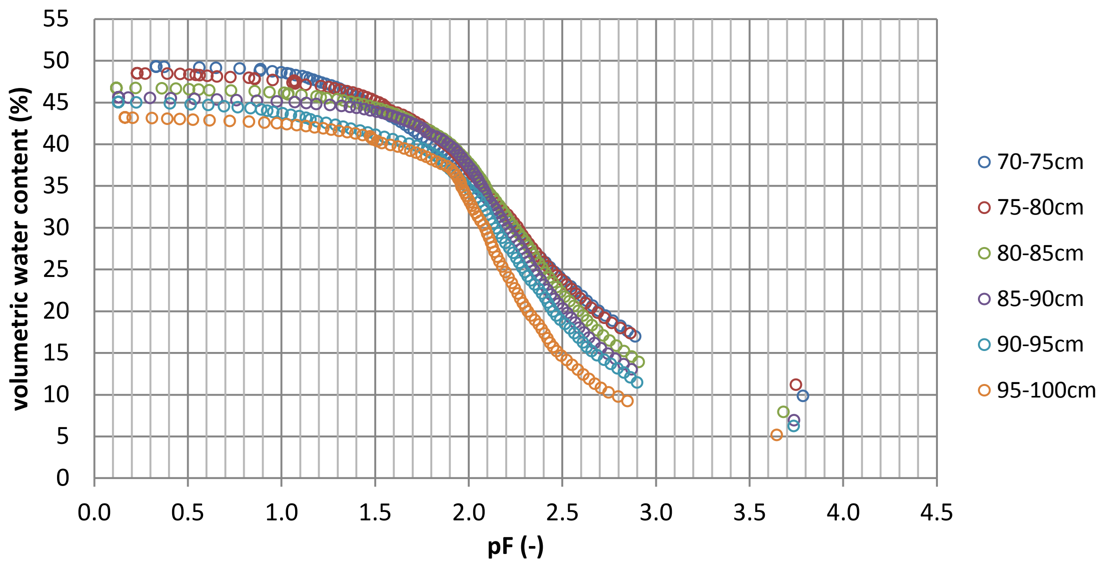

Figure 4-3. Retention curves of Gross Enzersdorf's pedological layer 3 at depth 70 - 100 cm.

Hydraulic conductivity (K) curve of each sample in a layer 1, 2 and 3 is shown in Figure 4-4, Figure 4-5 and Figure 4-6, respectively. Similar to retention curves the hydraulic conductivities vary more or less between each other, e.g. very similar are curves for 50 and 60 cm in Figure 4-5; or very dissimilar as 95 cm and 100 cm in Figure 4-6.

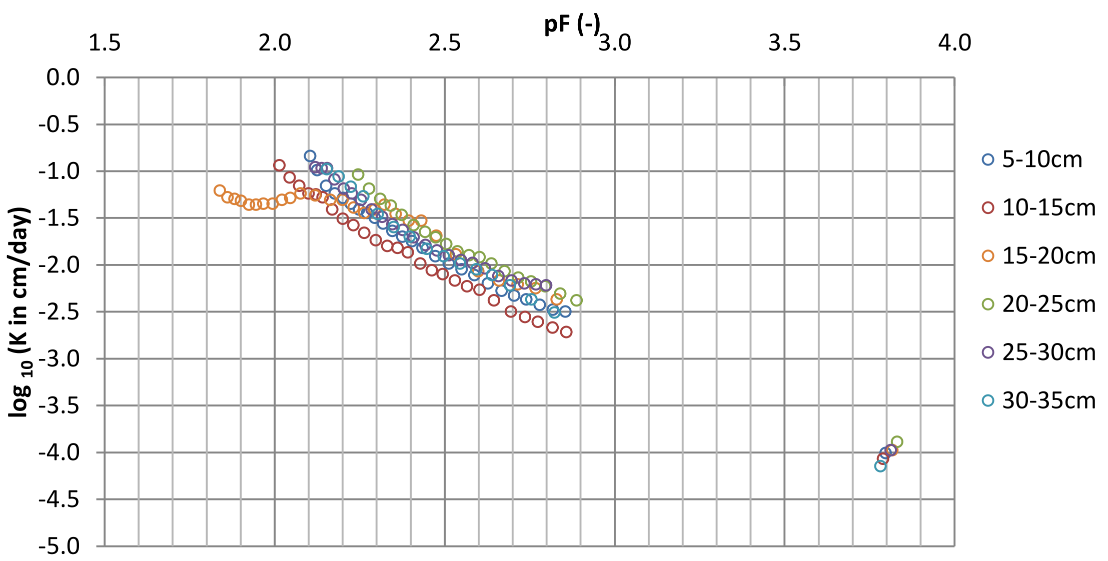

Figure 4-4. Hydraulic conductivity curves of Gross Enzersdorf's pedological layer 1 at depth 5-35 cm[a].

[a] Sample 20 cm was removed from SL and PL approaches due to its obvious measurement error.

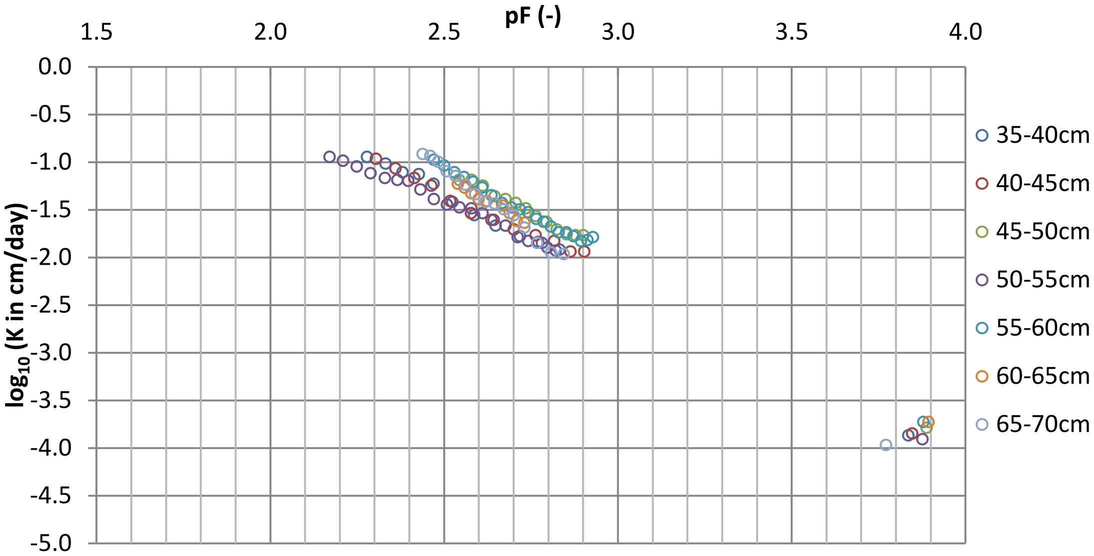

Figure 4-5. Hydraulic conductivity curves of Gross Enzersdorf's pedological layer 2 at depth 35-70 cm.

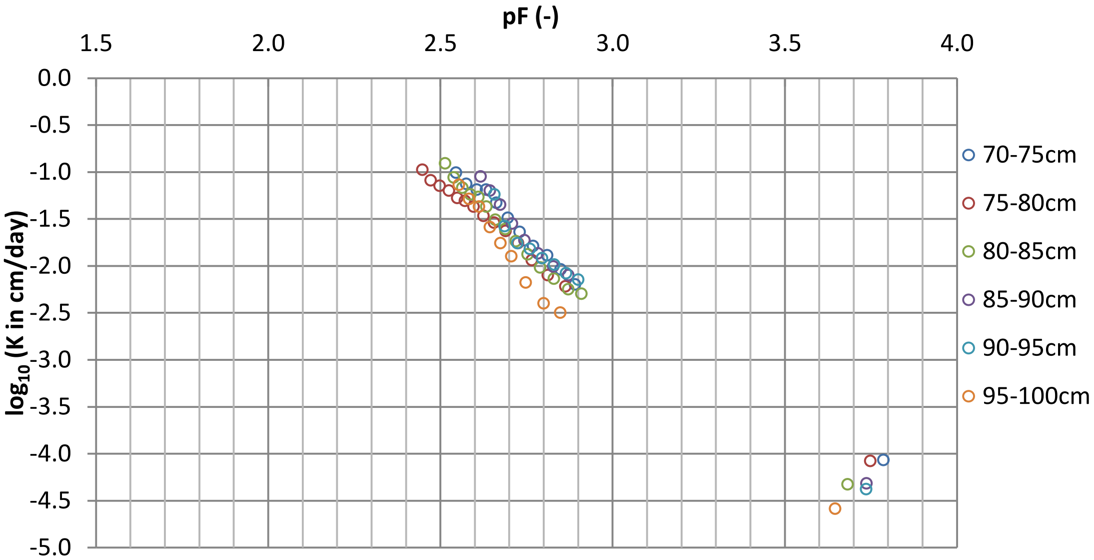

Figure 4-6. Hydraulic conductivity curves of Gross Enzersdorf's pedological layer 3 at depth 70-100 cm.

Presented figures show diversity of hydraulic properties within each soil layer (horizon).

4.1.2 Root mean square error and Akaike information criterion

Root mean square error and Akaike information criterion from the water retention and hydraulic conductivity fitting curves for every sample, pedological layer and common characteristics approach are shown in

Table 4-1 and Table 4-2. An RMSE of 0.001 for the retention data ($\log_{10}K$) fit indicates an average distance of the fitted curve to observed data of 0.1 % water content ($log_{10}K$). The lower value in Akaike information criterion, the more appropriate model for given data points.

Table 4-1. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Single Layers of Gross Enzersdorf.

Depth (cm)	*0-5*	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*35-40*
Name	**Value**							
RMSE_Theta	0.0066	0.0073	0.0101	0.0119	0.002	0.005	0.0067	0.0023
RMSE_logK	0.0678	0.0347	0.0238	0.2038	0.0167	0.0373	0.0563	0.043
AICc	-1621	-1826	-1793	-1769	-1980	-1895	-1715	-1836
Depth (cm)	*40-45*	*45-50*	*50-55*	*55-60*	*60-65*	*65-70*	*70-75*	*75-80*
Name	**Value**							
RMSE_Theta	0.002	0.0028	0.0016	0.002	0.0032	0.0021	0.0026	0.0014
RMSE_logK	0.0598	0.0345	0.0249	0.0729	0.0273	0.0303	0.0394	0.0438
AICc	-1829	-1834	-2078	-1938	-1718	-1893	-1770	-1960
Depth (cm)	*80-85*	*85-90*	*90-95*	*95-100*				
Name	**Value**							
RMSE_Theta	0.0014	0.0017	0.0026	0.0037				
RMSE_logK	0.0439	0.0535	0.0848	0.0421				
AICc	-1955	-1853	-1727	-1722				

Table 4-2. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Pedological Layers of Gross Enzersdorf.

Depth (cm)	*5-35*	*35-70*	*70-100*
Name	**Value**		
RMSE_Theta	0.0144	0.0194	0.0155
RMSE_logK	0.1628	0.1206	0.1227
AICc	-8629	-7248	-5951

4.1.3 Saturated hydraulic conductivity

First of all it is important to point out that saturated hydraulic conductivity is not a measured value. It is the estimated value by HYPROP – DES as one of parameters in a conductivity function based on measured data points. In the software it is termed Ks although here used term is K_{sat}.

Figure 4-7 shows differences between the approaches in saturated hydraulic conductivity within a soil profile. General high K_{sat} in certain depths (e.g. 17-30 cm) indicates changes in water flow through the soil profile, thus water storage. Moreover, while a K_{sat} of Pedological Layers approach is increasing (except of first centimeters) with depth a K_{sat} of SL approach is much more changeable. It must be noted, that samples representing hydraulic properties of 15-20 cm were removed due to its measurement error and fitting problems, thus it was split between values of 2 adjacent samples. Hence, hydraulic properties of 11-15 cm and 20-25 cm are valid for a depth of 11-17 cm and 18-25 cm, respectively.

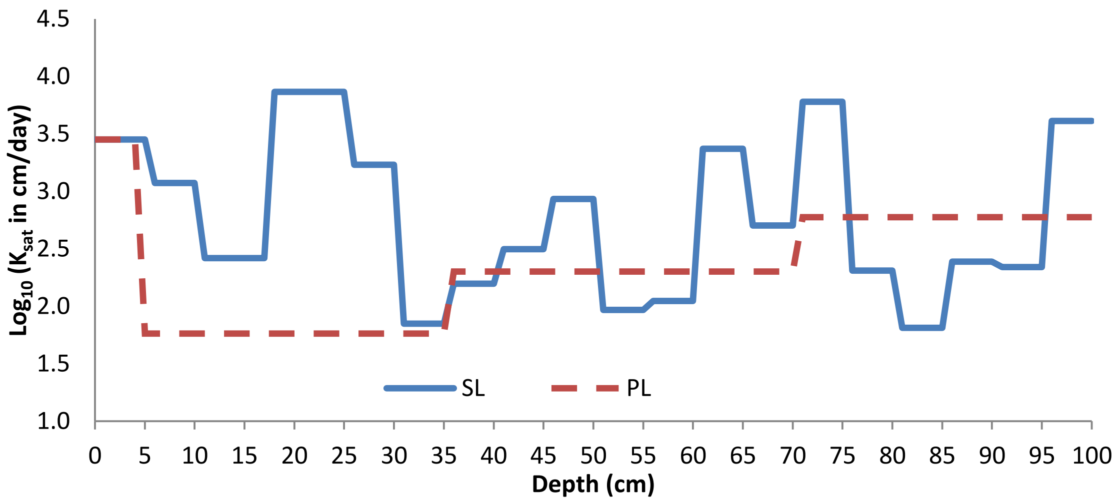

Figure 4-7. Comparison of saturated hydraulic conductivity ($log_{10}(K_{sat})$) within soil profile from Gross Enzersdorf; SL – Single Layers approach; PL – Pedological Layers approach.

Table 4-3 shows all saturated hydraulic conductivity (K_{sat}) corresponding to its depth and approach.

Table 4-3. Saturated hydraulic conductivity (Ksat) of depth for the approaches from Gross Enzersdorf's soil profile.

Single Layer		Pedological Layers	
Depth (cm)	K_{sat} (cm/day)	Depth (cm)	K_{sat} (cm/day)
0-5	2817.531	0-5	2817.530
5-10	1176.704	5-35	57.639
10-17	262.087	35-75	200.801
17-25	7335.429	75-100	595.788
25-30	1699.920		
30-35	70.463		
35-40	157.413		
40-45	314.108		
45-50	856.192		
50-55	93.061		
55-60	111.098		
60-65	2337.145		
65-70	502.221		
70-75	6007.145		
75-80	203.527		
80-85	64.890		
85-90	244.042		
90-95	219.117		
95-100	4088.411		

4.1.4 Physical and chemical properties

Beside analysis of hydraulic properties were also analyzed soil particle size distribution and organic carbon content.

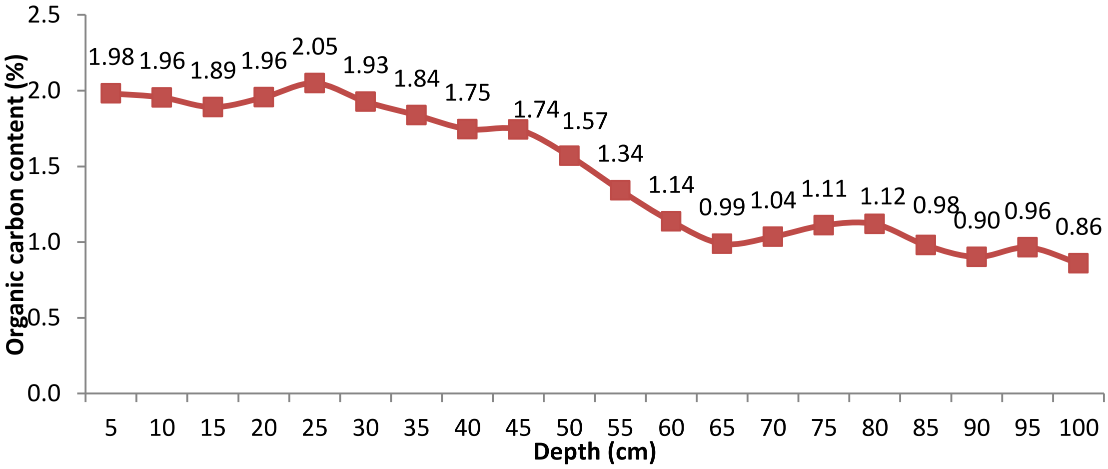

Figure 4-8. Organic carbon content within a soil profile - Gross Enzersdorf.

Saturated hydraulic conductivity was directly compared to soil particle size distribution and organic carbon content. There was found no relationship between K_{sat} – organic carbon with 0.006% of correlation and K_{sat} – clay content with 0.87% of correlation (Figure 4-9). However, Figure 4-10 shows a positive correlation between organic carbon and saturated volumetric water content (Θs) with 42.72% fitting as well as between clay content and Θs with 51.75% fitting. The more organic carbon the higher is saturated volumetric water content. Likewise, the more clay matter in the soil the more water can be stored. It just confirms that organic matter and clay particles strongly influence water retention (Leeper and Uren, 1993; Charman and Murphy, 1977; Bot and Benites, 2005). Θ

There is a slight correlation between bulk density and saturated hydraulic conductivity indicated by 9.38% fitting. Figure 4-11 shows negative relationship between those variables; when bulk density increases the saturated hydraulic conductivity decreases.

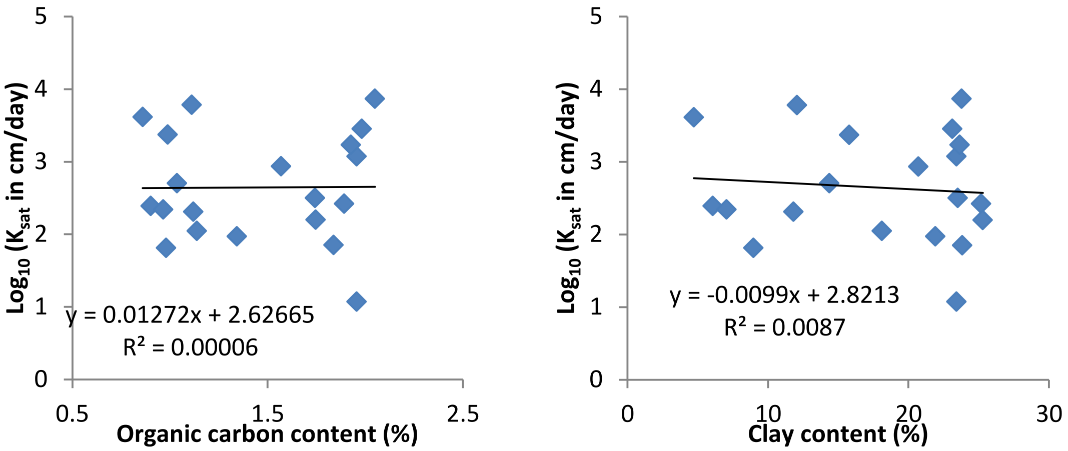

Figure 4-9. Relationship between saturated hydraulic conductivity ($Log_{10}K_{sat}$) and organic carbon (left) and relationship between saturated hydraulic conductivity ($Log_{10}K_{sat}$) and clay content (right) - Gross Enzersdorf.

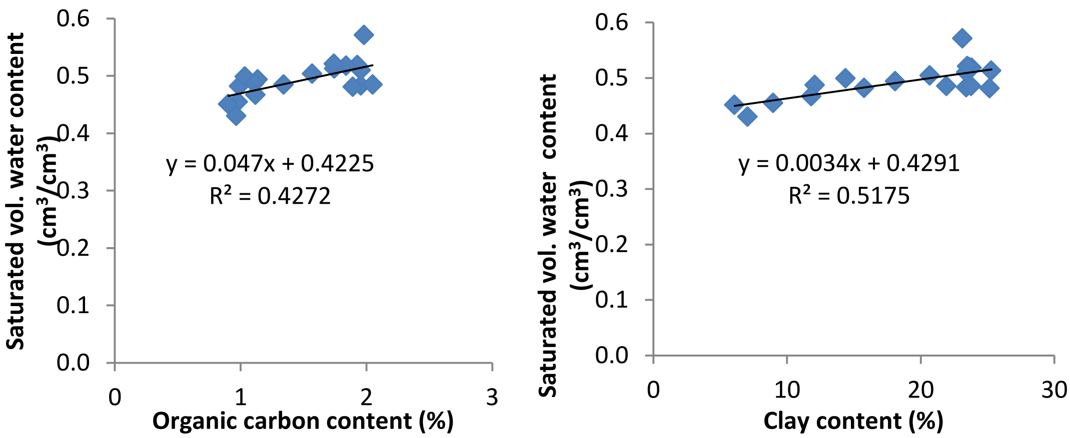

Figure 4-10. Relationship between saturated volumetric water content and organic carbon content (left); saturated volumetric water content and clay content (right) - Gross Enzersdorf.

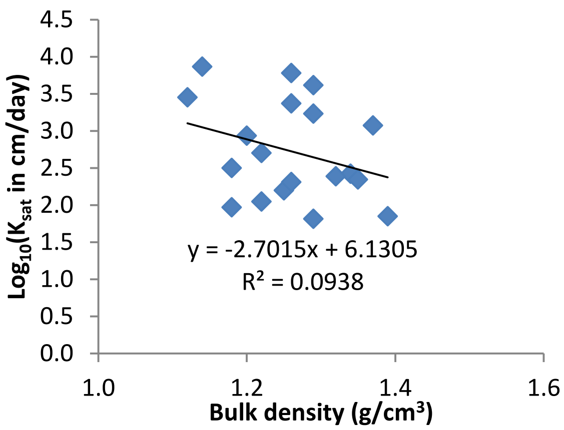

Figure 4-11. Saturated hydraulic conductivity ($log_{10}(K_{sat})$) of bulk density - Gross Enzersdorf.

4.1.5 Soil water simulation output

Water flow through the soil profile was simulated in each approach. Water content was registered for every observation point. Those points were at depth 21, 33, 63, 83 and 90 cm and further they are termed: OP21, OP33, OP63, OP83 and OP90, respectively. Those points were chosen regarding a variation of the saturated hydraulic conductivity between the approaches as in Figure 4-7 and Table 4-3.

Figure 4-12, Figure 4-13 and Figure 4-14 show water content at OP21 where saturated hydraulic conductivity of Single Layers approach is the highest (7331 cm/day). Moreover there is a huge difference in comparison to PL approach where saturated hydraulic conductivity is lower for more than 2 orders of magnitude (58 cm/day). The difference in hydraulic conductivity indicates changes in water content, due to higher infiltration rate, which does not significantly occur in any year.

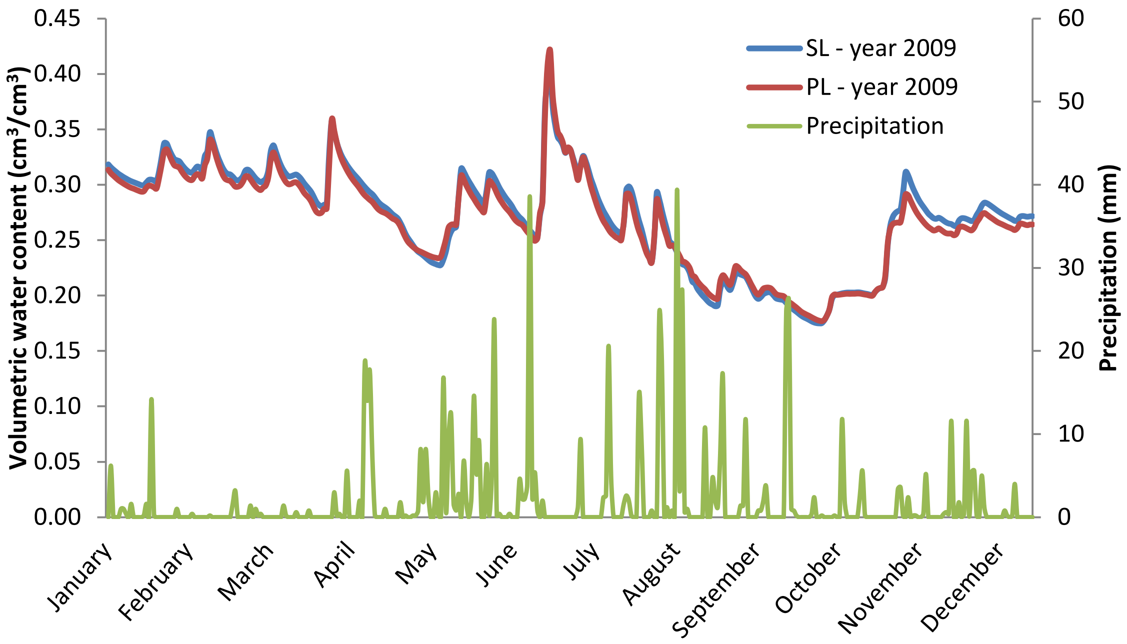

Figure 4-12. Water content data obtained from the water flow simulation at 21 cm depth (OP21) for climatic data from year 2009 - Gross Enzersdorf.

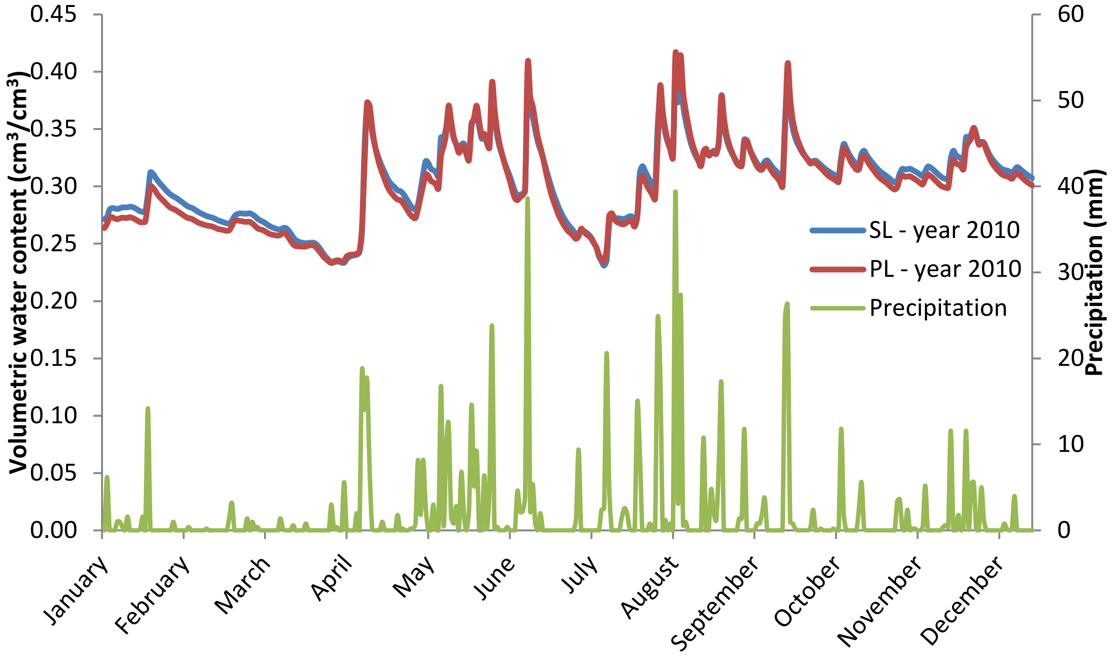

Figure 4-13. Water content data obtained from the water flow simulation at 21 cm depth (OP21) for climatic data from year 2010 - Gross Enzersdorf.

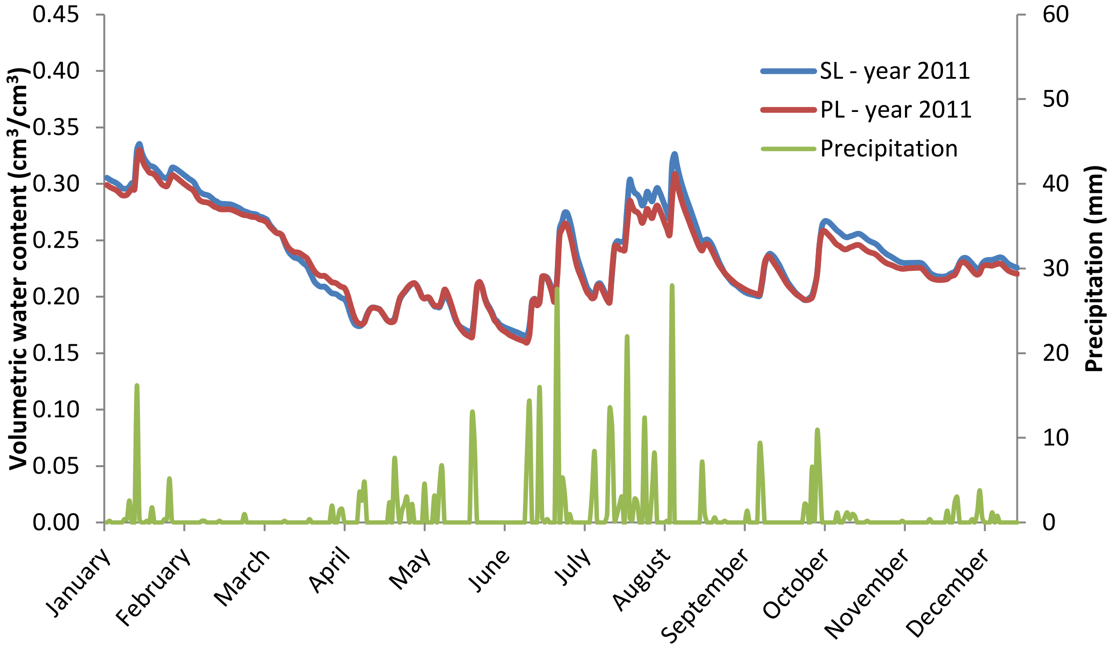

Figure 4-14. Water content data obtained from the water flow simulation at 21 cm depth (OP21) for climatic data from year 2011 - Gross Enzersdorf.

Figure 4-15 shows differences in water content over 3 years. Maximum difference is 0.0309 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0056 cm^3/cm^3. Up-and-down character of the curve responds to the atmospheric conditions. In general, whenever high intensity precipitation occurs then more water is hold by soil in PL approach for short time duration.

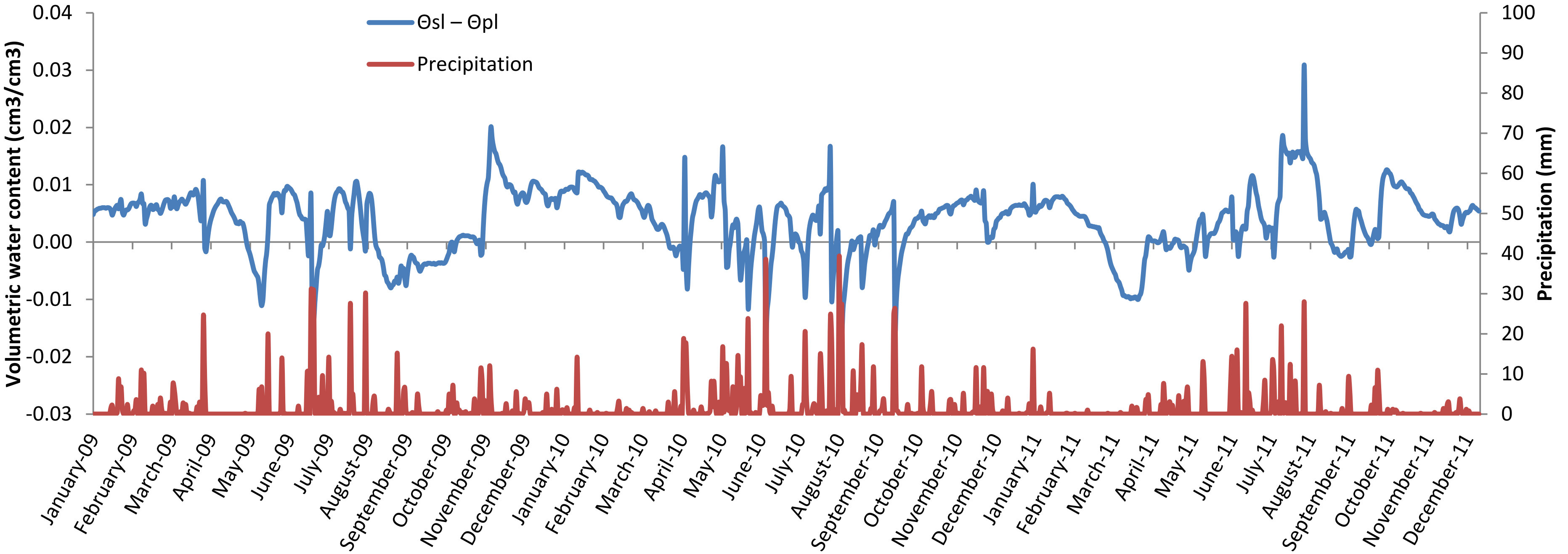

Figure 4-15. Difference in water content between approaches during 3 years for OP21 (Gross Enzersdorf), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-16, Figure 4-17 and Figure 4-18 show water content of OP33. At depth of 33 cm the K_{sat} of SL is 70 cm/day and of PL is 58 cm/day.

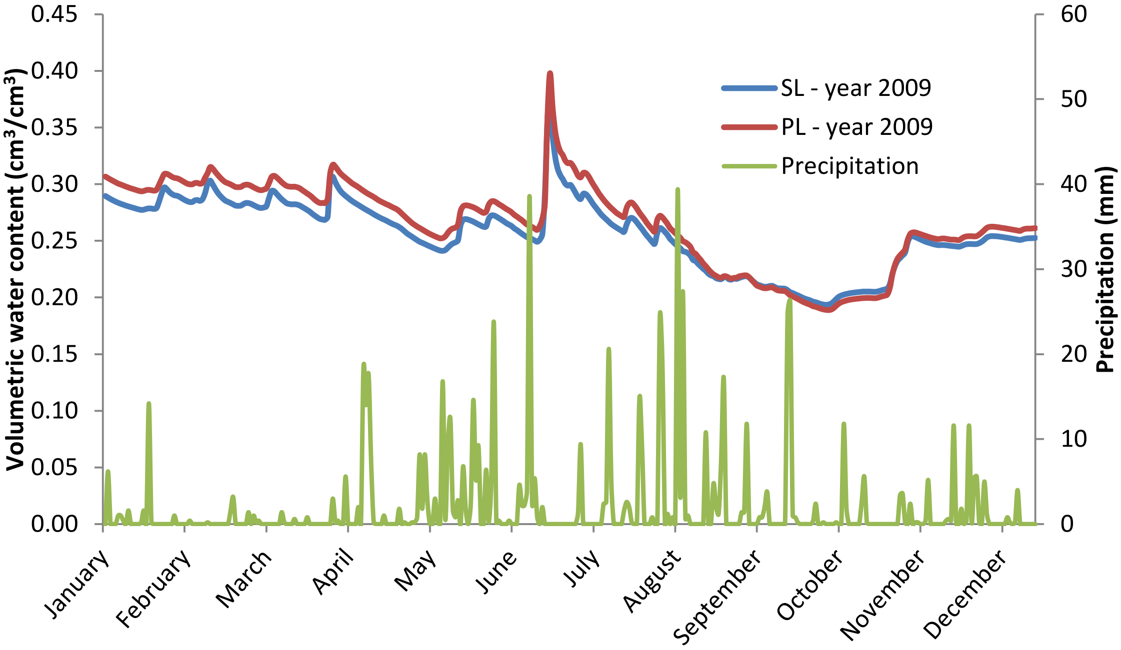

Figure 4-16. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2009 - Gross Enzersdorf.

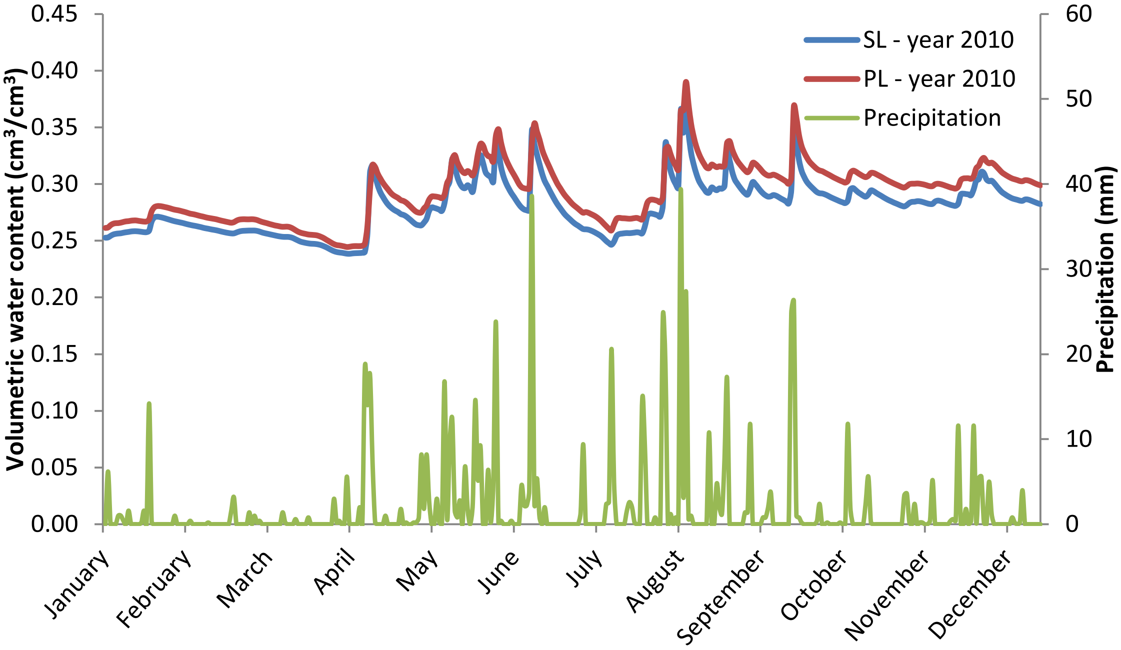

Figure 4-17. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2010 - Gross Enzersdorf.

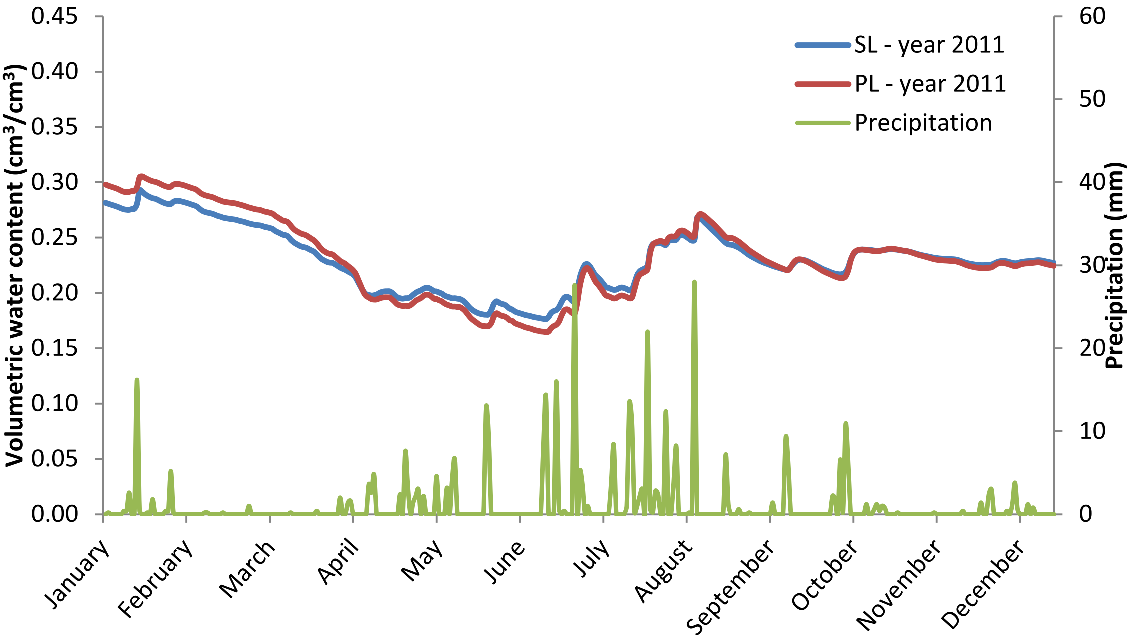

Figure 4-18. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2011 - Gross Enzersdorf.

At this point saturated hydraulic conductivity in Single Layers approach is the second lowest from the whole soil profile. Additionally it is preceded by high K_{sat} values, e.g. 1700 cm/day for 25-30 cm, 7335 cm/day for 17-25 cm. Generally at this observation point water content of SL is lower than PL except of few periods, Figure 4-19. Average difference of absolute value during whole 3 years is 0.0104 cm^3/cm^3. The maximum difference is 0.0255 cm^3/cm^3.

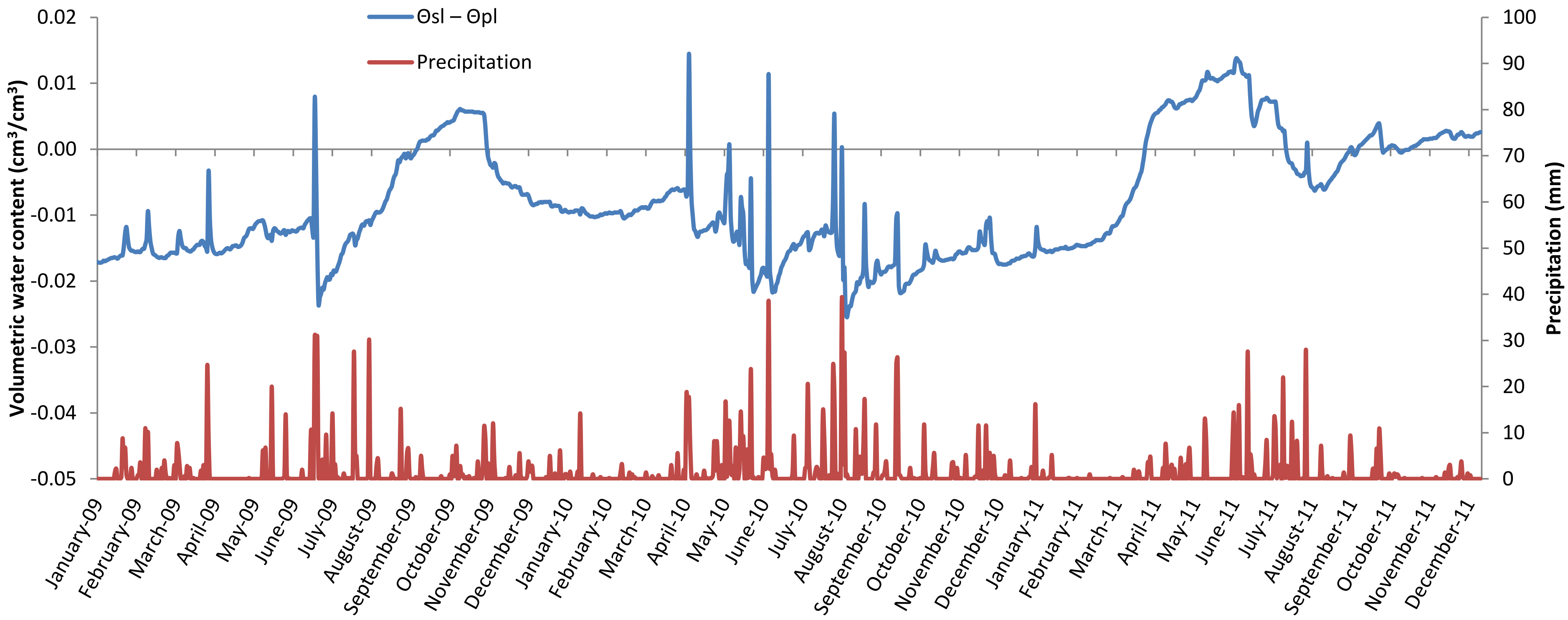

Figure 4-19. Differences in water content between the approaches during 3 years for OP33 (Gross Enzersdorf), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-20, Figure 4-21 and Figure 4-22 show water content of OP63. At this point K_{sat} of SL is 2337 cm/day, PL is 201 cm/day. At this depth occurs the highest difference between SL and PL approaches.

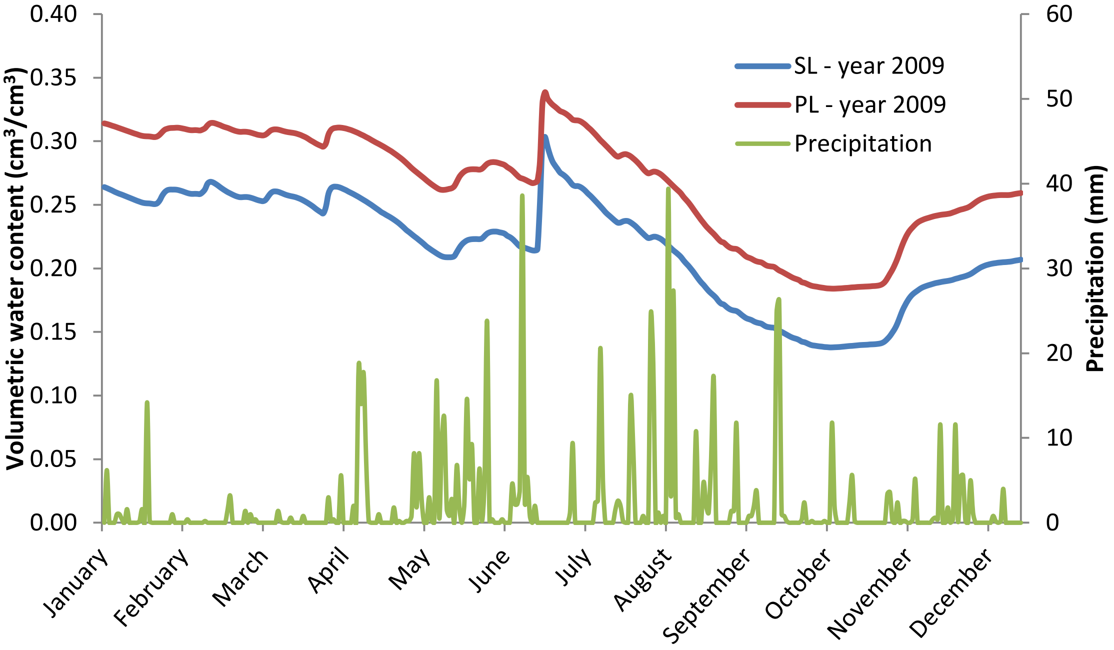

Figure 4-20. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2009 - Gross Enzersdorf.

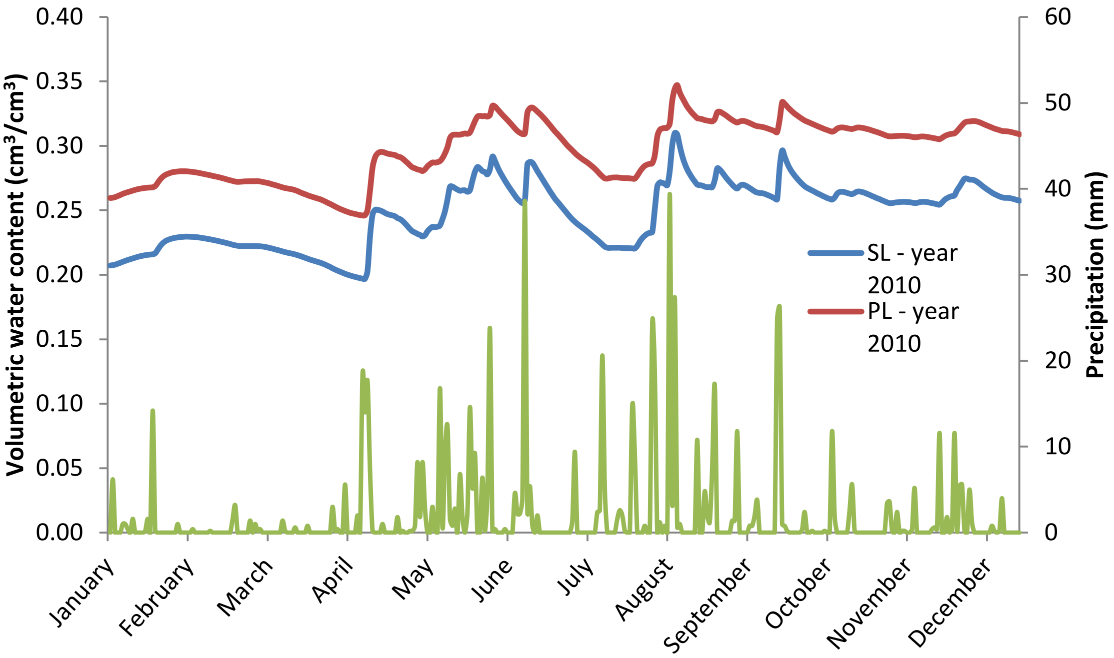

Figure 4-21. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2010 - Gross Enzersdorf.

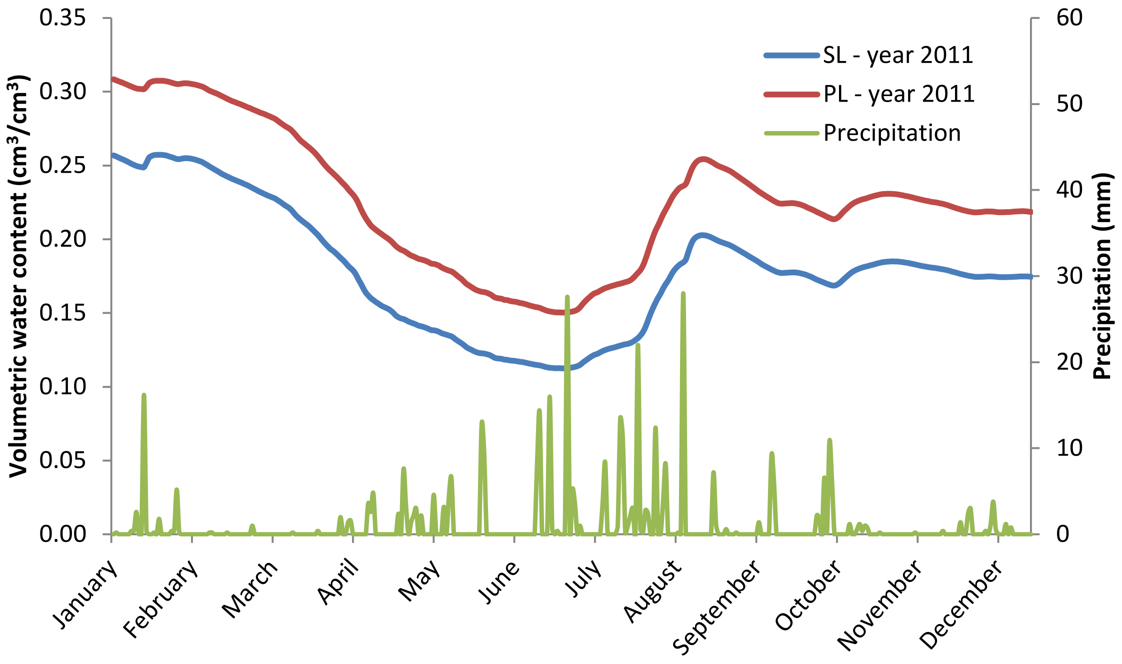

Figure 4-22. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2011 - Gross Enzersdorf.

Average difference of absolute value during whole 3 years is 0.049 in volumetric water content (cm^3/cm^3). The maximum difference is 0.0558 cm^3/cm^3. It is a noteworthy difference considering water content during year 2009, 2010 around 0.25 - 0.30 cm^3/cm^3, and in 2011 decreasing to 0.13 – 0.17 cm^3/cm^3.

As it can be seen on Figure 4-23 a decreasing difference between both approaches occurs only during longer and heavier rain falls (July 2009, April-September 2010) and after a dry period when precipitation had increased (April-August 2011).

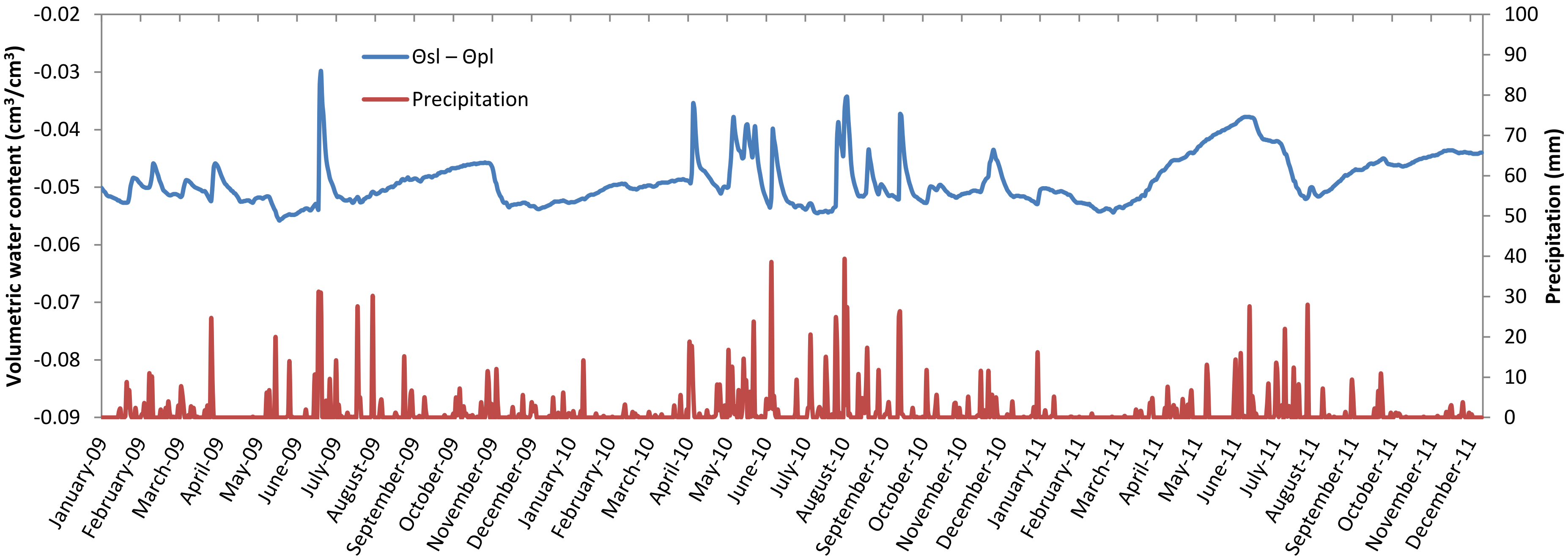

Figure 4-23. Differences in water content between the approaches during 3 years for OP63 (Gross Enzersdorf), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers

Figure 4-24, Figure 4-25 and Figure 4-26 show water content at the depth of 83 cm. Saturated hydraulic conductivity of SL (65 cm/day) in this point is lower than PL (596 cm/day). Moreover, water content of PL approach is lower than SL at this depth, as can be seen on Figure 4-27.

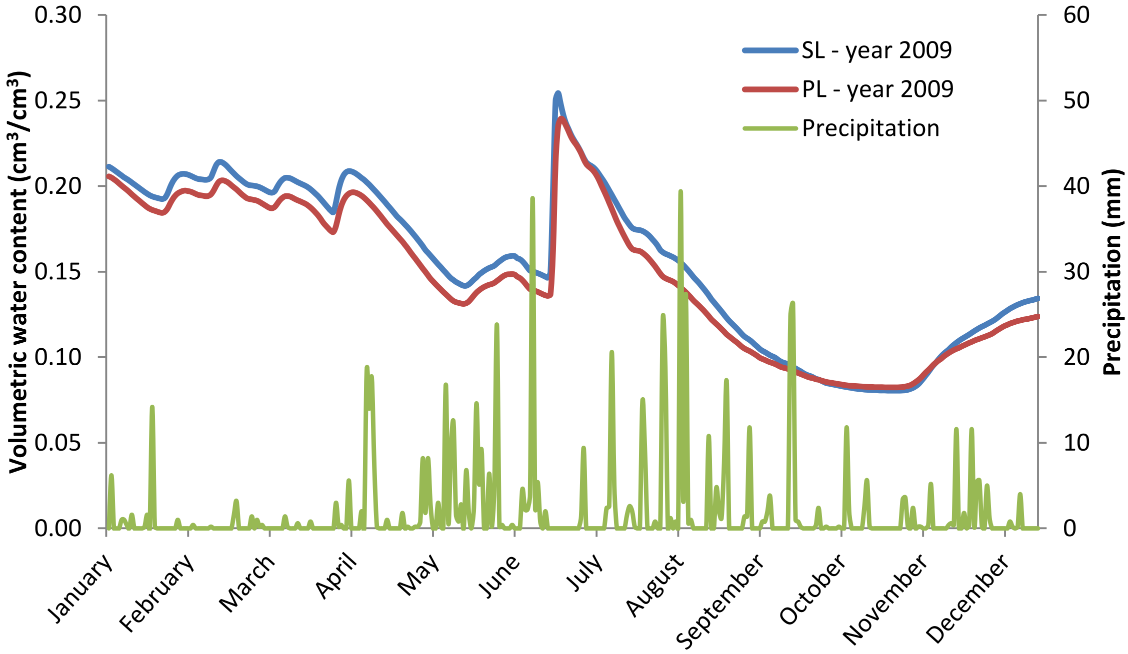

Figure 4-24. Water content data obtained from the water flow simulation at 83 cm depth (OP83) for climatic data from year 2009 - Gross Enzersdorf.

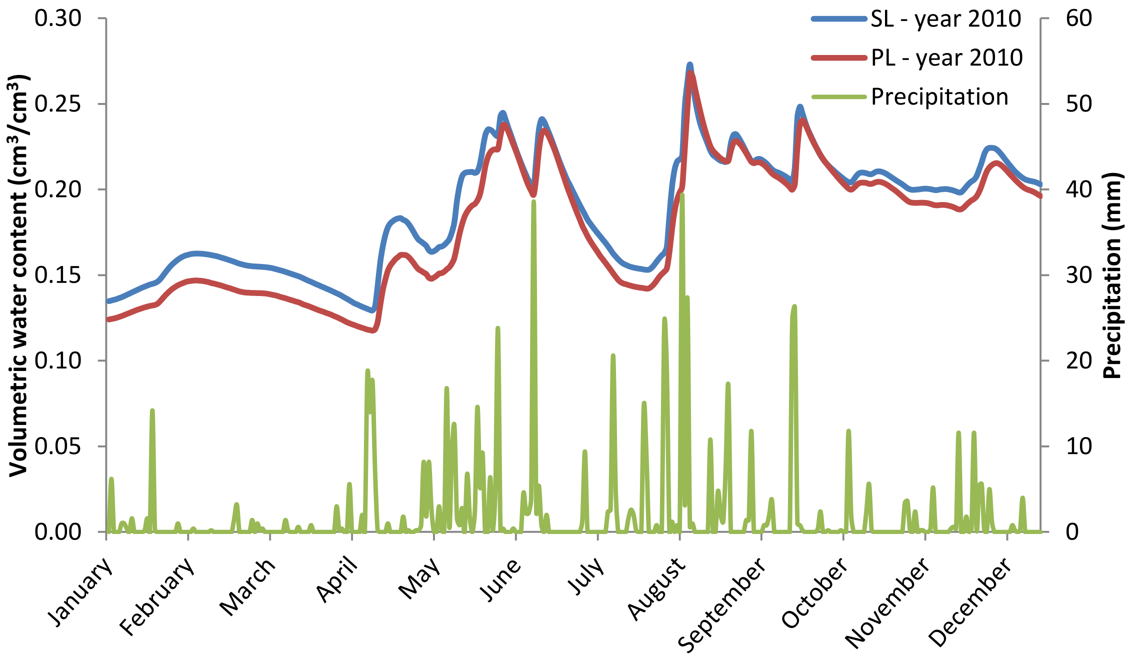

Figure 4-25. Water content data obtained from the water flow simulation at 83 cm depth (OP83) for climatic data from year 2010 - Gross Enzersdorf.

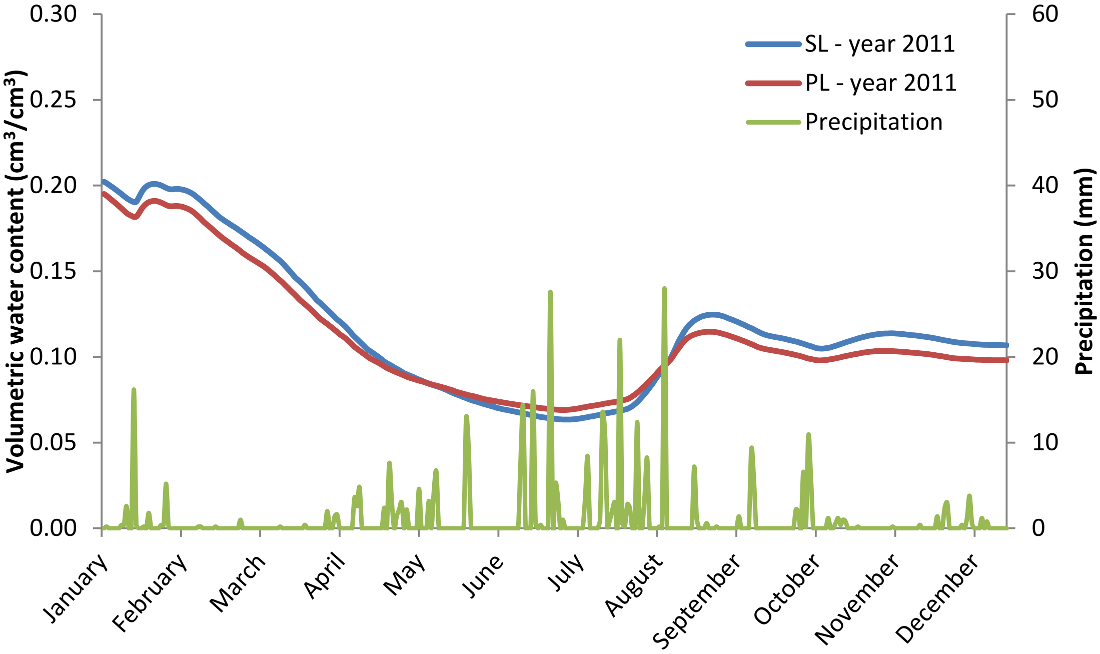

Figure 4-26. Water content data obtained from the water flow simulation at 83 cm depth (OP83) for climatic data from year 2011 - Gross Enzersdorf.

Water content is higher in SL than PL approach because of the lower hydraulic saturated conductivity by approximately one order of magnitude. Moreover, it might be essential that in range 76 - 95 cm of depth is characterized by lower K_{sat} in SL approach in comparison to PL Figure 4-7.

An average difference of absolute value during whole 3 years is equal to 0.0087 cm^3/cm^3. The maximum difference is 0.0361 cm^3/cm^3. Due to higher saturated hydraulic conductivity of PL approach soil dries faster (decreasing its water content) and starts to recharge faster. Hence, it is a reason why in some periods water content in SL approach is lower than in PL.

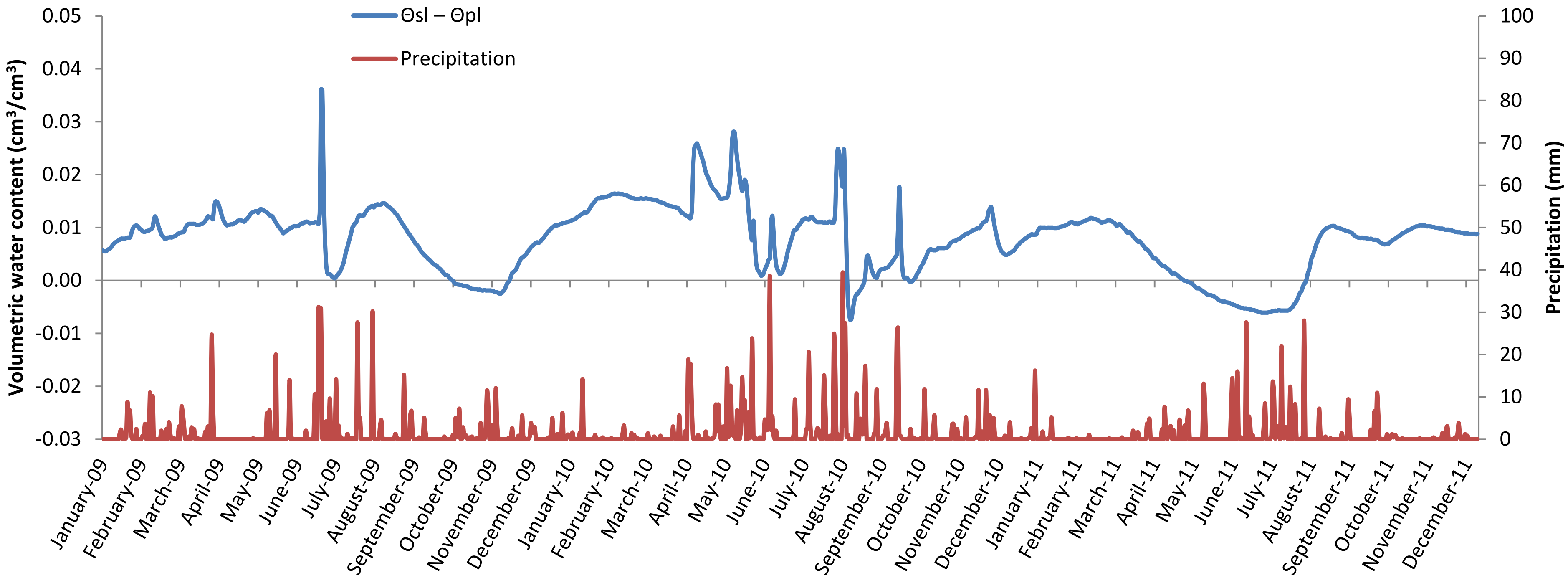

Figure 4-27. Differences in water content between the approaches during 3 years for OP83 (Gross Enzersdorf), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-28, Figure 4-29 and Figure 4-30 show water content at the depth of 90 cm. Saturated hydraulic conductivity of SL (244 cm/day) in this point is lower than PL (596 cm/day).

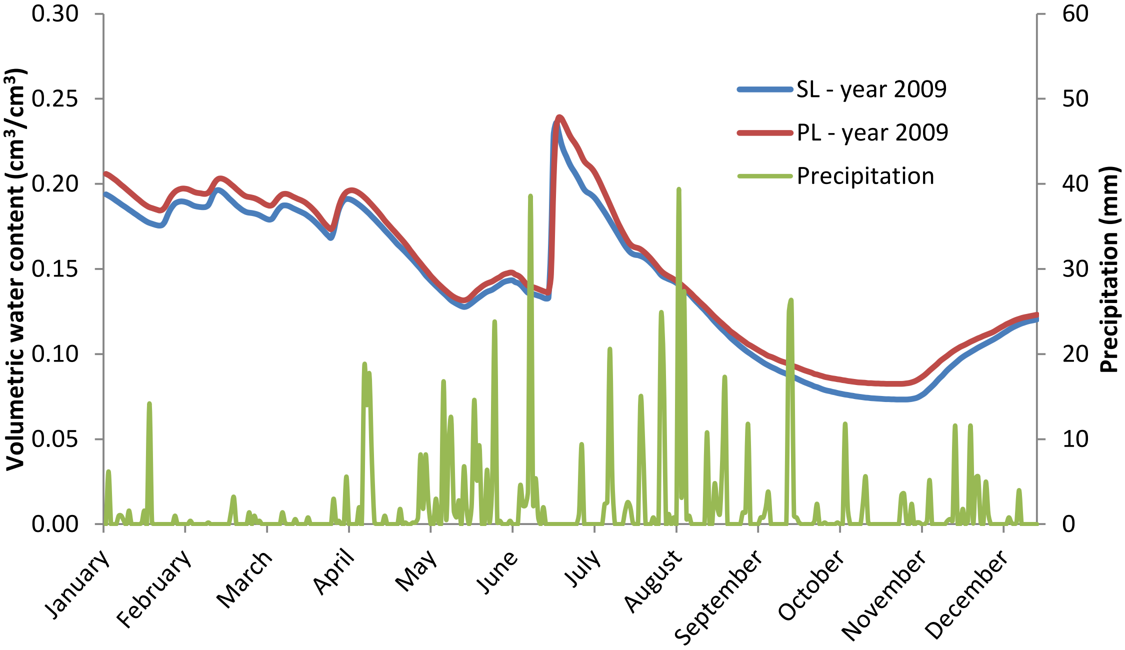

Figure 4-28. Water content data obtained from the water flow simulation at 90 cm depth (OP90) for climatic data from year 2009 - Gross Enzersdorf.

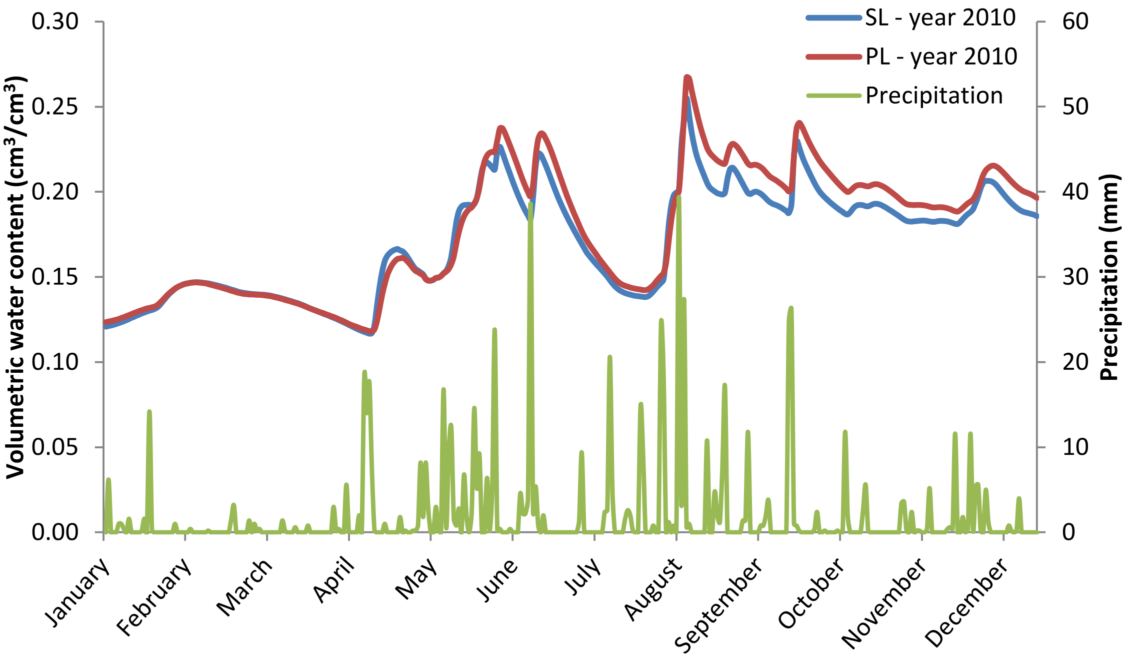

Figure 4-29. Water content data obtained from the water flow simulation at 90 cm depth (OP90) for climatic data from year 2010 - Gross Enzersdorf.

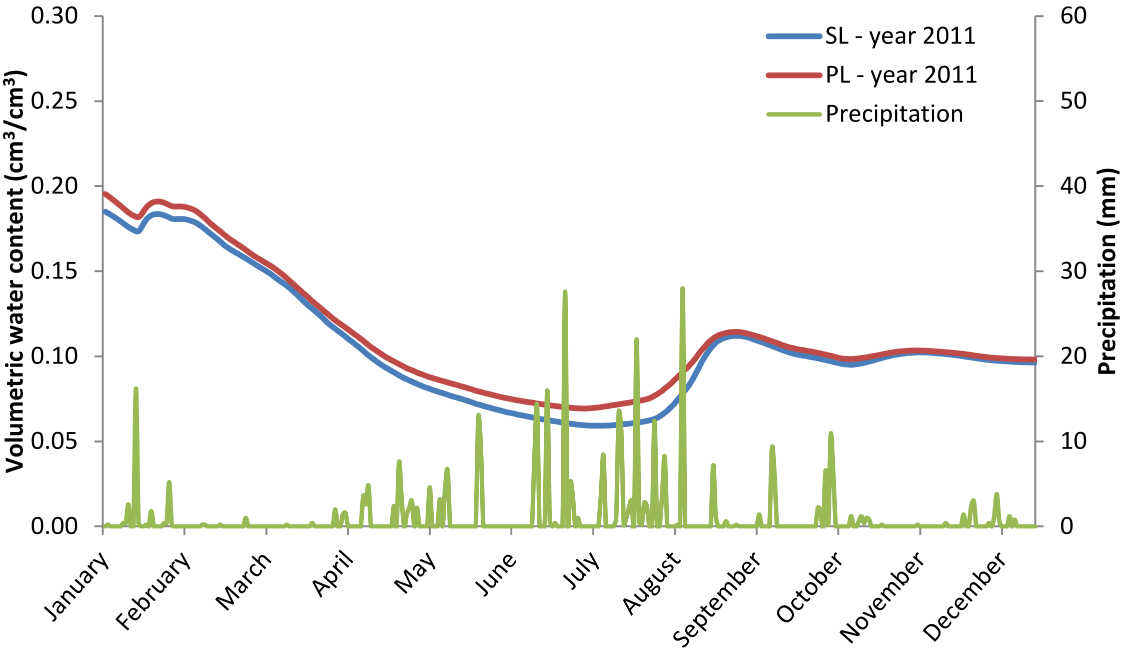

Figure 4-30. Water content data obtained from the water flow simulation at 90 cm depth (OP90) for climatic data from year 2011 - Gross Enzersdorf.

At this observation point is a similar situation to the OP83 where K_{sat} of PL is lower than K_{sat} of SL approach. However, as it can be seen on Figure 4-31 most of the time the water content of PL is higher than SL. This revers situation can be caused by a fact that the saturated hydraulic conductivity of SL approach at this point increased from 65 to 244 cm/day.

An average difference of absolute value during whole 3 years is equal to 0.0067 cm^3/cm^3. This is a 2[nd] lowest difference value. The maximum difference is 0.0266 cm^3/cm^3.

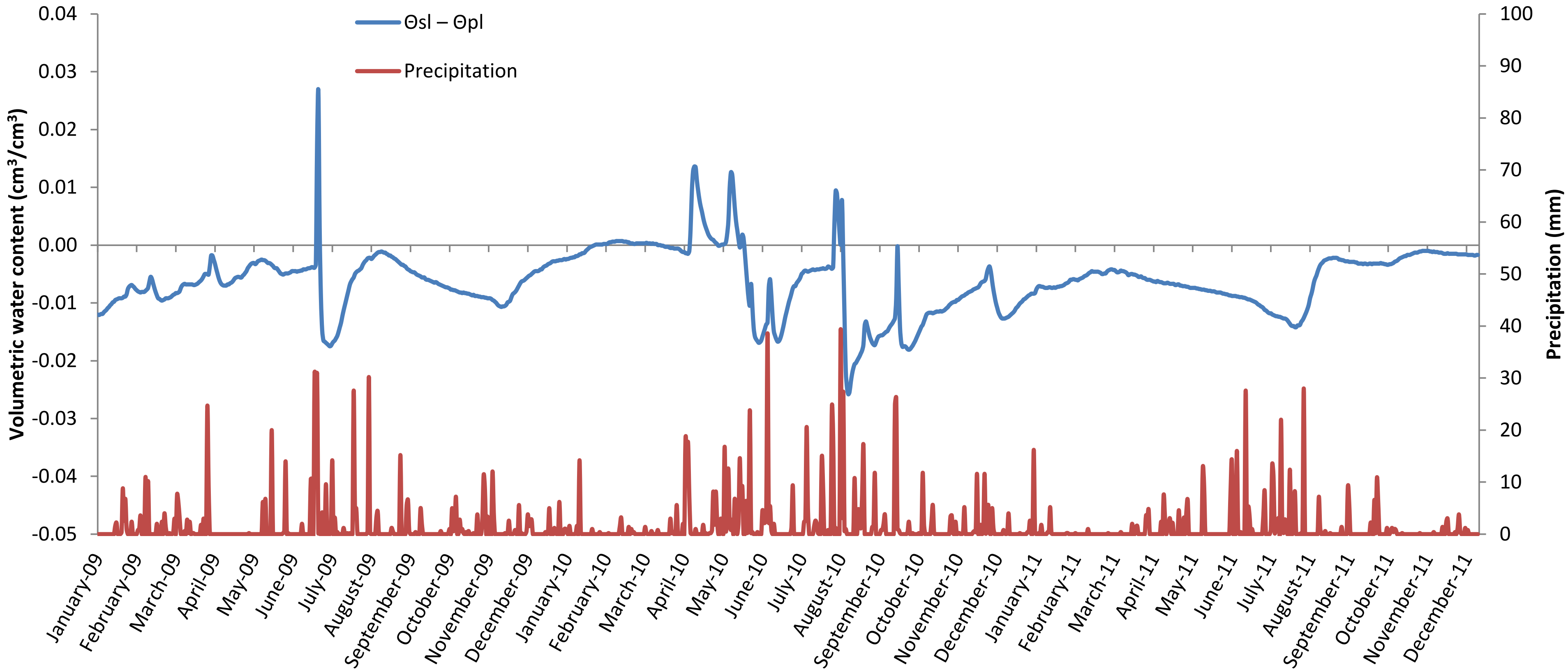

Figure 4-31. Differences in water content between the approaches during 3 years for OP90 (Gross Enzersdorf), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

At some depth in the soil profile the water content changes more or less significantly due to the difference in the hydraulic properties. However, as it is shown in Figure 4-32, there is no substantial change in the cumulative bottom flux between the approaches. A small difference is seen in the year 2011 which was considered as a dry year due to small amount of precipitation.

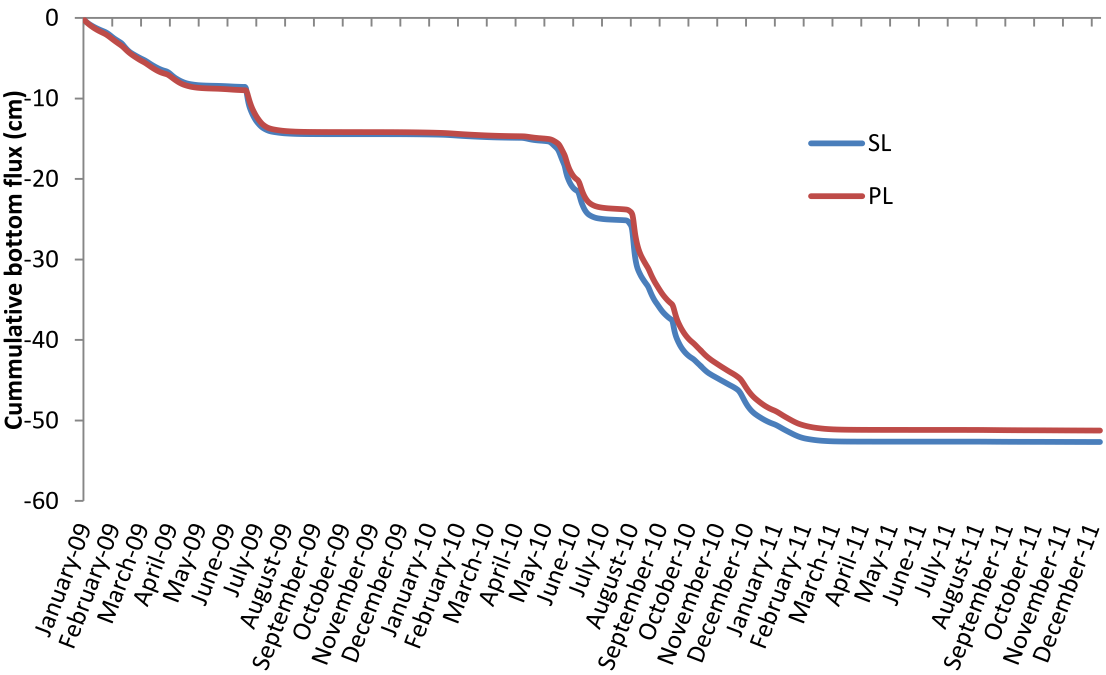

Figure 4-32. Cumulative bottom flux – Gross Enzersdorf 2009-2011.

Figure 4-32 shows a cumulative bottom flux (cm) of Gross Enzersdorf soil profile. A negative value represents an amount of water that has left the profile to deeper parts of soil. From soil profile described by SL approach discharged 52.67 cm of water and from soil profile described by PL approach discharged 51.25 cm of water. In the end an overall higher K_{sat} of SL approach resulted in higher water discharge.

Figure 4-33 shows a difference in bottom flux between both approaches. A negative difference between SL and PL represents a higher discharge value due to negative values considered in calculations. An average difference of absolute value during whole 3 years is equal to 0.99 cm. The maximum difference is 2.9 cm.

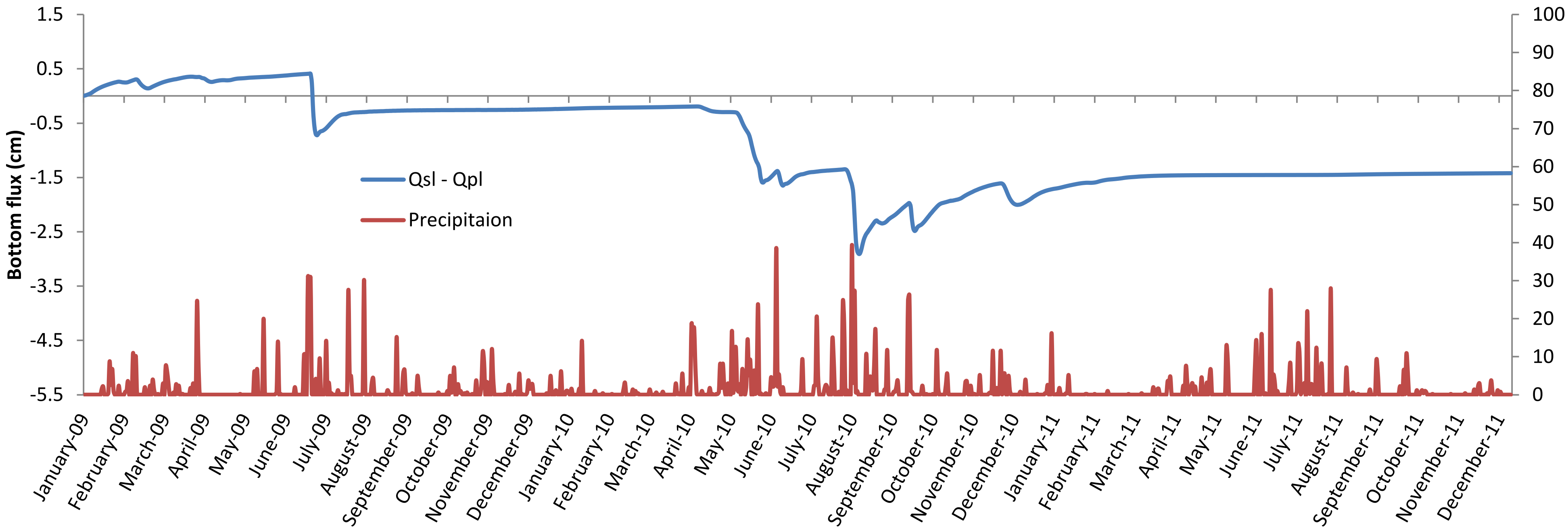

Figure 4-33. Differences in cumulative bottom flux between the approaches during 3 years for Gross Enzersdorf soil profile, where: Θsl – Θpl is a difference of cumulative flux between Single Layers and Pedological Layers.

4.1.6 Summary

Two approaches were compared together based on the analysis of soil from agricultural research farm. Hyprop measurements provided information about water retention and hydraulic conductivity of single samples. Comparison of those data show significant variety of properties within 3 individual soil horizons and especially in lower parts of the soil profile. Moreover, data analysis established saturated hydraulic conductivity for every single sample and joint samples. It proved the variety of K_{sat} within a soil profile.

There were attempts to find a relationship between K_{sat} and organic carbon content or soil particle size distribution. There was found no strong relationship.

Soil water simulations, carried out by Hydrus 1D software, gave an insight into a water movement through the soil profile with given parameters. In general there was noticed no significant differences between Single Layer and Pedological Layer approaches. The lowest noticed average difference in water content for 3 years was 0.0056 cm^3/cm^3 at OP21; the highest was equal to 0.049 cm^3/cm^3 at OP63. Simulations showed also that there is no big difference in bottom flux. The average difference was 0.99 cm, and in the last day the outflow of SL approach was higher for 2.7% than PL approach.

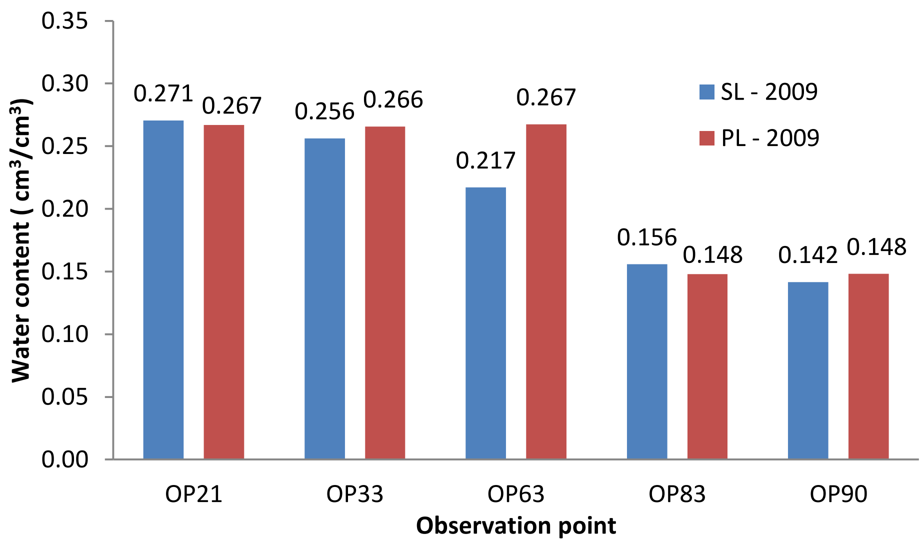

Figure 4-34. Average water content captured for the observation points of soil profile in Gross Enzersdorf, year 2009.

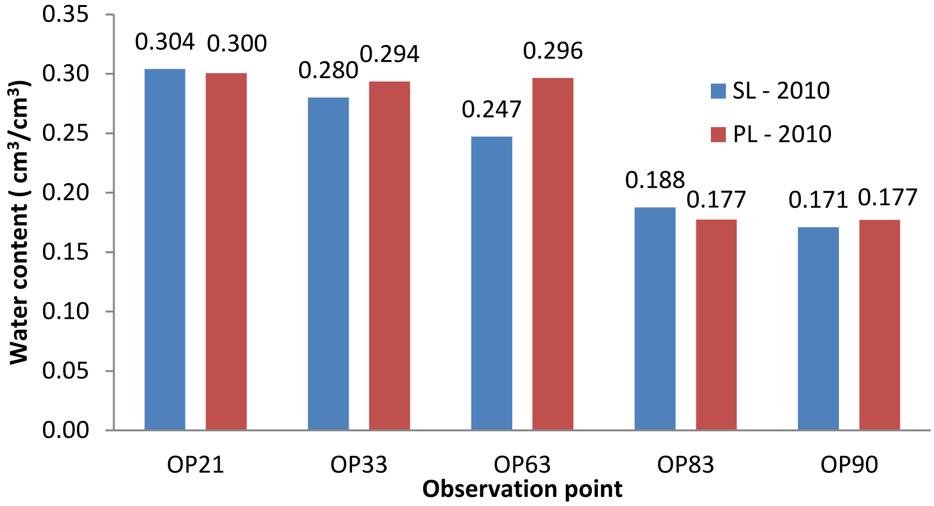

Figure 4-35. Average water content captured for the observation points of soil profile in Gross Enzersdorf, year 2010.

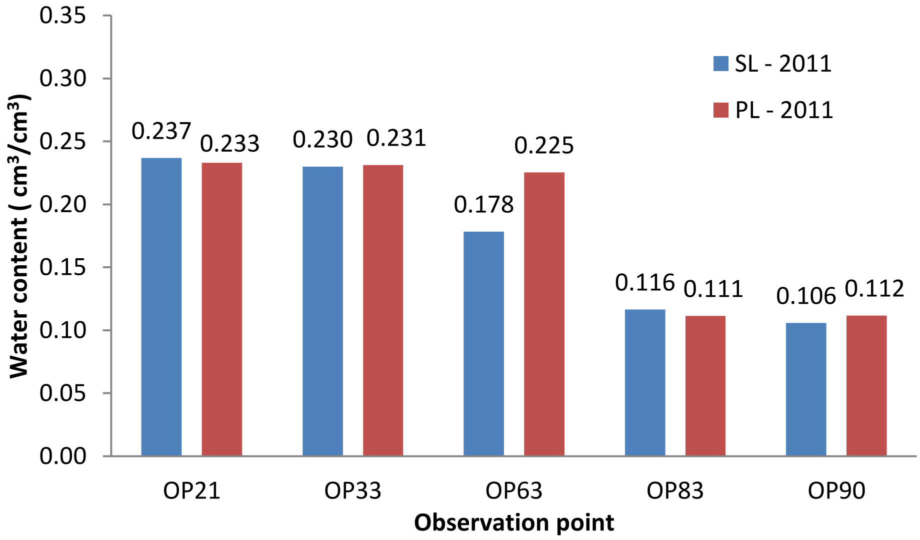

Figure 4-36. Average water content captured for the observation points of soil profile in Gross Enzersdorf, year 2011.

Year 2009 is considered here as a moderate one regarding a precipitation during the year. Figure 4-34 shows the average water content in the specific observation point and as can be seen the highest difference in water content is at depth of 63 cm. In Pedological Layers approach water content in average is around 0.267 cm^3/cm^3 for three first observation points. In the deeper parts it decreases to 0.148 cm^3/cm^3. However, in Single Layers approach can be observed a decrease of average water content in depth. A similar trend can be seen in year 2010 (Figure 4-35) and 2011 (Figure 4-36).

In this soil profile the differences in properties do not have a significant impact on the overall water storage in the soil nor for groundwater recharge.

4.2 Forest demonstration center in the Rosalian Mountains – soil profile 1

4.2.1 Retention and hydraulic conductivity curves

This soil profile was divided on 4 pedological layers. As can be seen in Figure 4-37, Figure 4-38, Figure 4-39 and Figure 4-40 a significant difference occurs in water retention curves within a layer as it was in soil profile from Gross Enzersdorf. Only the last 4th layer is more unified than the other three.

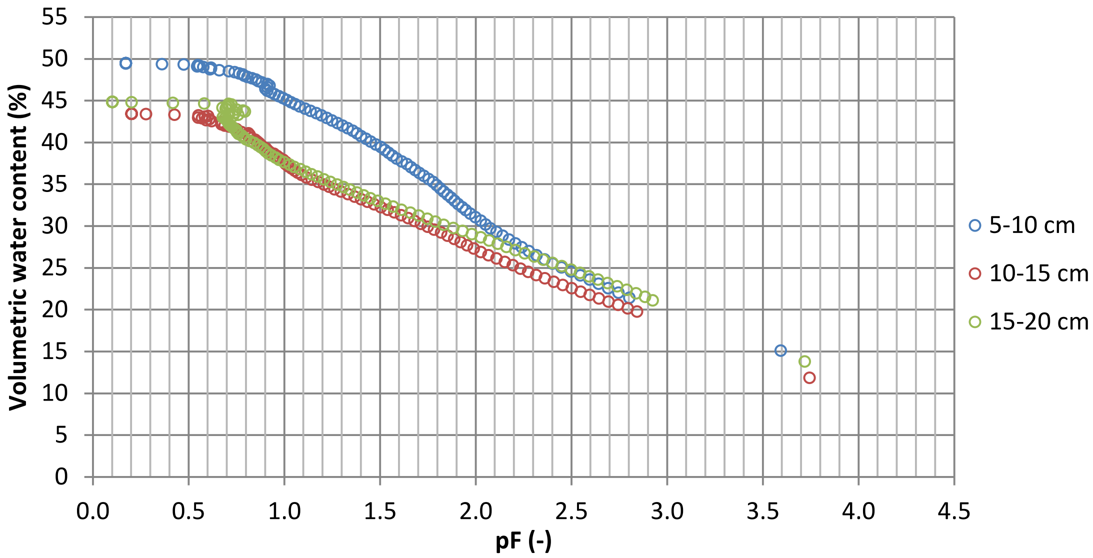

Figure 4-37. Retention curves of Rosalian Mountains soil profile 1, layer 1 at depth 5-20 cm.

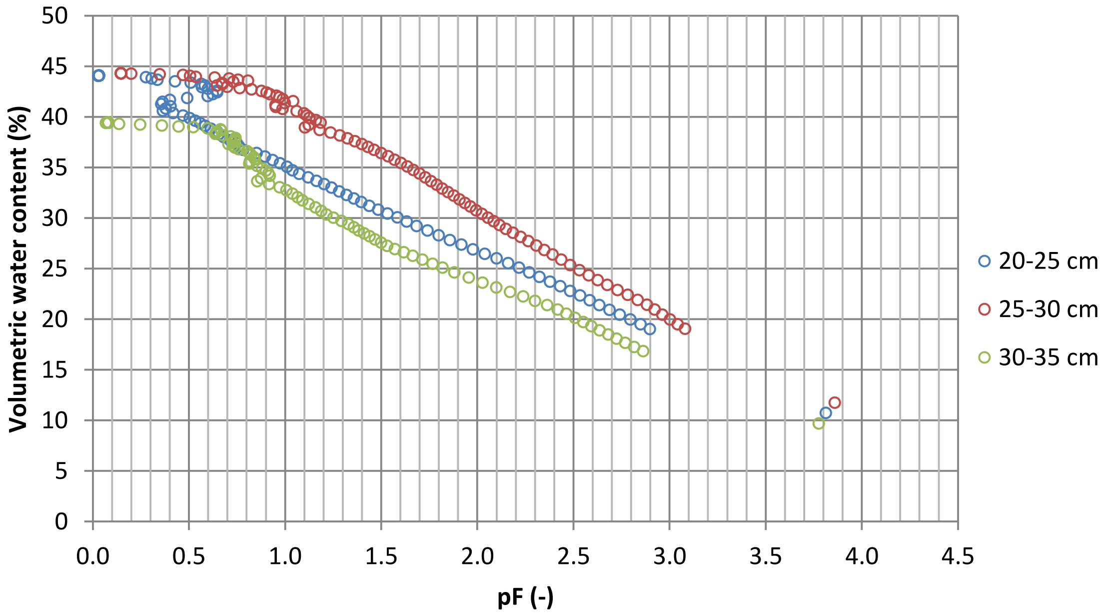

Figure 4-38. Retention curves of Rosalian Mountains soil profile 1, layer 2 at depth 20-35 cm.

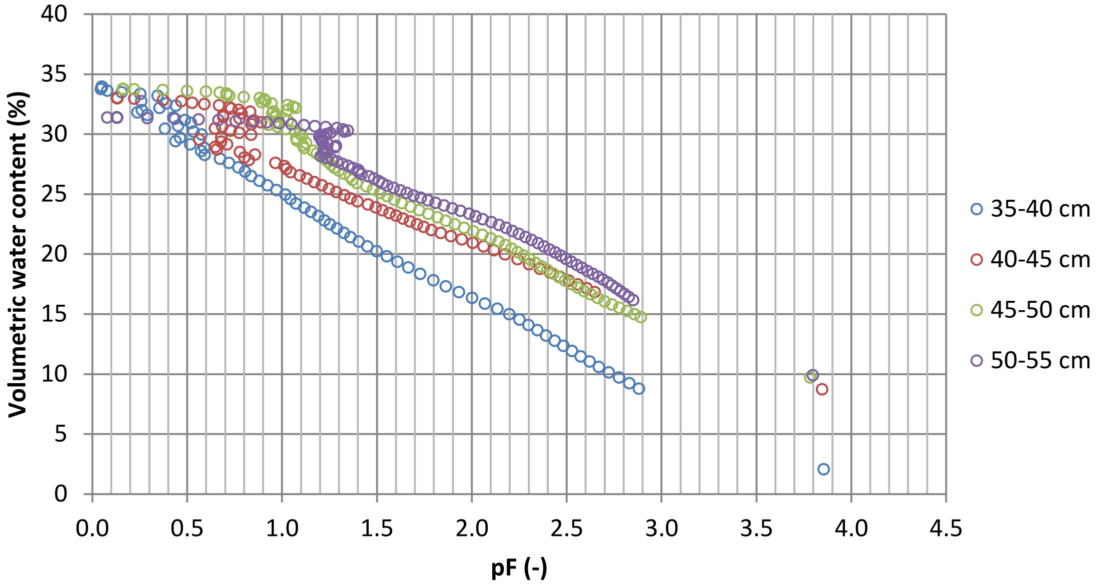

Figure 4-39. Retention curves of Rosalian Mountains soil profile 1, layer 3 at depth 35-55 cm.

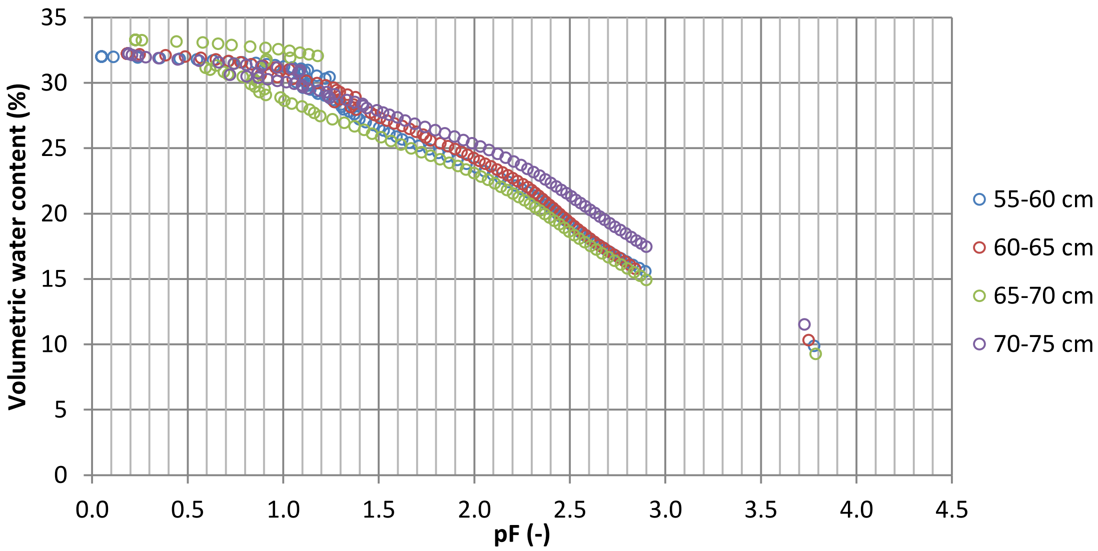

Figure 4-40. Retention curves of Rosalian Mountains soil profile 1, layer 4 at depth 55-75 cm.

Hydraulic conductivity curve of each sample in a layer 1, 2, 3 and 4 is shown in Figure 4-41, Figure 4-42, Figure 4-43 and Figure 4-44, respectively. Similar to retention curves the hydraulic conductivities vary more or less between each other, e.g. very similar are curves for 60 and 65 cm in Figure 4-44; or very dissimilar as 10 and 15 cm in Figure 4-41.

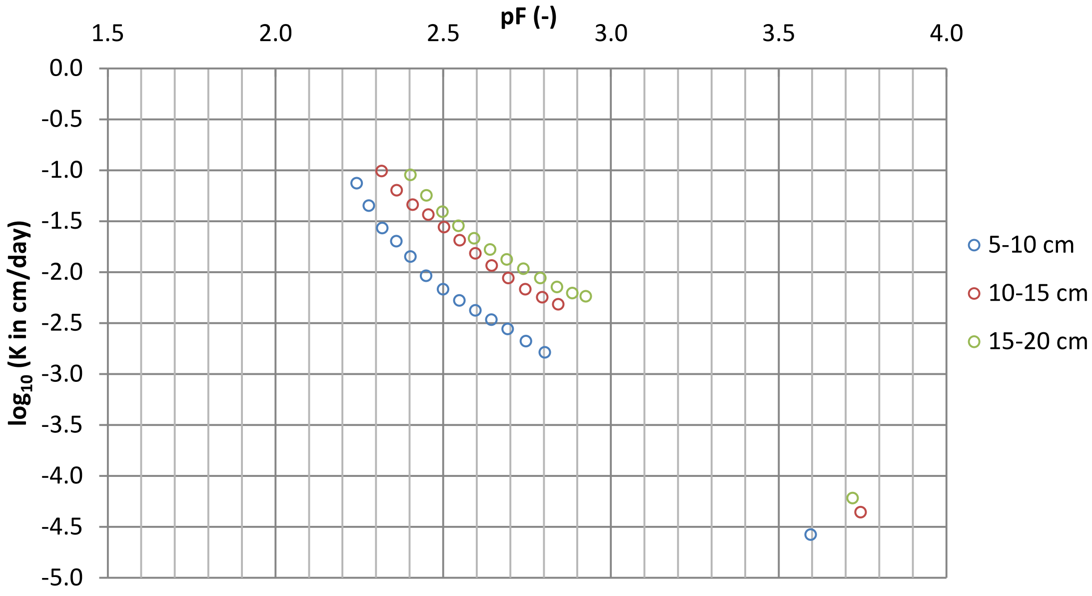

Figure 4-41. Hydraulic conductivity curves of Rosalian Mountains soil profile 1, layer 1 at depth 5-20 cm.

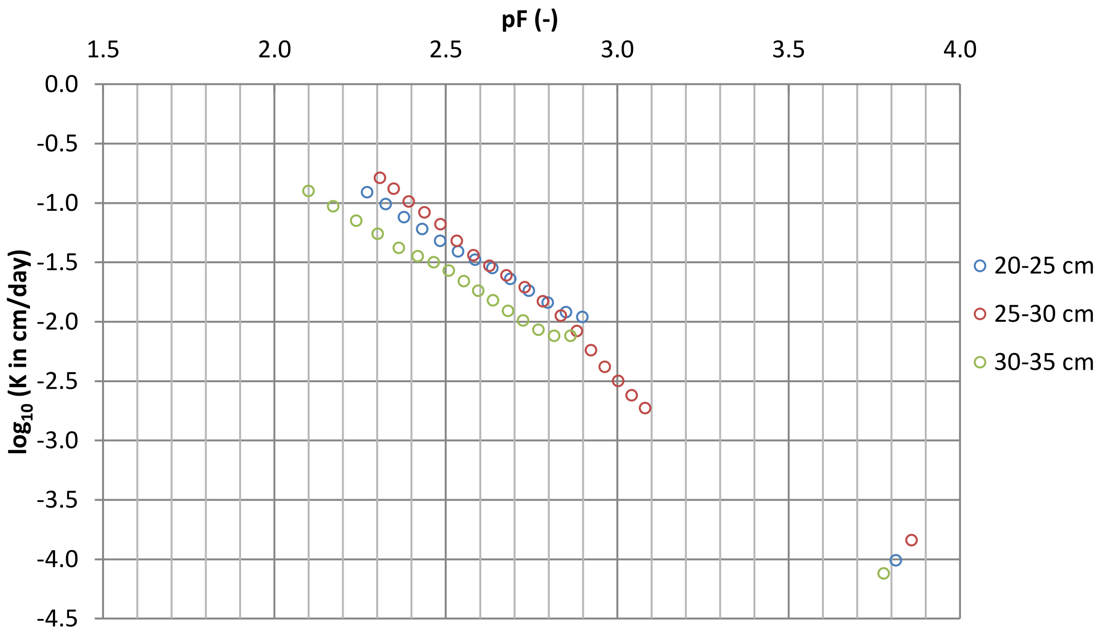

Figure 4-42. Hydraulic conductivity curves of Rosalian Mountains soil profile 1, layer 2 at depth 20-35 cm.

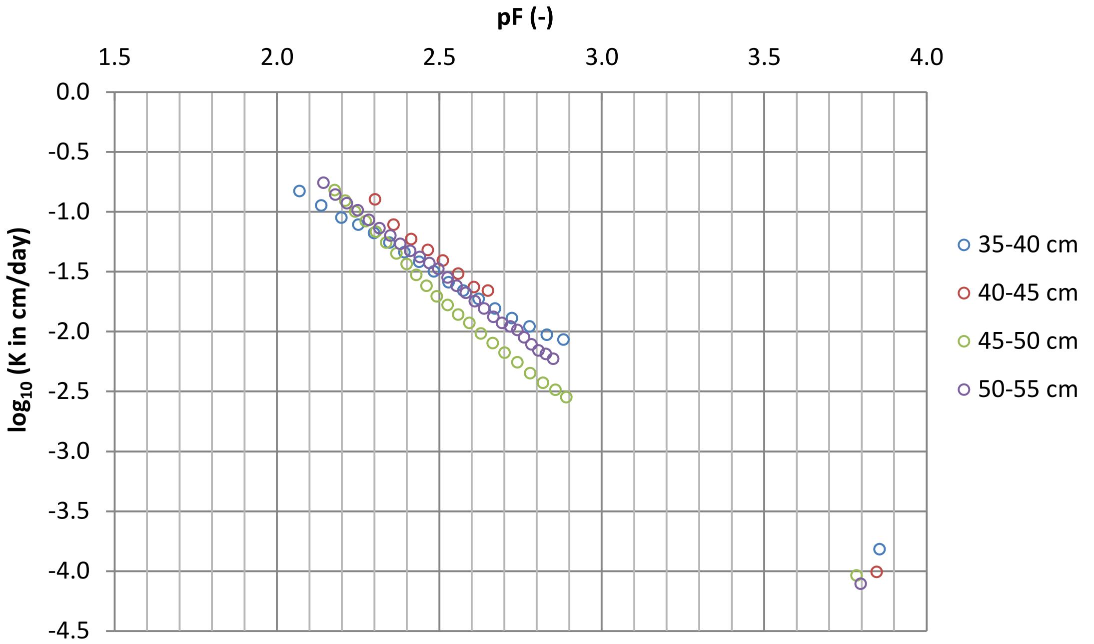

Figure 4-43. Hydraulic conductivity curves of Rosalian Mountains soil profile 1, layer 3 at depth 35-55 cm.

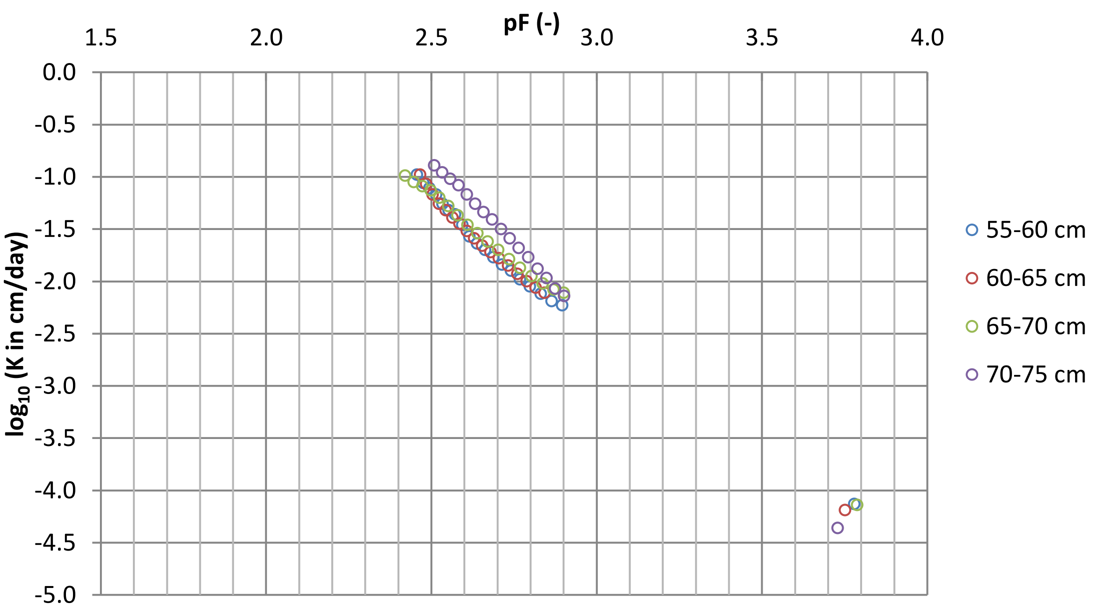

Figure 4-44. Hydraulic conductivity curves of Rosalian Mountains soil profile 1, layer 3 at depth 55-75 cm.

4.2.2 Root mean square error and Akaike information criterion

Root mean square error and Akaike information criterion from the water retention and hydraulic conductivity fitting curves for every sample, Pedological Layers and Common Characteristics approach are shown in Table 4-4, Table 4-5 and Table 4-6.

Table 4-4. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Single Layers of Rosalian Mountains soil profile 1.

Depth (cm)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40
Name	Value							
RMSE_Theta	0.0027	0.0029	0.0043	0.0083	0.0100	0.0035	0.0045	0.0055
RMSE_logK	0.0291	0.0669	0.0496	0.0858	0.0403	0.0557	0.0627	0.0543
AICc	-1849	-1782	-1689	-1617	-1578	-1861	-1784	-1724
Depth (cm)	40-45	45-50	50-55	55-60	60-65	65-70	70-75	
Name	Value							
RMSE_Theta	0.0082	0.0044	0.0059	0.0033	0.0020	0.0099	0.0028	
RMSE_logK	0.0514	0.0161	0.0118	0.0473	0.0332	0.0356	0.0111	
AICc	-1537	-1930	-1944	-1886	-1974	-1636	-1848	

Table 4-5. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Pedological Layers of Rosalian Mountains soil profile 1.

Depth (cm)	5-20	20-35	35-55	55-75
Name	Value			
RMSE_Theta	0.0277	0.0173	0.0128	0.0077
RMSE_logK	0.3323	0.1450	0.1310	0.0836
AICc	-4090	-2936	-4951	-5256

Table 4-6. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Common Characteristics approach of Rosalian Mountains soil profile 1.

Depth (cm)	15-20	45-50	55-75
Name	Value		
RMSE_Theta	0.0100	0.0119	0.0079
RMSE_logK	0.1151	0.1279	0.0864
AICc	-2943	-3181	-5216

4.2.3 Saturated hydraulic conductivity

First of all it is important to point out that this is not a measured value. It is the estimated value by HYPROP – DES as one of parameters in a conductivity function based on measured data points. In the software it is termed Ks although here used term is K_{sat}.

Figure 4-45 shows differences between all approaches in saturated hydraulic conductivity within a soil profile. In all approaches from 0 to 5 cm of depth is the same

K_{sat}. At 5-30 cm K_{sat} of SL approach is higher than PL's. From 30 cm to 55 cm saturated hydraulic conductivity of PL is mostly higher than SL. Moreover, Single Layers approach's K_{sat} is changing from low to high and in 55-75 cm it is increasing and exceeding K_{sat} of Pedological Layers approach.

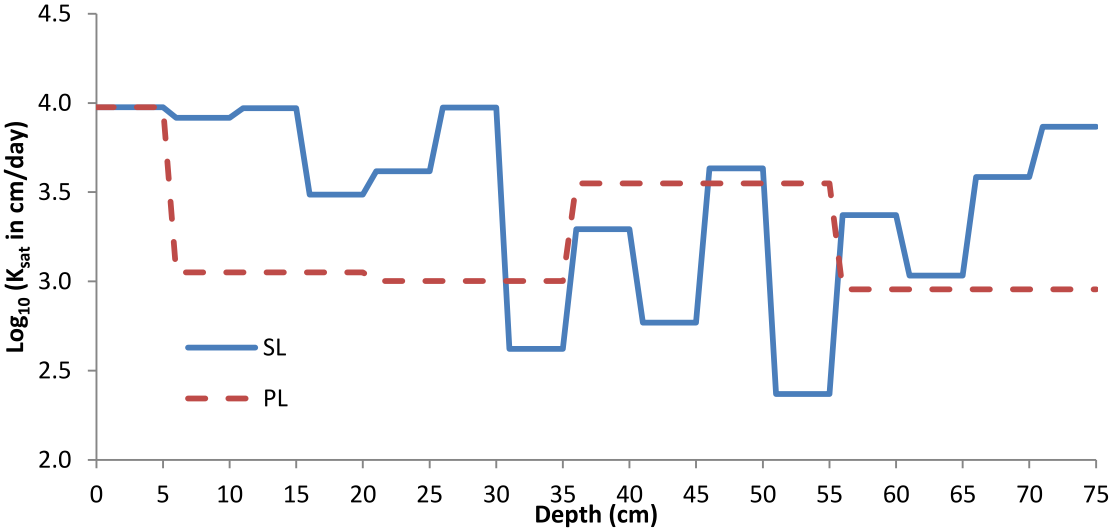

Figure 4-45. Comparison of saturated hydraulic conductivity ($log_{10}(K_{sat})$) within soil profile from Rosalian Mountains (soil profile 1); SL – Single Layers approach; PL – Pedological Layers approach.

Table 4-7 shows all saturated hydraulic conductivity (K_{sat}) corresponding to its depth and approach. Saturated hydraulic conductivity of some individuals is exceeding 9000 cm/day. Generally, K_{sat} is greater than in Gross Enzersdorf in every approach making it highly permeable up to impervious bedrock layer.

Table 4-7. Saturated hydraulic conductivity (Ksat) of depth for the approaches from Rosalian Mountains' soil profile 1.

Single Layer		Pedological Layers	
Depth (cm)	K_{sat} (cm/day)	Depth (cm)	K_{sat} (cm/day)
0-5	9444.733	0-5	9444.733
5-10	8271.863	5-20	1124.835
10-15	9354.19	20-35	1004.578
15-20	3063.629	35-55	3535.819
20-25	4140.762	55-75	902.546
25-30	9410.102		
30-35	419.432		
35-40	1959.483		
40-45	588.389		
45-50	4304.203		
50-55	234.458		
55-60	2356.775		
60-65	1080.553		
65-70	3840.452		
70-75	7363.516		

4.2.4 Physical and chemical properties

This soil profile is characterized by very small amount of organic carbon reaching maximum 5.1% at the horizon 0 and decreasing to insignificant amount as shown in Figure 4-46.

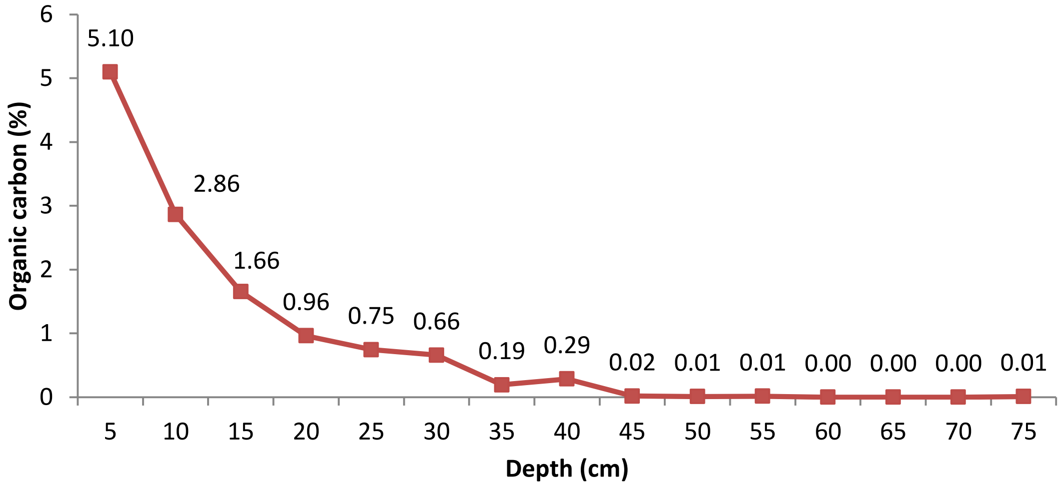

Figure 4-46. Organic carbon content within a Rosalian Mountains' soil profile 1.

There was found small positive relationship between K_{sat} and organic carbon indicated by 26.62% of correlation, and insignificant relationship of K_{sat} – clay content with 6.12% of correlation (Figure 4-47). Although, correlation between K_{sat} and organic carbon content is relatively high the relationship between those two variables is not linear. It is due to different saturated hydraulic conductivity in depth where organic carbon content remains approximately the same.

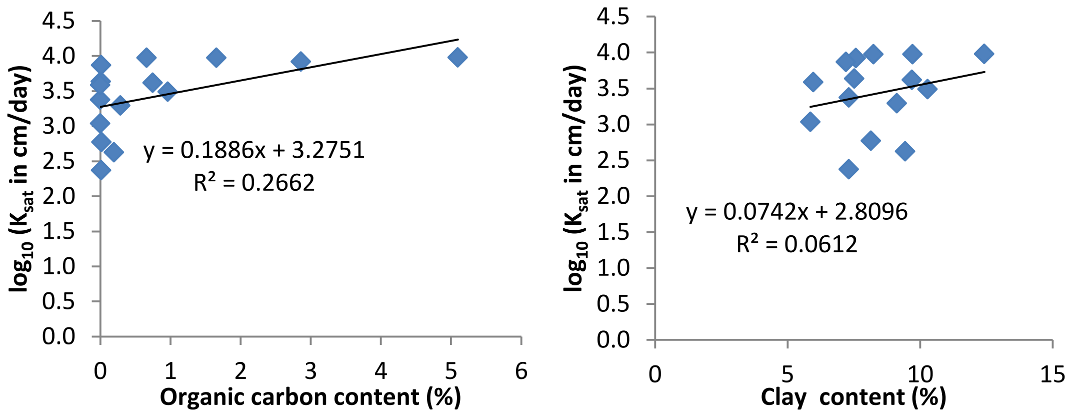

Figure 4-47. Relationship between saturated hydraulic conductivity ($\log_{10}K_{sat}$) and organic carbon (left) and relationship between saturated hydraulic conductivity ($\log_{10}K_{sat}$) and clay content (right) – Rosalian Mountains soil profile 1.

Figure 4-48 shows a correlation between organic carbon and saturated volumetric water content (Θs) with 81.69% fitting as well as between clay content and

Θ_s with 60.94% fitting. High linear relationship shows importance of organic carbon and clay particles on water retention.

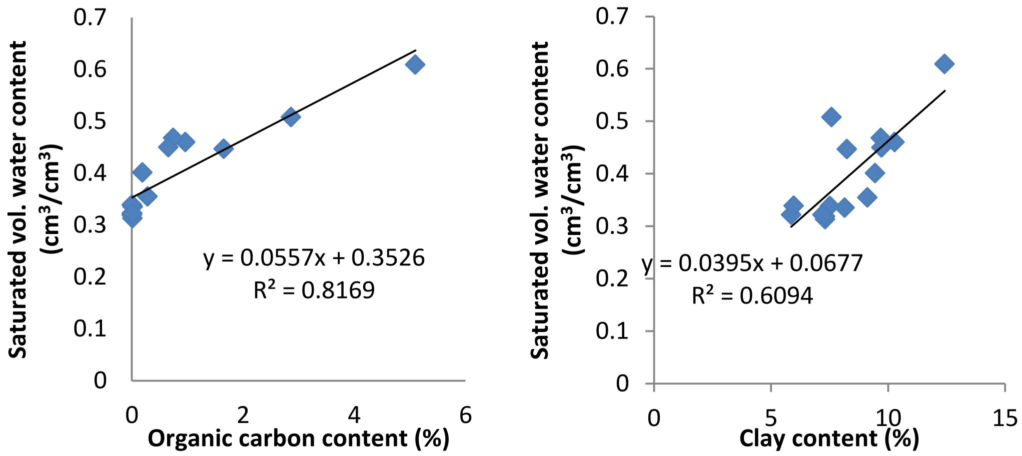

Figure 4-48. Relationship between saturated volumetric water content and organic carbon content (left); saturated volumetric water content and clay content (right) - Rosalian Mountains soil profile 1.

The same as the correlation of K_{sat} and bulk density from the Gross Enzersdorf's soil profile the relationship between those two variables is negative. Although, the coefficient of determination (R^2) is higher. It shows 25.11% fitting to linear regression.

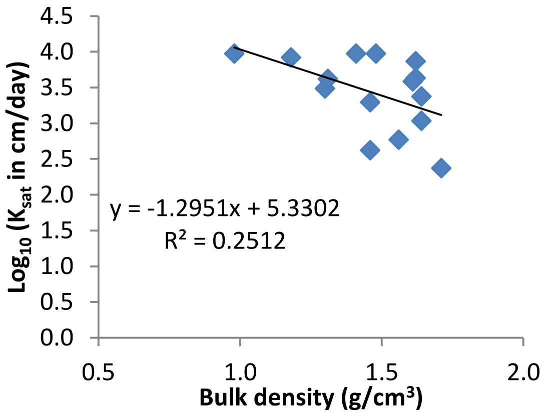

Figure 4-49. Saturated hydraulic conductivity ($\log_{10}(K_{sat})$) of bulk density - Rosalian Mountains soil profile 1.

4.2.5 Soil water simulation output

Water flow through the soil profile was simulated in each approach. Water content was registered for every observation point. Those points were at depth 13, 22, 33, 47 and 63 cm and further they are termed: OP13, OP22, OP33, OP47 and OP63, respectively. Those points were chosen regarding a variation of the saturated hydraulic conductivity between the approaches as in Figure 4-45 and Table 4-7. Because of impermeable layer set as a lower boundary condition the results from the bottom flux are not included.

Figure 4-50, Figure 4-51 and Figure 4-52 represent water content captured in 13 cm below the surface. Saturated hydraulic conductivity of SL approach is 9354 cm/day where K_{sat} of PL approach is 1125 cm/day. As can be seen on the figures, both approaches show high susceptibility to precipitation rate. Moreover, in PL approach, soil holds more water during the simulation time than soil in SL approach, regardless the precipitation rate, as it is shown in Figure 4-53.

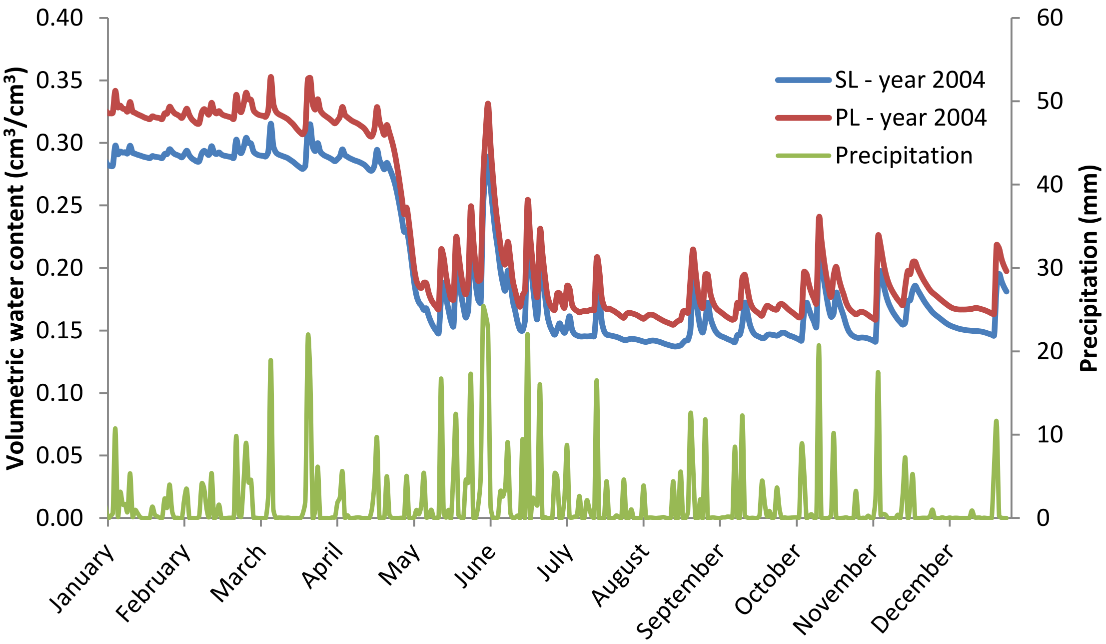

Figure 4-50. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2004 – Rosalian Mountains (soil profile 1).

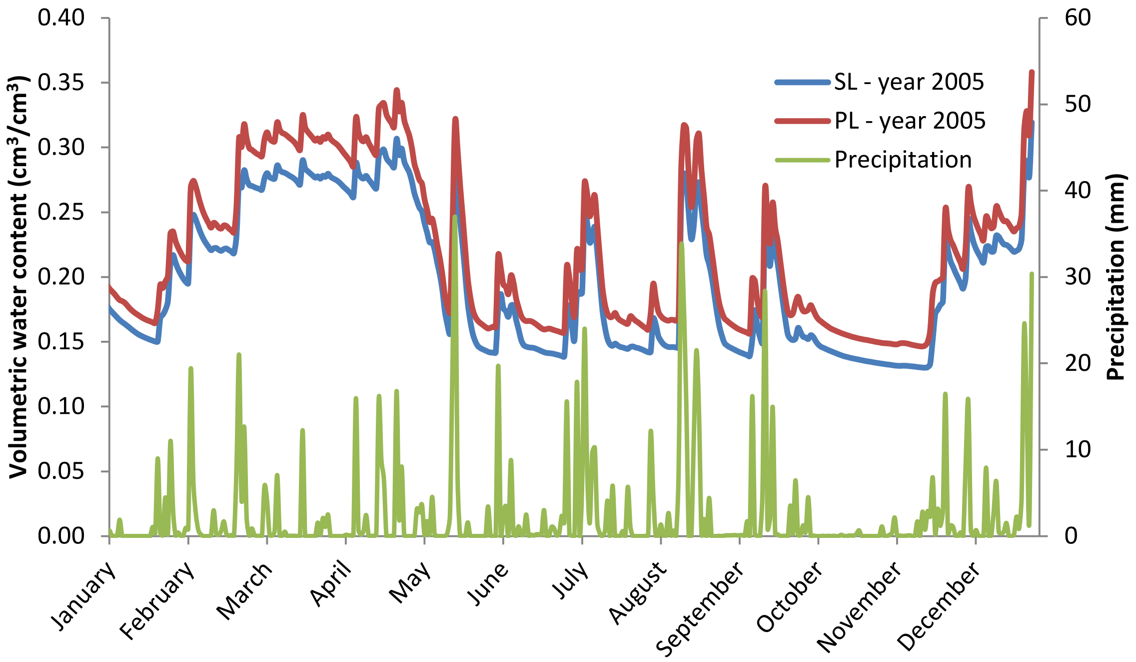

Figure 4-51. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2005 – Rosalian Mountains (soil profile 1).

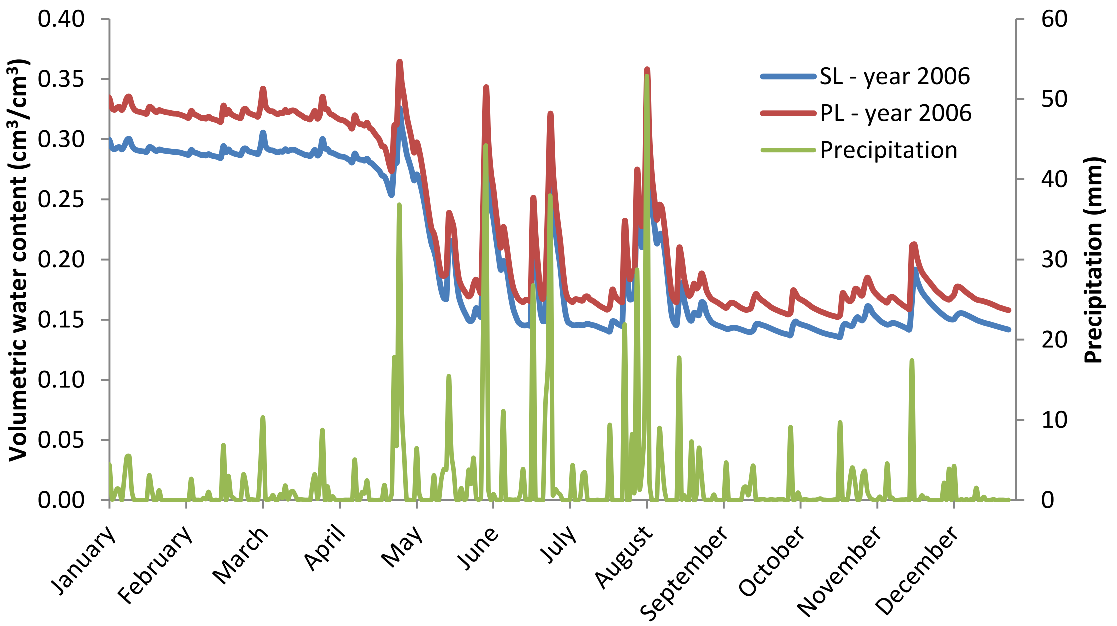

Figure 4-52. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2006 – Rosalian Mountains (soil profile 1).

Figure 4-53 shows differences in water content over 3 years. Maximum difference is 0.0471 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0232 cm^3/cm^3.

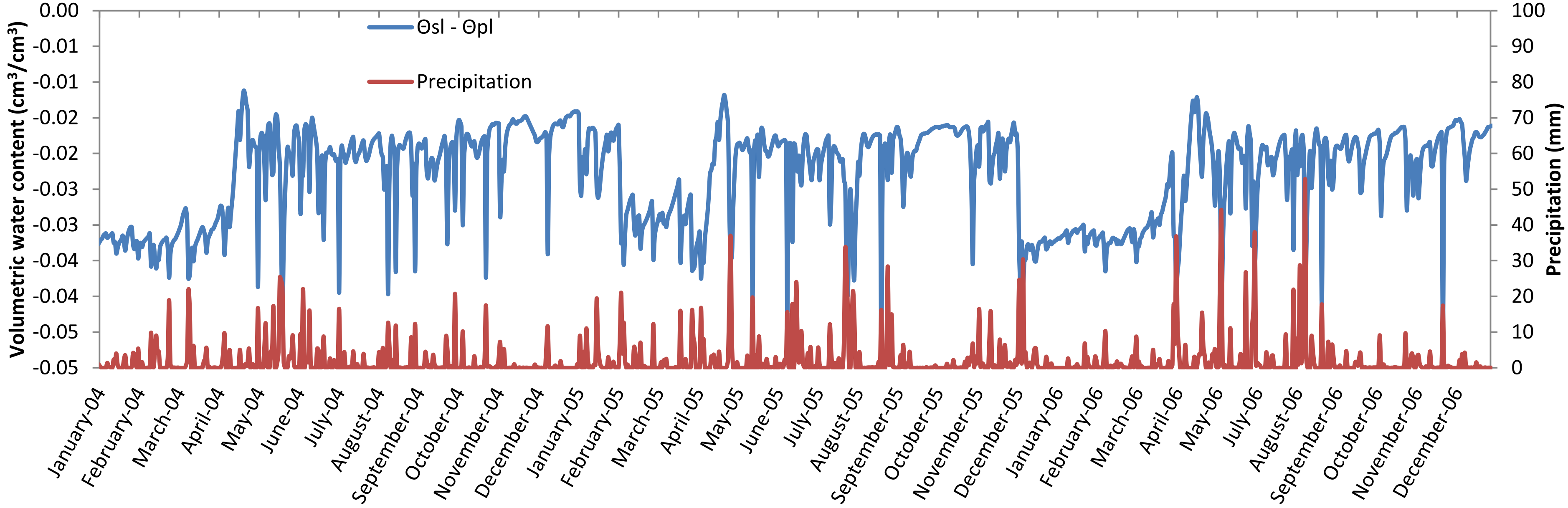

Figure 4-53. Differences in water content between the approaches during 3 years for OP13 (Rosalian Mountains – soil profile 1), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-54, Figure 4-55 and Figure 4-56 show water content at OP22. Single Layer approach is characterized by K_{sat} value equal to 4141 cm/day and Pedological Layers by K_{sat} = 1005 cm/day. The most noticeable difference in water content between both approaches is during periods of long and high saturation which occur mostly at the beginning of each year.

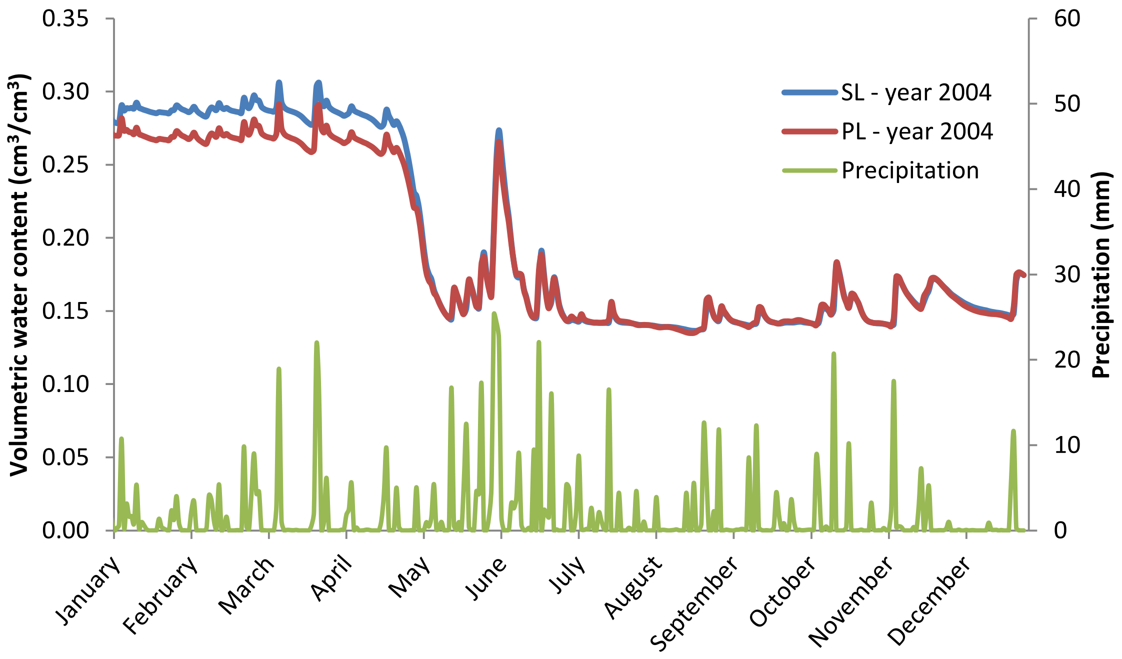

Figure 4-54. Water content data obtained from the water flow simulation at 22 cm depth (OP22) for climatic data from year 2004 – Rosalian Mountains (soil profile 1).

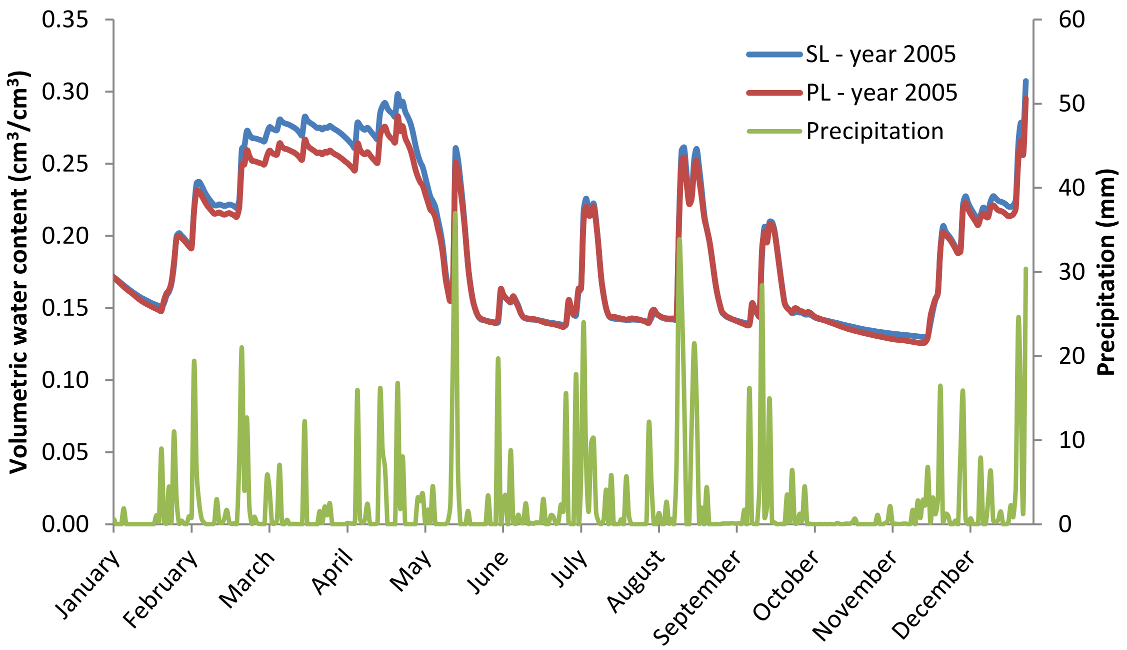

Figure 4-55. Water content data obtained from the water flow simulation at 22 cm depth (OP22) for climatic data from year 2005 – Rosalian Mountains (soil profile 1).

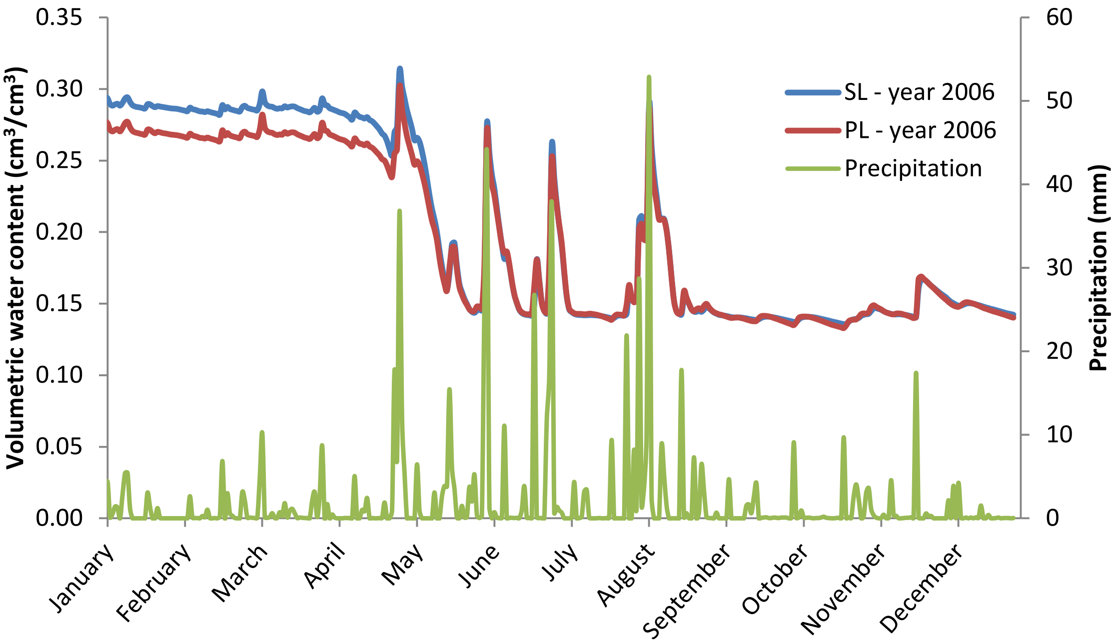

Figure 4-56. Water content data obtained from the water flow simulation at 22 cm depth (OP22) for climatic data from year 2006 – Rosalian Mountains (soil profile 1).

Figure 4-57 shows differences in water content over 3 years. Maximum difference is 0.0189 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0066 cm^3/cm^3.

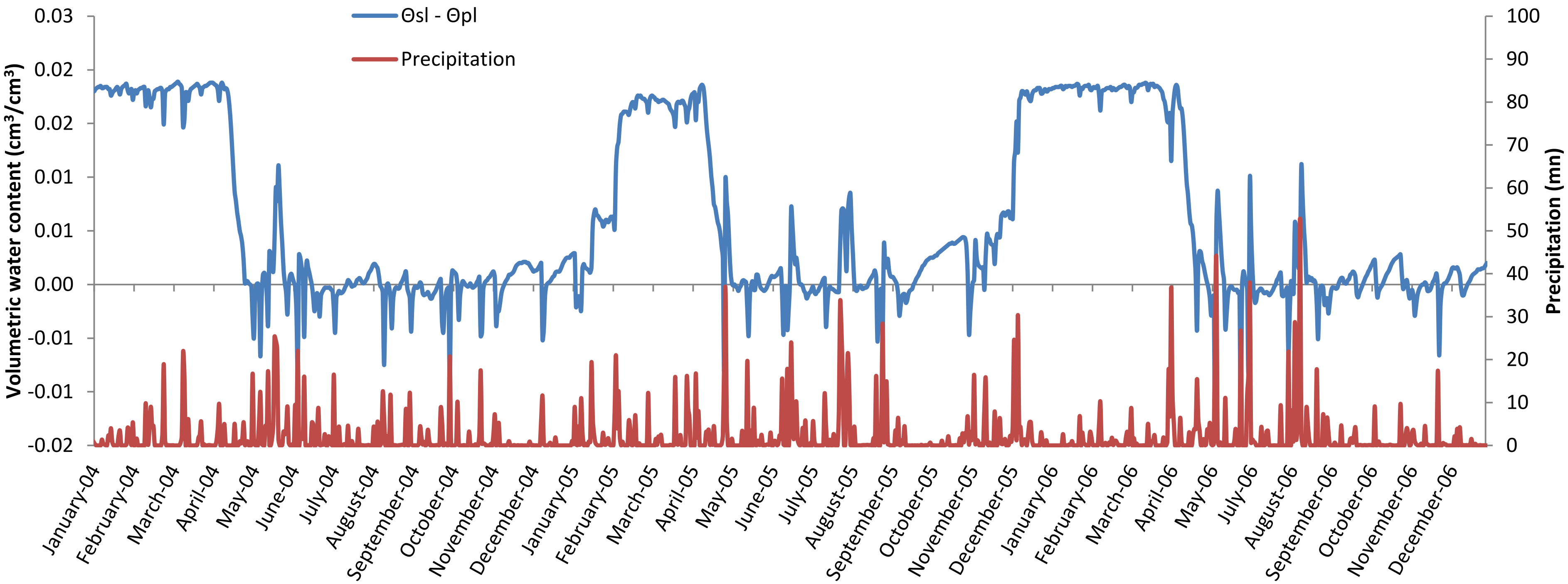

Figure 4-57. Differences in water content between the approaches during 3 years for OP22 (Rosalian Mountains – soil profile 1), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-58, Figure 4-59 and Figure 4-60 show water content at OP33. Single Layer approach is characterized by K_{sat} value equal to 419 cm/day and Pedological Layers by K_{sat} = 1005 cm/day. Clearly at this observation point more water is hold in PL approach.

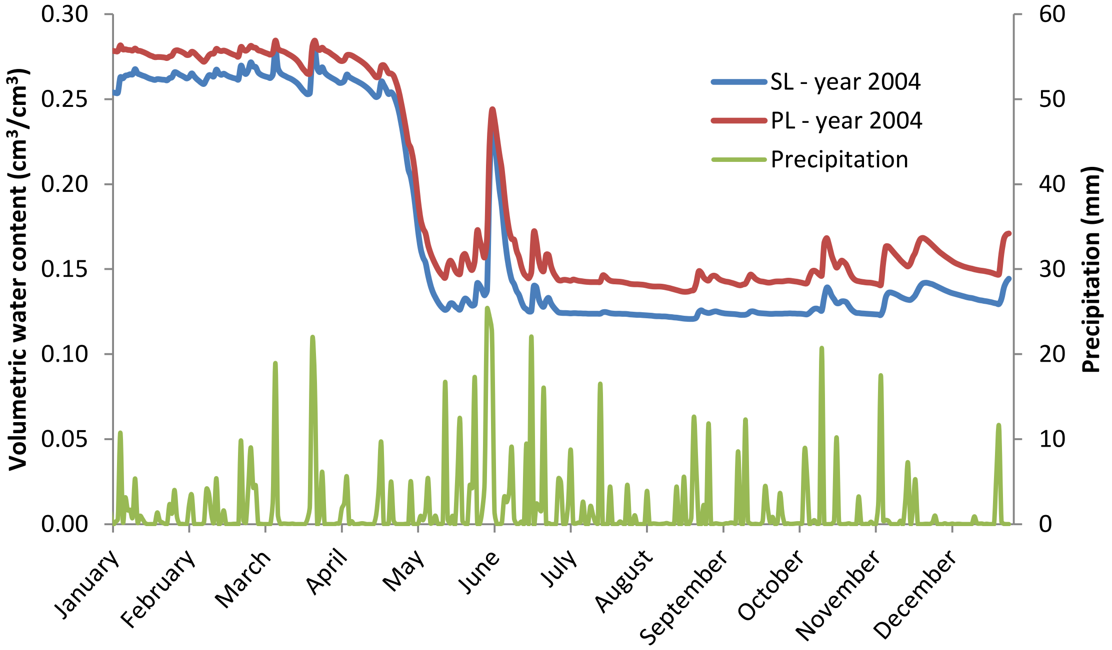

Figure 4-58. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2004 – Rosalian Mountains (soil profile 1).

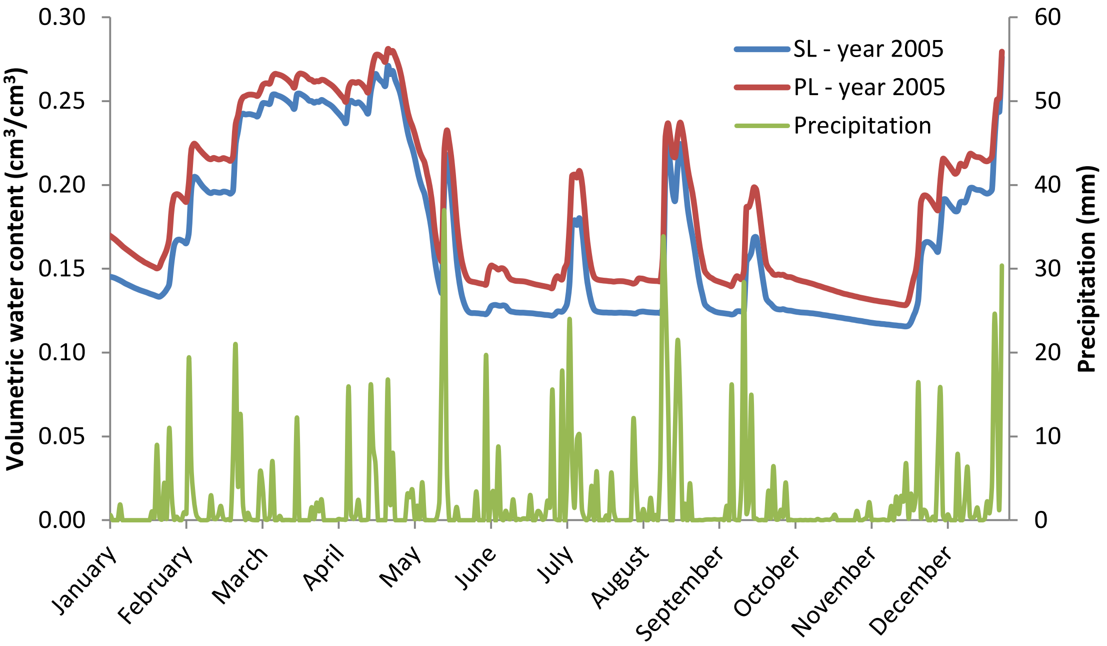

Figure 4-59. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2005 – Rosalian Mountains (soil profile 1).

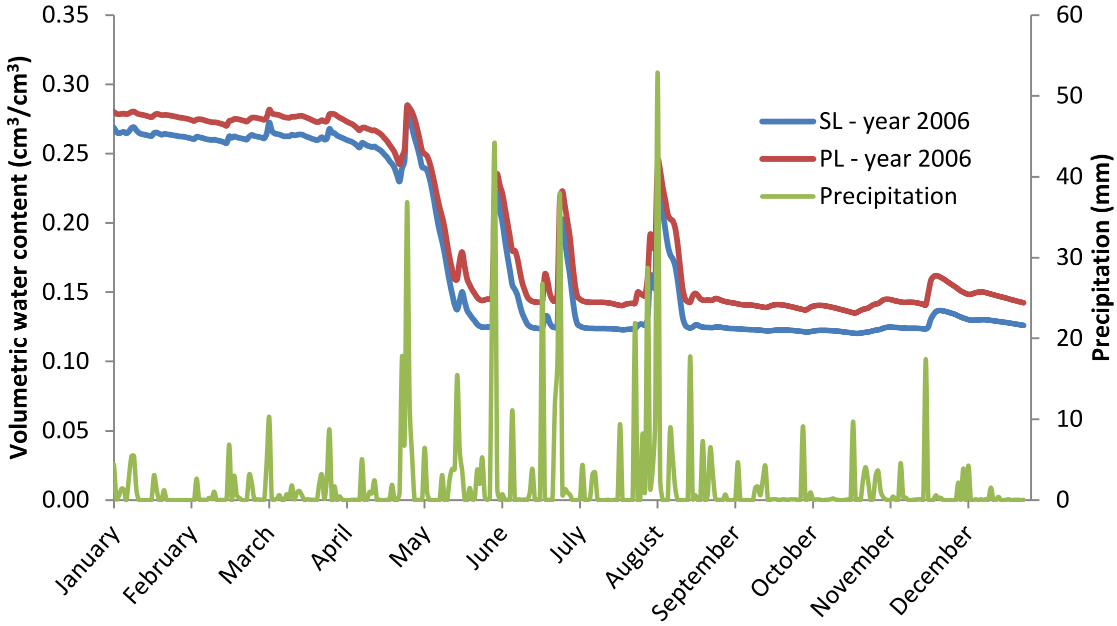

Figure 4-60. Water content data obtained from the water flow simulation at 33 cm depth (OP33) for climatic data from year 2006 – Rosalian Mountains (soil profile 1).

Figure 4-61 shows differences in water content over 3 years. Maximum difference is 0.0336 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0178 cm^3/cm^3.

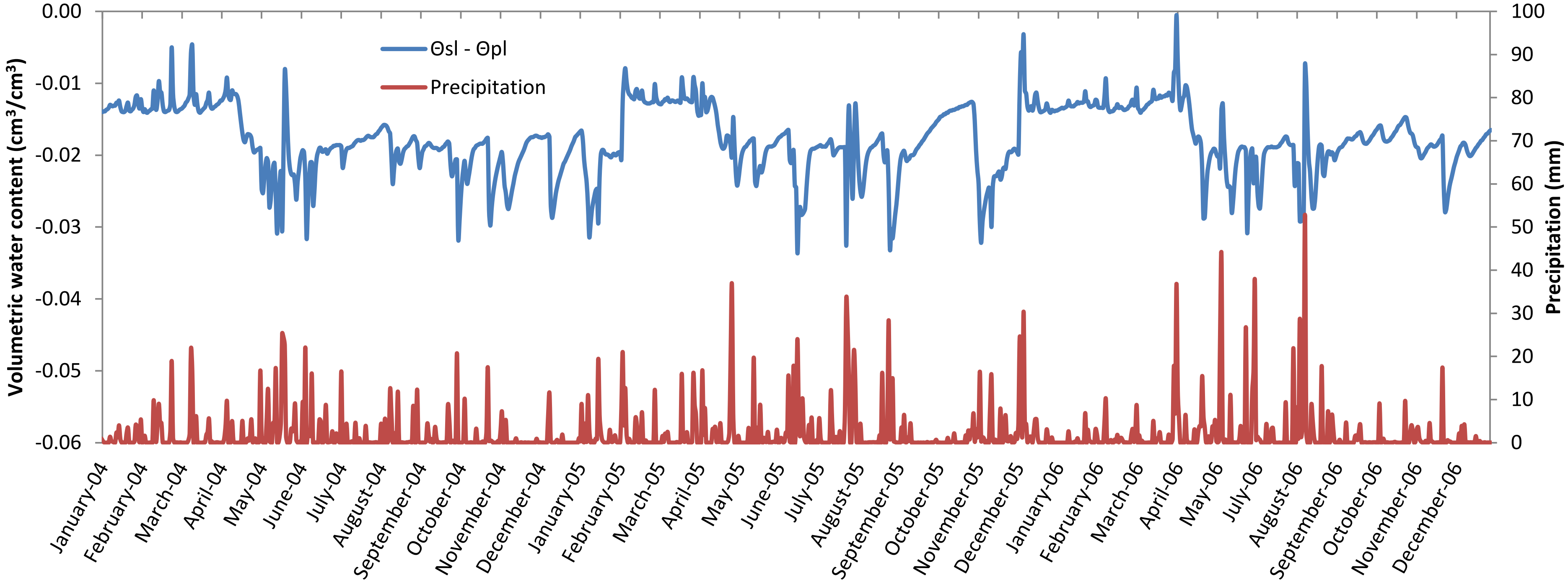

Figure 4-61. Differences in water content between the approaches during 3 years for OP33 (Rosalian Mountains – soil profile 1), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-62, Figure 4-63 and Figure 4-64 show water content at OP47. Single Layer approach is characterized by K_{sat} value equal to 4304 cm/day and Pedological Layers by K_{sat} = 3536 cm/day. At this depth the changes in water content caused by precipitation rate are less abrupt than in preceding observation points.

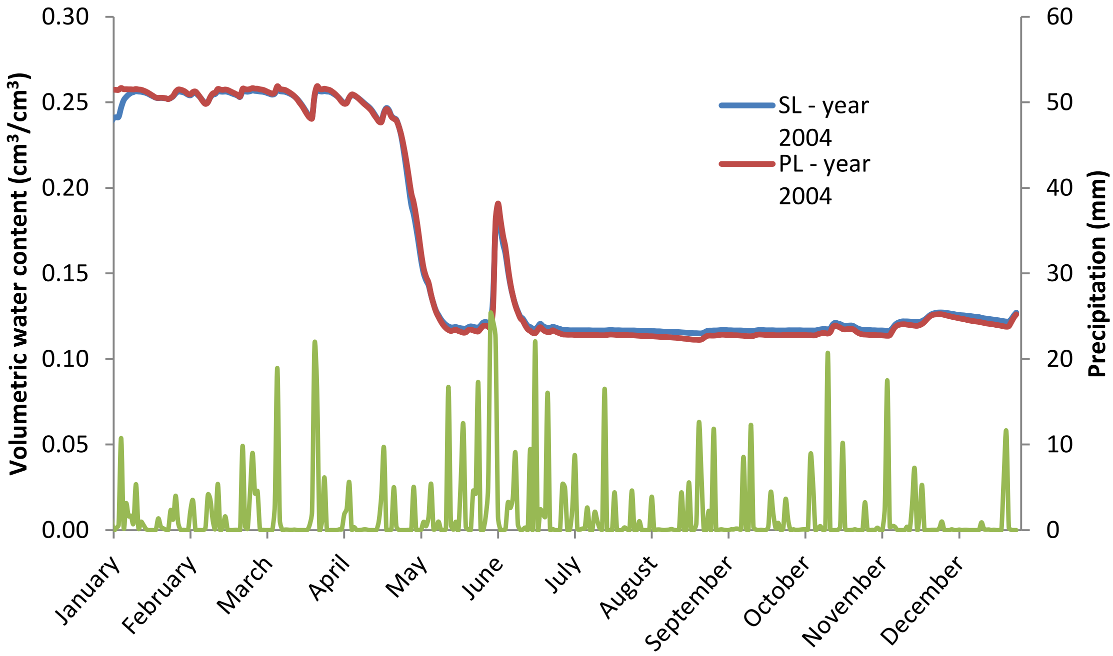

Figure 4-62. Water content data obtained from the water flow simulation at 47 cm depth (OP47) for climatic data from year 2004 – Rosalian Mountains (soil profile 1).

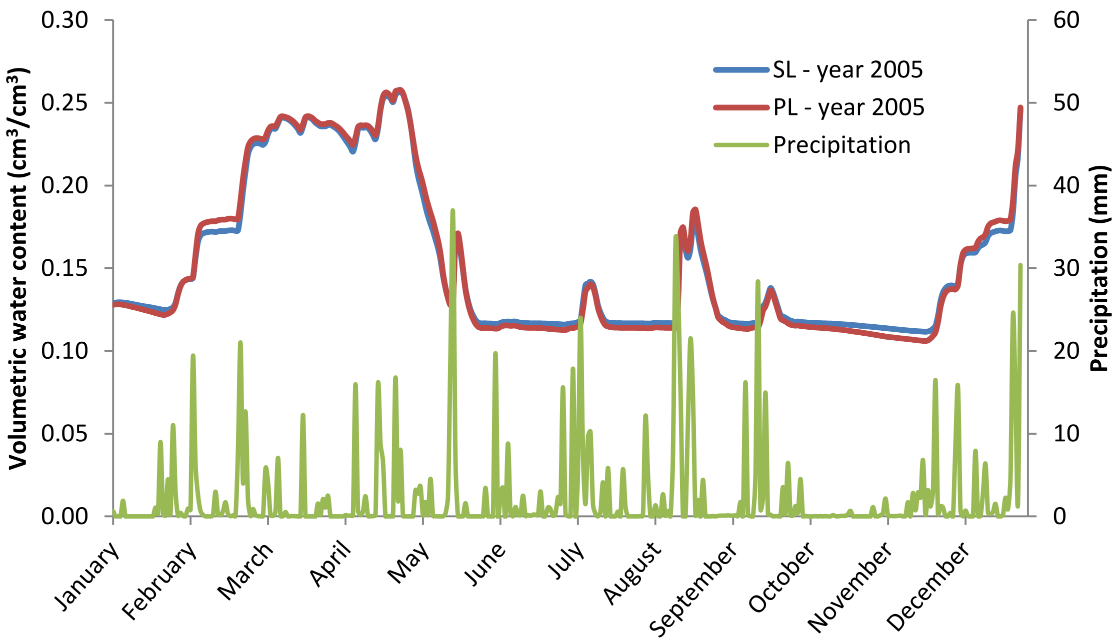

Figure 4-63. Water content data obtained from the water flow simulation at 47 cm depth (OP47) for climatic data from year 2005 – Rosalian Mountains (soil profile 1).

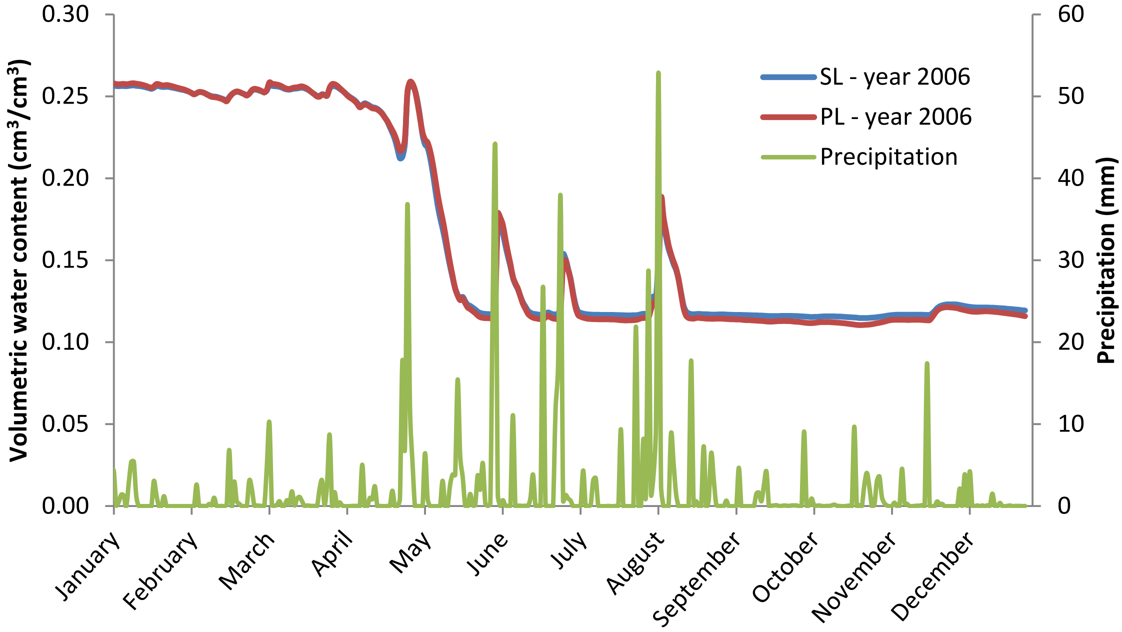

Figure 4-64. Water content data obtained from the water flow simulation at 47 cm depth (OP47) for climatic data from year 2006 – Rosalian Mountains (soil profile 1).

Figure 4-65 shows differences in water content over 3 years. Maximum difference is 0.0190 cm^3/cm^3 which occurs at the beginning of year 2004. Moreover, average difference of absolute value during those 3 years is 0.0025 cm^3/cm^3.

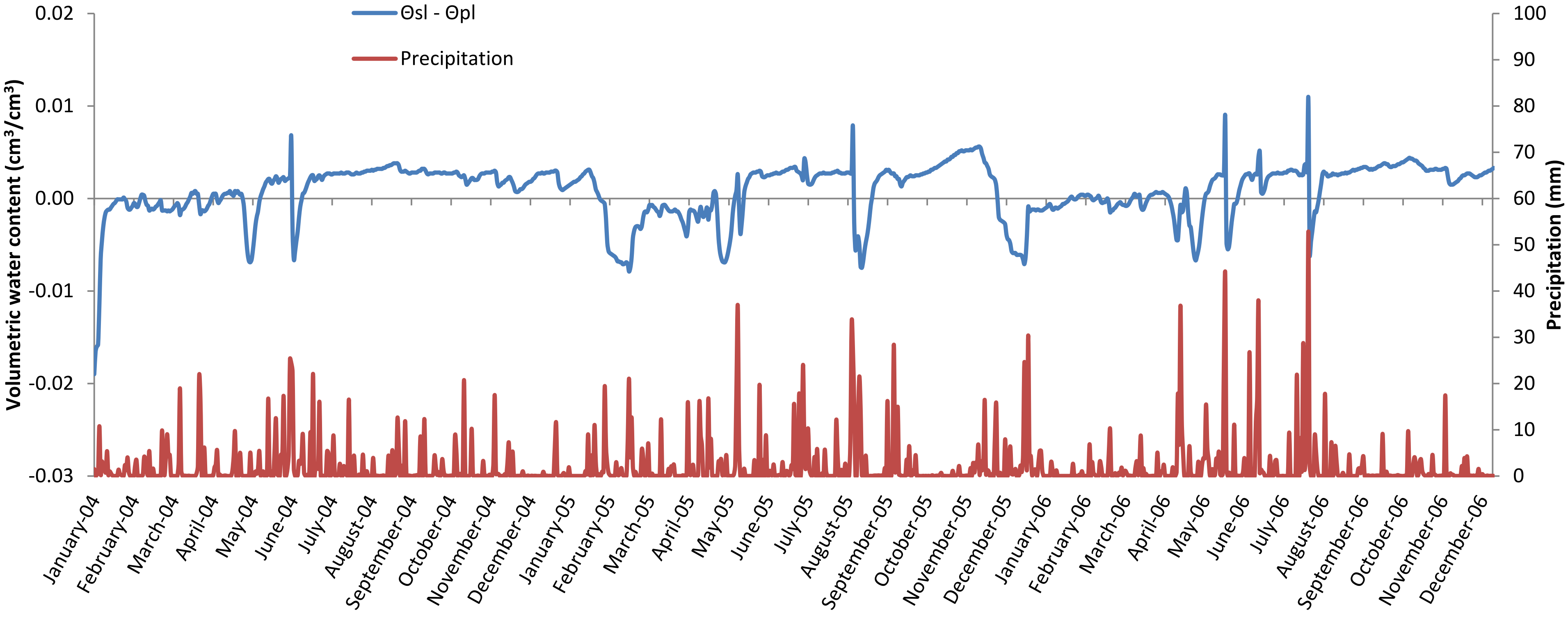

Figure 4-65. Differences in water content between the approaches during 3 years for OP47 (Rosalian Mountains – soil profile 1), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-66, Figure 4-67 and Figure 4-68 show water content at the deepest observation point OP63. Single Layer approach is characterized by K_{sat} value equal to 1081 cm/day and Pedological Layers by K_{sat} = 903 cm/day.

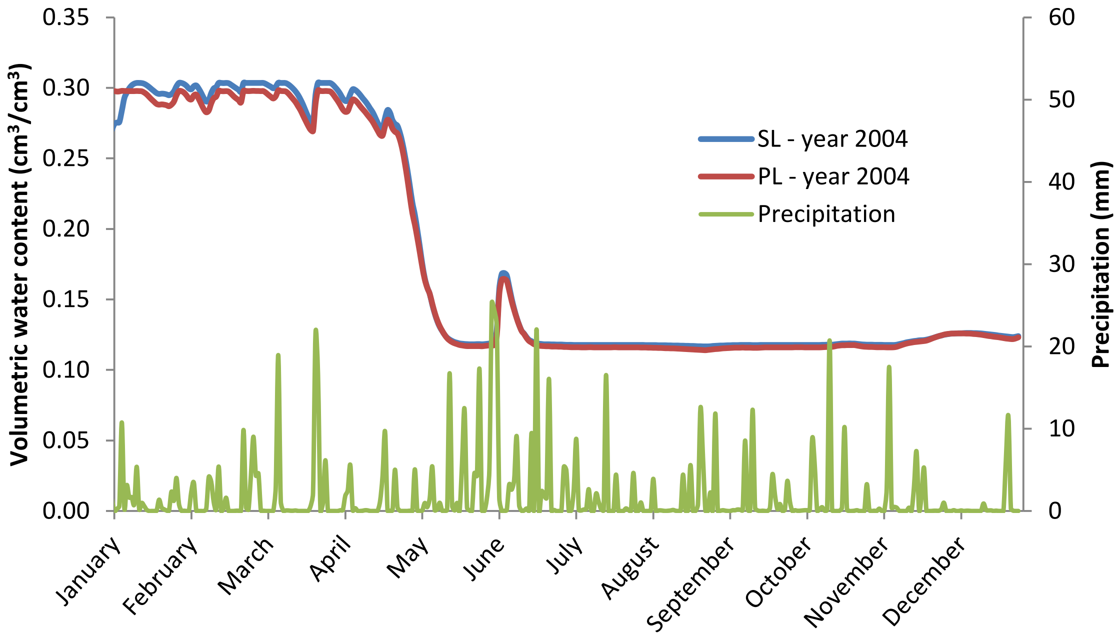

Figure 4-66. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2004 – Rosalian Mountains (soil profile 1).

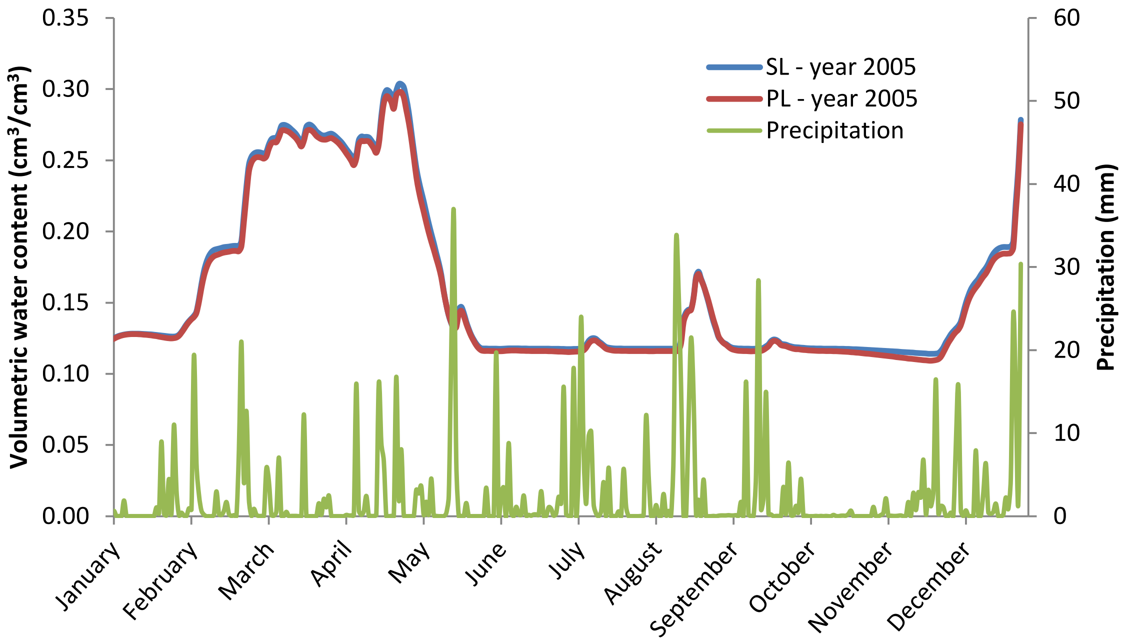

Figure 4-67. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2005 – Rosalian Mountains (soil profile 1).

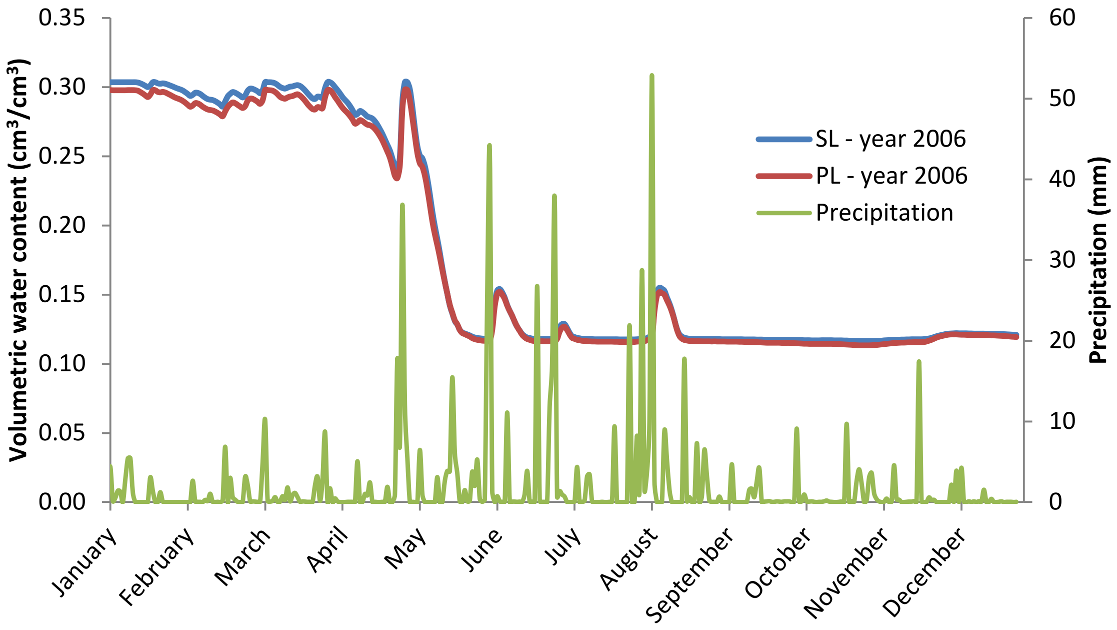

Figure 4-68. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2006 – Rosalian Mountains (soil profile 1).

Figure 4-69 shows differences in water content over 3 years. Maximum difference is 0.0275 cm^3/cm^3 which occurs at the beginning of year 2004. Moreover, average difference of absolute value during those 3 years is 0.0031 cm^3/cm^3.

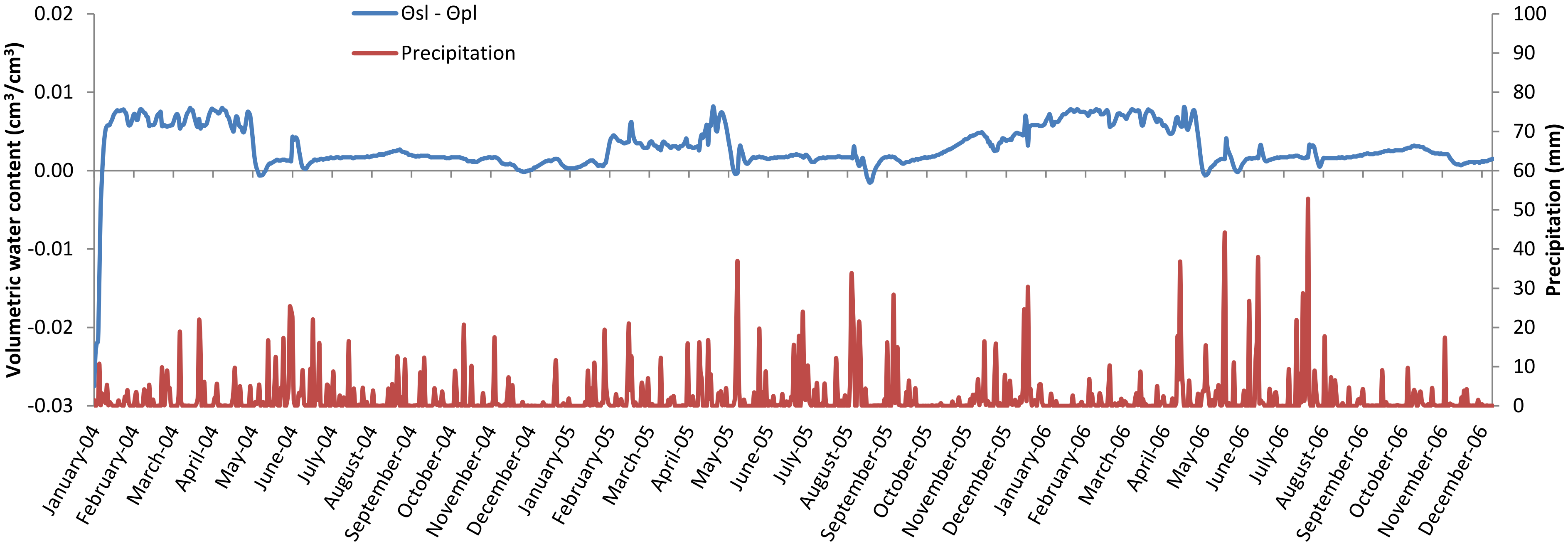

Figure 4-69. Differences in water content between the approaches during 3 years for OP63 (Rosalian Mountains – soil profile 1), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

4.2.6 Summary

Two approaches were compared together based on the analysis of the first soil profile from Forest demonstration center in Rosalian Mountains. Hyprop measurements provided information about water retention and hydraulic conductivity of single samples. Comparison of those data show significant variety of properties within 4 individual soil horizons. Moreover, data analysis established saturated hydraulic conductivity for every single sample and joint samples. It proved the variety of K_{sat} within a soil profile. High values of saturated hydraulic conductivities may be explained by high amount of course-size particles in the samples, reaching even 50% of a sample's mass. Organic carbon content in this soil profile was very low.

There was found no relationship between K_{sat} and organic carbon content or soil particle size distribution.

Soil water simulations showed that generally there is no significant difference between two compared approaches. For 3 years the highest average water content difference was 0.0232 cm^3/cm^3 at observation point OP13; the lowest difference occurred at OP47 and it was equal to 0.0025 cm^3/cm^3.

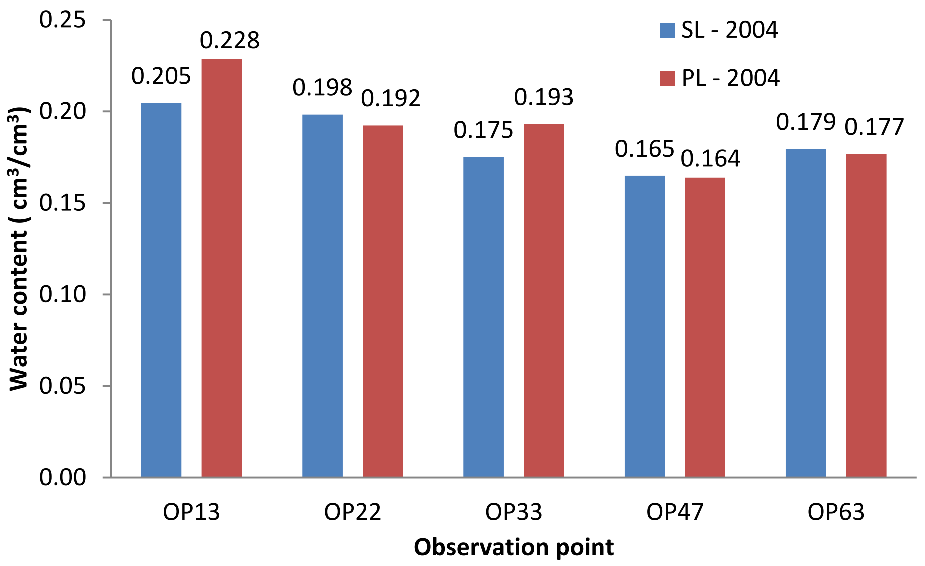

Figure 4-70. Average water content captured for the observation points of soil profile 1 in Rosalian Mountains, y. 2004.

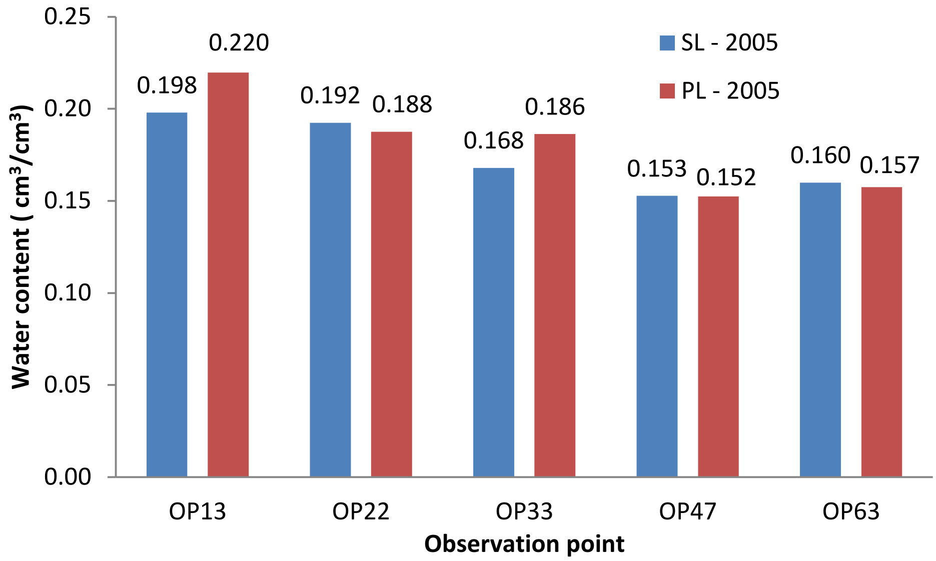

Figure 4-71. Average water content captured for the observation points of soil profile 1 in Rosalian Mountains, y. 2005.

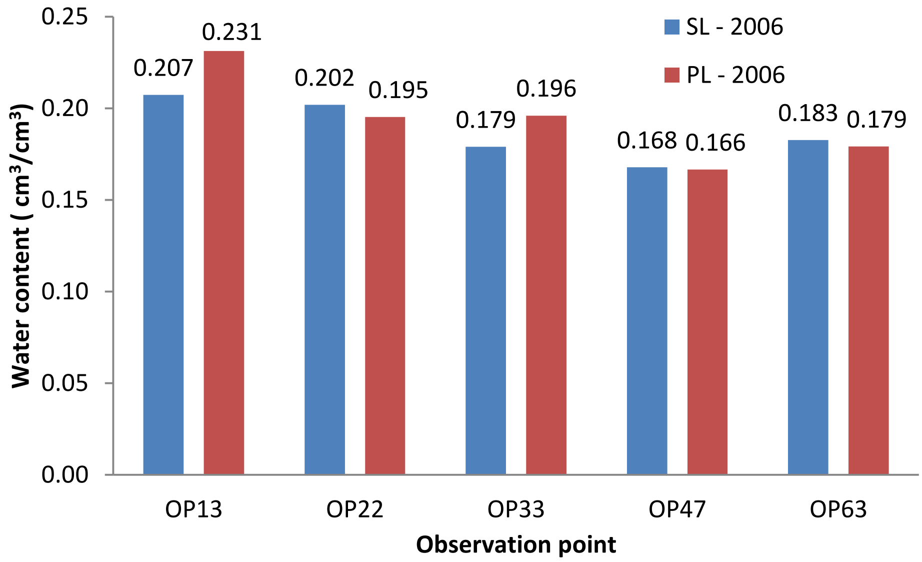

Figure 4-72. Average water content captured for the observation points of soil profile 1 in Rosalian Mountains, y. 2006.

Figure 4-70, Figure 4-71 and Figure 4-72 show the average water content in each observation point and both approaches. In general the deeper the water content is lower except of the last observation point which is caused by impermeable bottom layer. Differences between approaches change. In one observation point more water is hold in SL approach and in the other case in PL approach. High hydraulic conductivity, low amount of clay particles, low organic carbon content and high amount of gravel affected water content in the soil profile. In comparison to Agricultural research farm in Gross Enzersdorf the water content is lower whilst the precipitation rate was higher.

4.3 Forest demonstration center in the Rosalian Mountains - soil profile 2

4.3.1 Retention curves

Soil profile 2 from Rosalian Mountains is divided on 3 pedological layers. As can be seen in Figure 4-73, Figure 4-74 and Figure 4-75 here come into view a significant difference in water retention curves within a layer as it was noticed in to previous soil profiles. At layer 1, sample 5 cm differs from the others. At layer 2 the highest difference can be seen between 1-2 pF. Layer 3 differs the most at the close to saturation point.

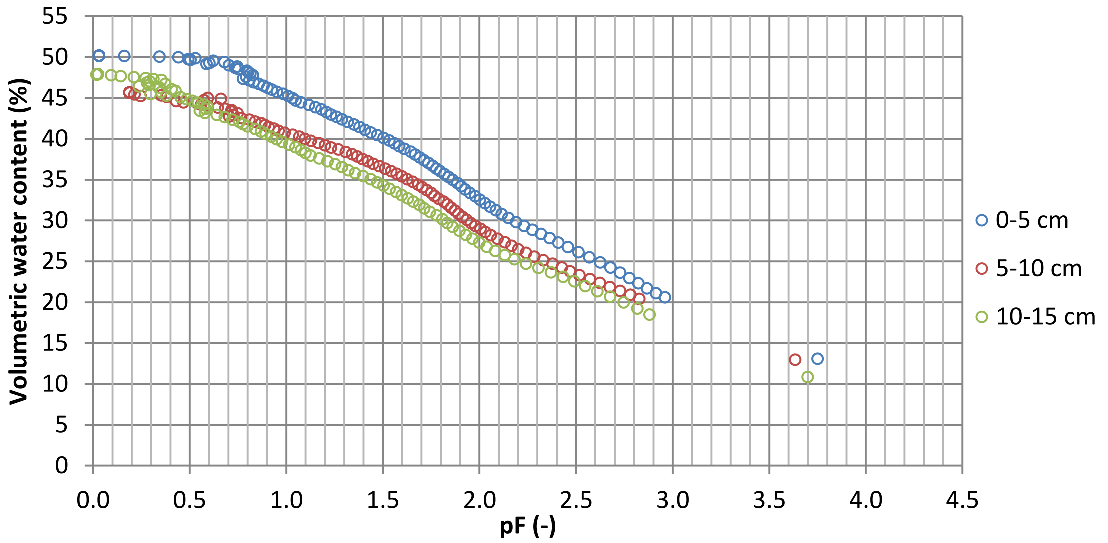

Figure 4-73. Retention curves of Rosalian Mountains soil profile 2, layer 1 at depth between 0-15 cm.

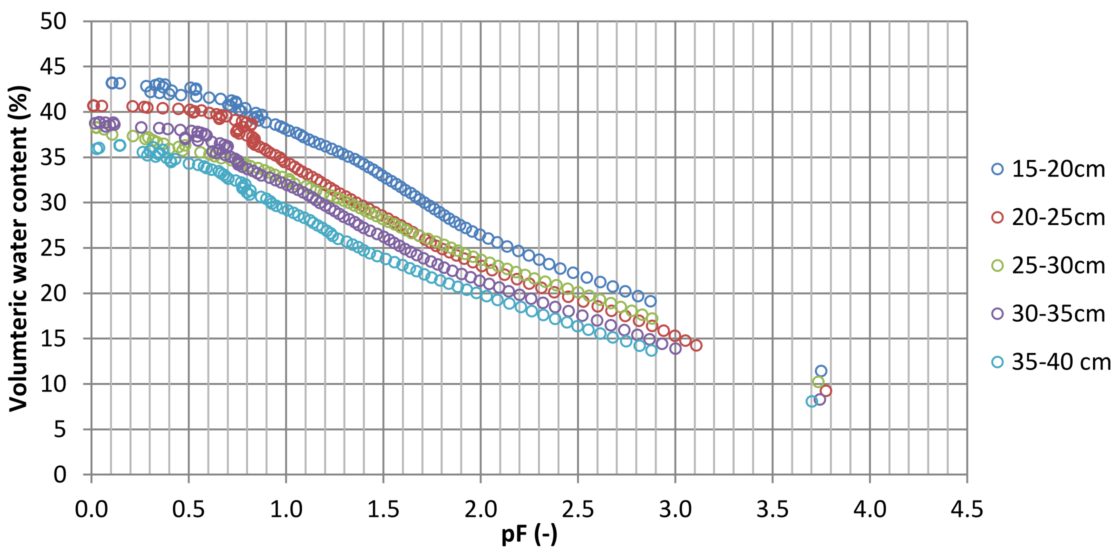

Figure 4-74. Retention curves of Rosalian Mountains soil profile 2, layer 2 at depth between 15-40 cm.

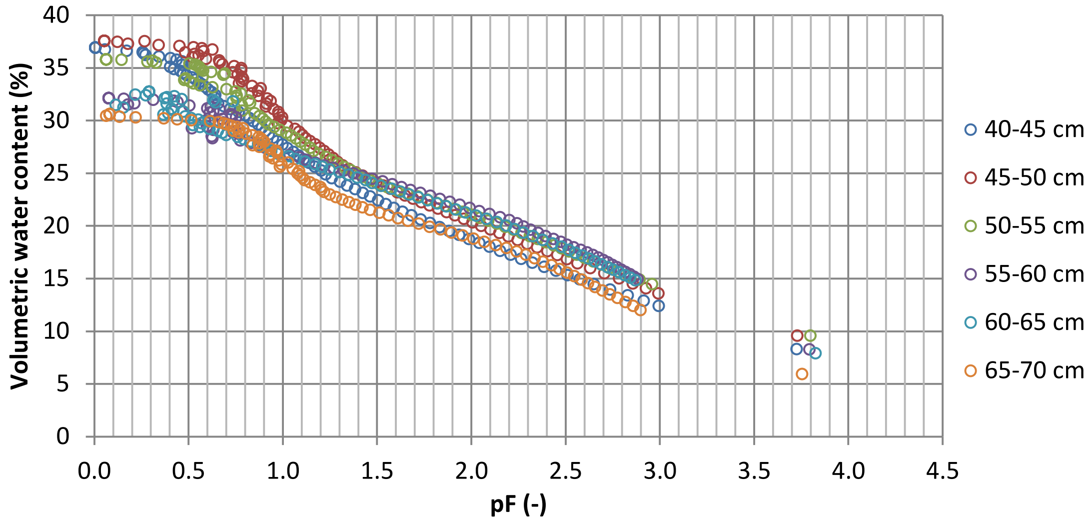

Figure 4-75. Retention curves of Rosalian Mountains soil profile 2, layer 3 at depth between 40-70 cm.

Unsaturated hydraulic conductivity (K) curve of layer 1 is shown in Figure 4-76, of layer 2 in Figure 4-77 and of layer 3 in Figure 4-78.

In layer 1 the K of 5 cm and 10 cm samples are the most similar, sample 15 cm differs the most especially in range of 2.5 - 3 pF.

In layer 2 the highest difference is in a range between 2 - 2.4 pF. Samples 30 cm and 40 cm show similar K curves.

Unsaturated hydraulic conductivity differs the most in layer 3, although some pairs of similar curves can be distinguished. Samples 60 cm and 70 cm shows similar K curves, as well as samples 45 cm and 50 cm.

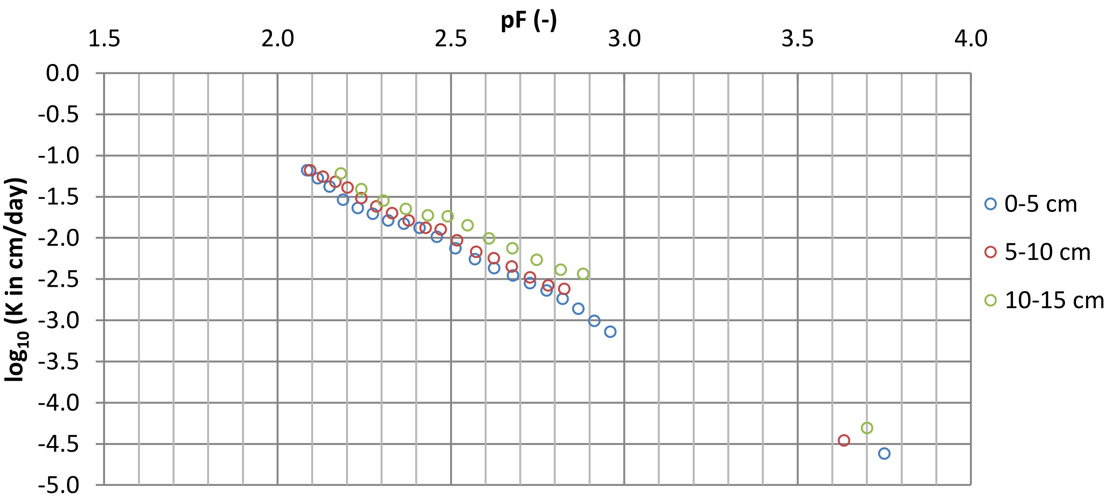

Figure 4-76. Hydraulic conductivity curves of Rosalian Mountains soil profile 2, layer 1 at depth between 0-15 cm.

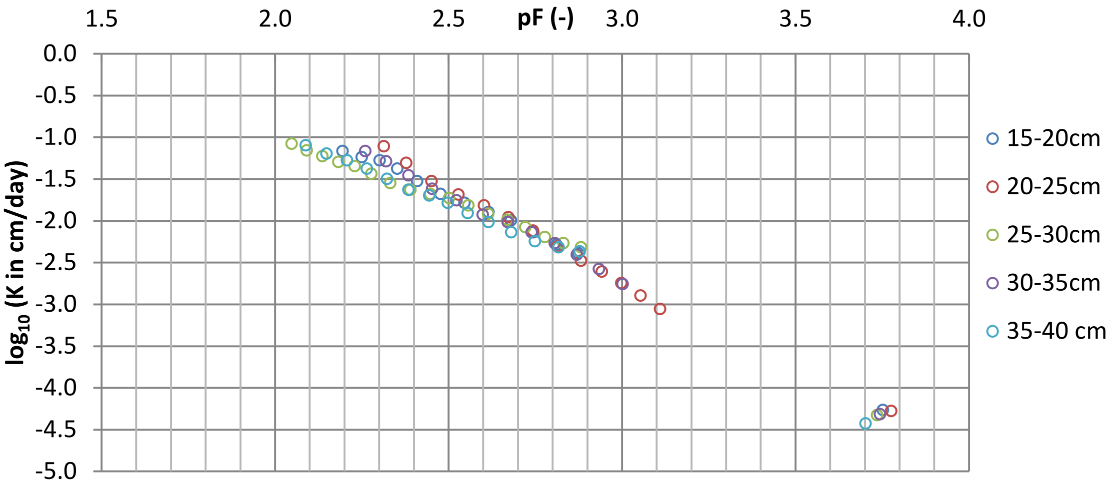

Figure 4-77. Hydraulic conductivity curves of Rosalian Mountains soil profile 2, layer 1 at depth between 15-40 cm.

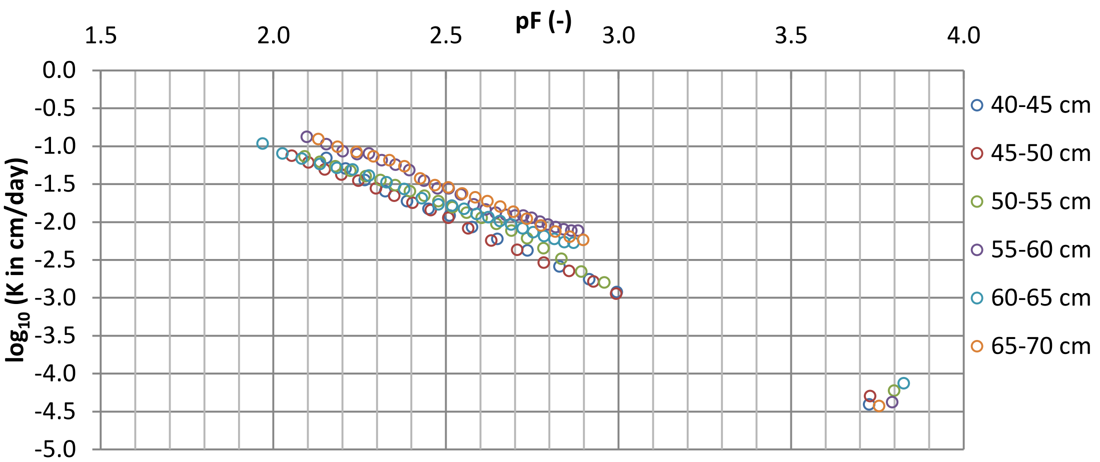

Figure 4-78. Hydraulic conductivity curves of Rosalian Mountains soil profile 2, layer 1 at depth between 40-70 cm

4.3.2 Root mean square error and Akaike information criterion

Root mean square error and Akaike information criterion from the water retention and hydraulic conductivity fitting curves for every sample, Pedological Layers and Common Characteristics approach are shown in Table 4-8, Table 4-9 and Table 4-10.

Table 4-8. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Single Layers of Rosalian Mountains soil profile 2.

Depth (cm)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40
Name				**Value**				
RMSE_Theta	0.0030	0.0049	0.0050	0.0030	0.0045	0.0043	0.0036	0.0027
RMSE_logK	0.0515	0.0392	0.0526	0.0328	0.0277	0.0519	0.0471	0.0510
AICc	-1807	-1702	-1608	-1765	-1712	-1756	-1752	-1816

Depth (cm)	40-45	45-50	50-55	55-60	60-65	65-70
Name				**Value**		
RMSE_Theta	0.0029	0.0029	0.0042	0.0053	0.0078	0.0024
RMSE_logK	0.0255	0.0200	0.0632	0.0900	0.0462	0.0429
AICc	-1817	-1914	-1870	-1837	-1765	-1934

Table 4-9. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Pedological Layers of Rosalian Mountains soil profile 2.

Depth (cm)	0-15	15-40	40-70
Name		**Value**	
RMSE_Theta	0.0222	0.0184	0.0174
RMSE_logK	0.1604	0.1187	0.1823
AICc	-4414	-6057	-6335

Table 4-10. Root mean square error of water content curve fitting (RMSE_Theta), conductivity curve fitting (RMSE_logK) and Akaike information criterion (AICc). Common Characteristics approach of Rosalian Mountains
soil profile 2.

Depth (cm)	5-20	20-35	35-45	45-55	55-65
Name			**Value**		
RMSE_Theta	0.0140	0.0132	0.0068	0.0081	0.0065
RMSE_logK	0.1497	0.1318	0.0903	0.0997	0.1331
AICc	-4648	-4729	-3342	-3444	-3674

4.3.3 Saturated hydraulic conductivity

First of all it is important to point out that this is not a measured value. It is the estimated value by HYPROP – DES as one of parameters in a conductivity function based on measured data points. In the software it is termed Ks although here used term is K_{sat}.

Comparison of saturated hydraulic conductivity of different approaches in soil profile 2 from Rosalian Mountains can be seen in Figure 4-79. Saturated hydraulic conductivity of Single Layers approach is highly diverse as it was in soil profile 1 form

Rosalian Mountains and in the soil profile from Gross Enzersdorf. Here, K_{sat} of Pedological Layers approach is mostly higher than two other approaches.

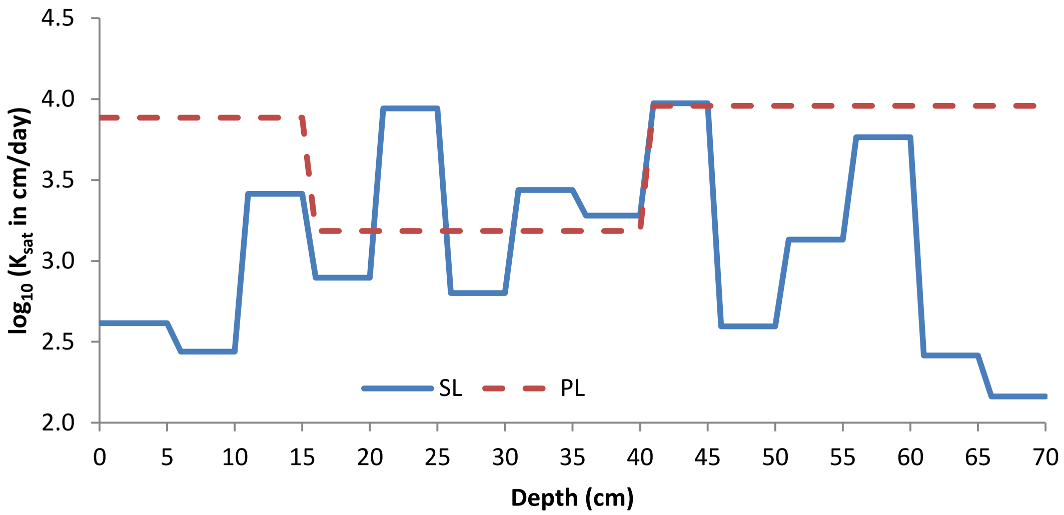

Figure 4-79. Comparison of saturated hydraulic conductivity ($log_{10}(K_{sat})$) within soil profile from Rosalian Mountains (soil profile 2); SL – Single Layers approach; PL – Pedological Layers approach.

Table 4-11 shows all saturated hydraulic conductivity (K_{sat}) corresponding to its depth and approach. Generally, K_{sat} is greater than in Gross Enzersdorf in every approach making it highly permeable up to impervious bedrock layer. However, values of saturated hydraulic conductivity are slightly lower than in soil profile 1 from Rosalian Mountains.

Table 4-11. Saturated hydraulic conductivity (K_{sat}) of depth for all approaches from Rosalian Mountains' soil profile 2.

Single Layer		Pedological Layers	
Depth (cm)	K_{sat} (cm/day)	Depth (cm)	K_{sat} (cm/day)
0-5	412.04	0-15	7681.211
5-10	275.065	15-40	1533.662
10-15	2598.303	40-70	9076.982
15-20	788.408		
20-25	8766.06		
25-30	633.343		
30-35	2747.074		
35-40	1900.841		
40-45	9407.028		
45-50	394.108		
50-55	1352.879		
55-60	5815.593		
60-65	260.772		
65-70	145.237		

4.3.4 Physical and chemical properties

Rosalian Mountains' soil profile 2 is characterized by very small amount of organic carbon reaching maximum 3.14% at the horizon 0 and decreasing to insignificant amount as shown in Figure 4-46. Both profiles from Rosalian Mountains show the same arrangement of organic carbon within a soil profile even though the amount of it slightly differs.

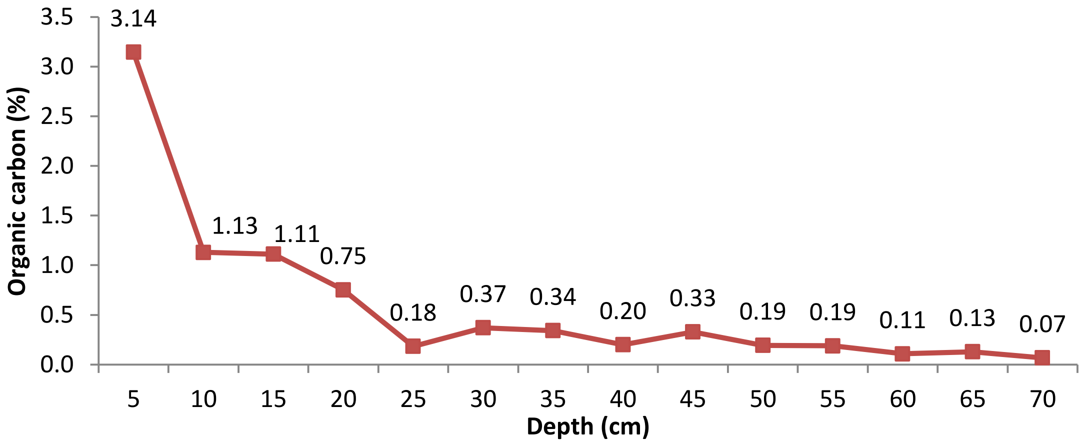

Figure 4-80. Organic carbon content within a Rosalian Mountains' soil profile 2.

Contrary to the Rosalian Mountains soil profile 1 results, organic carbon as well as clay content has slight negative relationship as can be seen in Figure 4-81. Both relationships are characterized by low coefficient of determination. Moreover, the relationship between organic carbon content and K_{sat} is not linear from the same reasons as it was in Rosalian Mountains' soil profile 1.

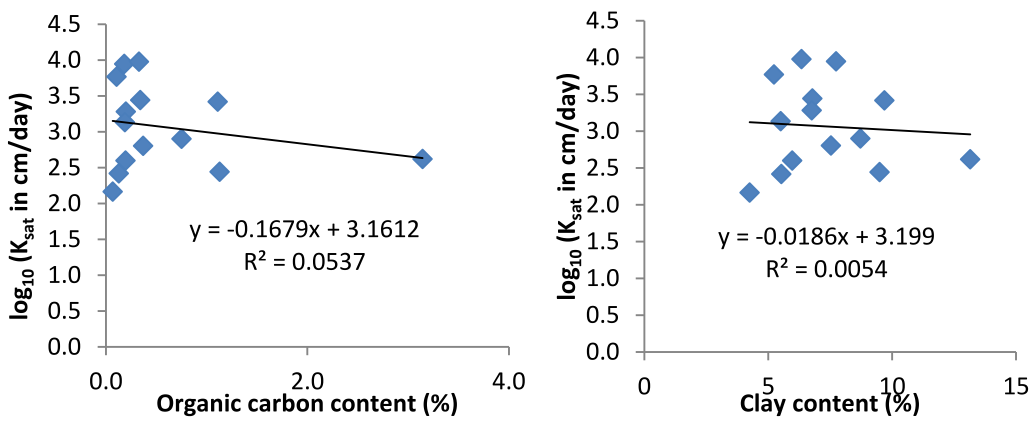

Figure 4-81. Relationship between saturated hydraulic conductivity ($log_{10}K_{sat}$) and organic carbon (left) and relationship between saturated hydraulic conductivity ($log_{10}K_{sat}$) and clay content (right) – Rosalian Mountains soil profile 2.

Figure 4-82 shows a correlation between organic carbon and saturated volumetric water content (Θs) with 63.74% fitting as well as between clay content and

Θs with 88.67% fitting. High linear relationship shows again the importance of organic carbon and clay particles on water retention.

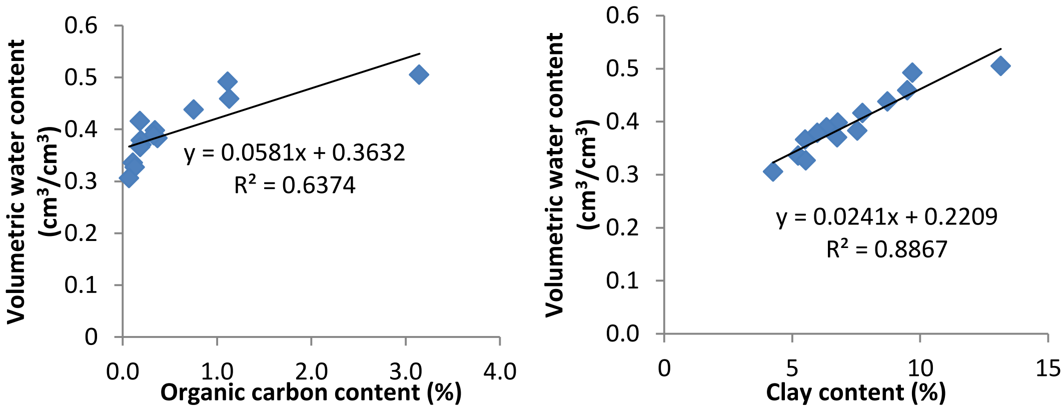

Figure 4-82. Relationship between saturated volumetric water content and organic carbon content (left); saturated volumetric water content and clay content (right) - Rosalian Mountains soil profile 2.

The same as the correlation of K_{sat} and bulk density from the Gross Enzersdorf's soil profile and Rosalian Mountains' soil profile 1 the relationship between those two variables is negative. Although, the coefficient of determination (R^2) is the smallest (0.7%).

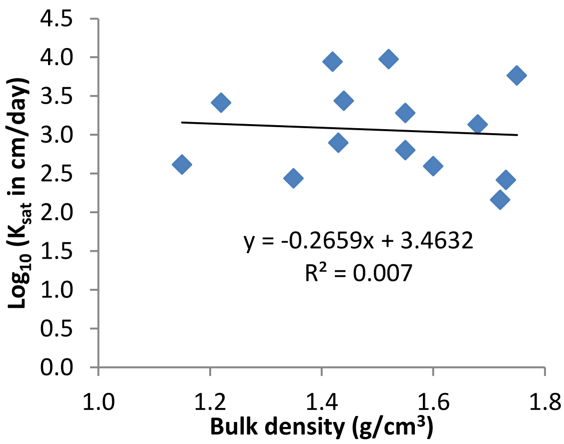

Figure 4-83. Saturated hydraulic conductivity ($log_{10}(K_{sat})$) of bulk density - Rosalian Mountains soil profile 2.

4.3.6 Soil water simulation output

Water flow through the soil profile was simulated in each approach. Water content was registered for every observation point. Those points were at depth 13, 23, 43, 53 and 63 cm and further they are termed: OP13, OP23, OP43, OP53 and OP63, respectively. Those points were chosen regarding a variation of the saturated hydraulic conductivity between the approaches as in Figure 4-79 and Table 4-11. Because of impermeable layer set as a lower boundary condition the results from the bottom flux are not included.

Figure 4-84, Figure 4-85 and Figure 4-86 represent water content captured in 13 cm below the surface. Saturated hydraulic conductivity of SL approach is 2598 cm/day where K_{sat} of PL approach is 7681 cm/day. As can be seen on the figures, both approaches show high susceptibility to precipitation rate. Moreover, in PL approach, soil holds more water during the simulation time than soil in SL approach (with some exceptions occurring in May every year when water content, after a longer stabilization, drastically dropped down), regardless the precipitation rate, as it is shown in Figure 4-87.

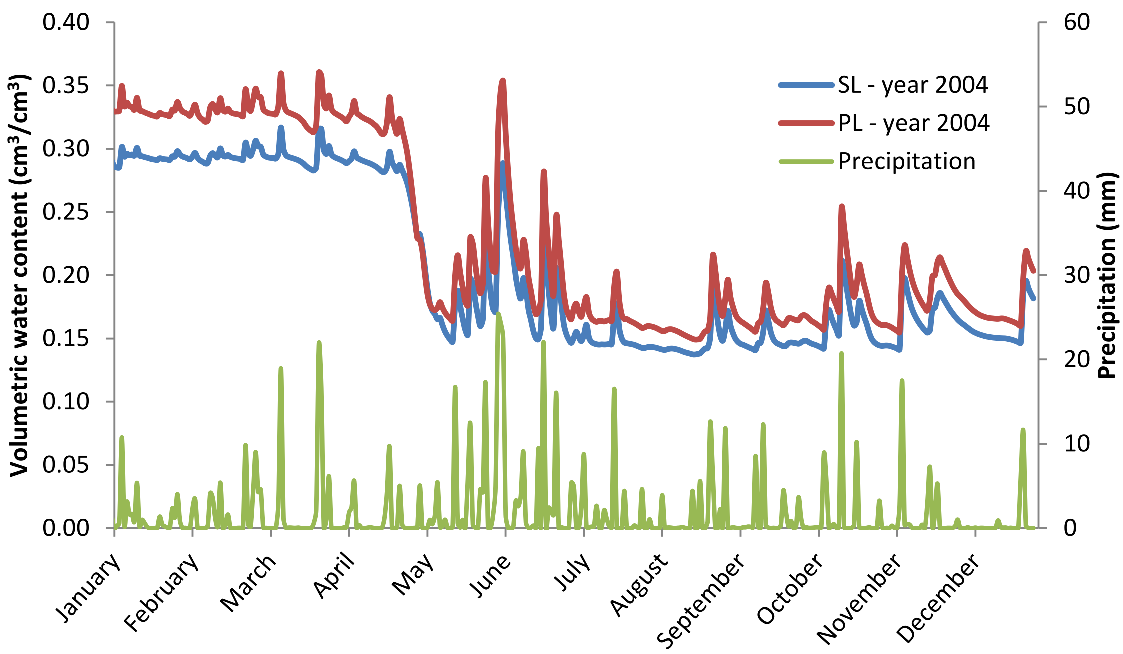

Figure 4-84. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2004 – Rosalian Mountains (soil profile 2).

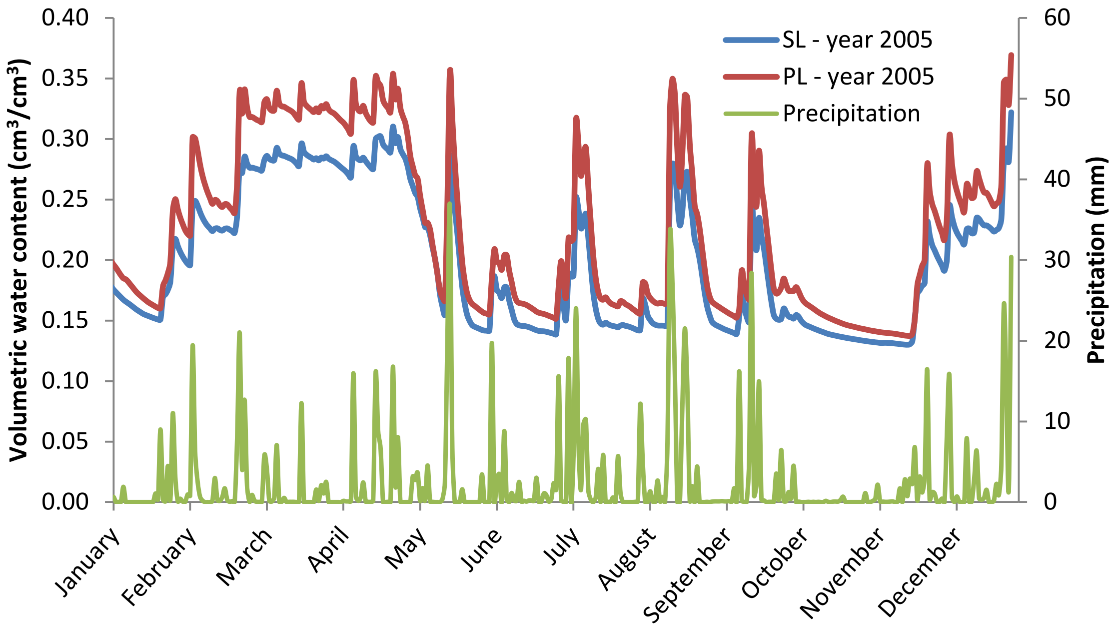

Figure 4-85. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2005 – Rosalian Mountains (soil profile 2).

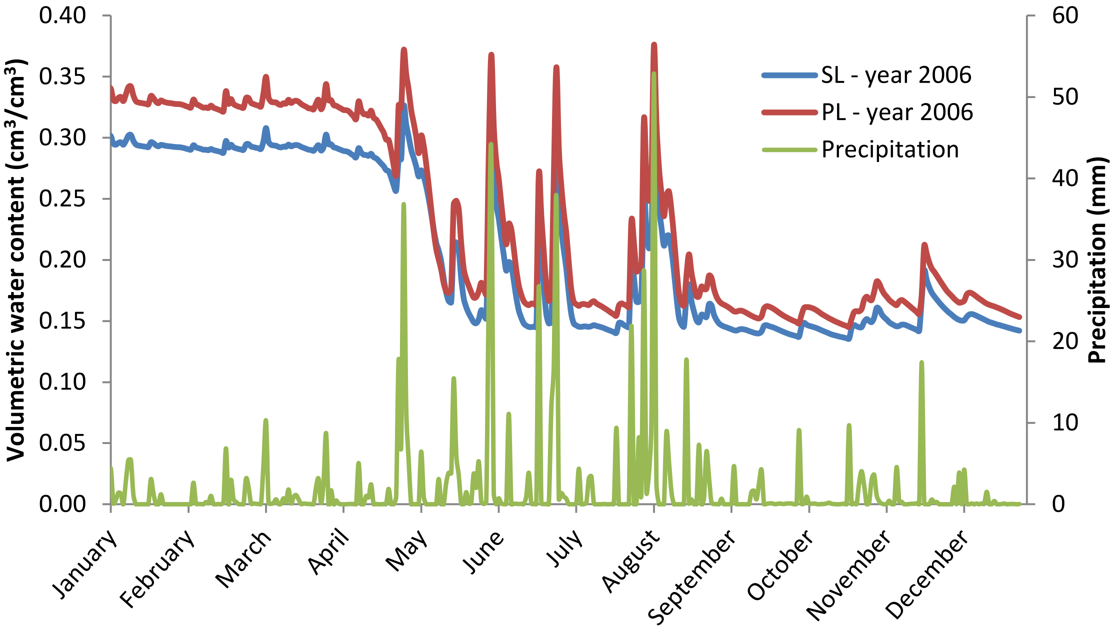

Figure 4-86. Water content data obtained from the water flow simulation at 13 cm depth (OP13) for climatic data from year 2006 – Rosalian Mountains (soil profile 2).

Figure 4-87 shows differences in water content over 3 years. Maximum difference is 0.0723 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0253 cm^3/cm^3. Up-and-down character of the curve responds to the atmospheric conditions. In general, whenever high intensity precipitation occurs then more water is hold by soil in PL approach for short time duration.

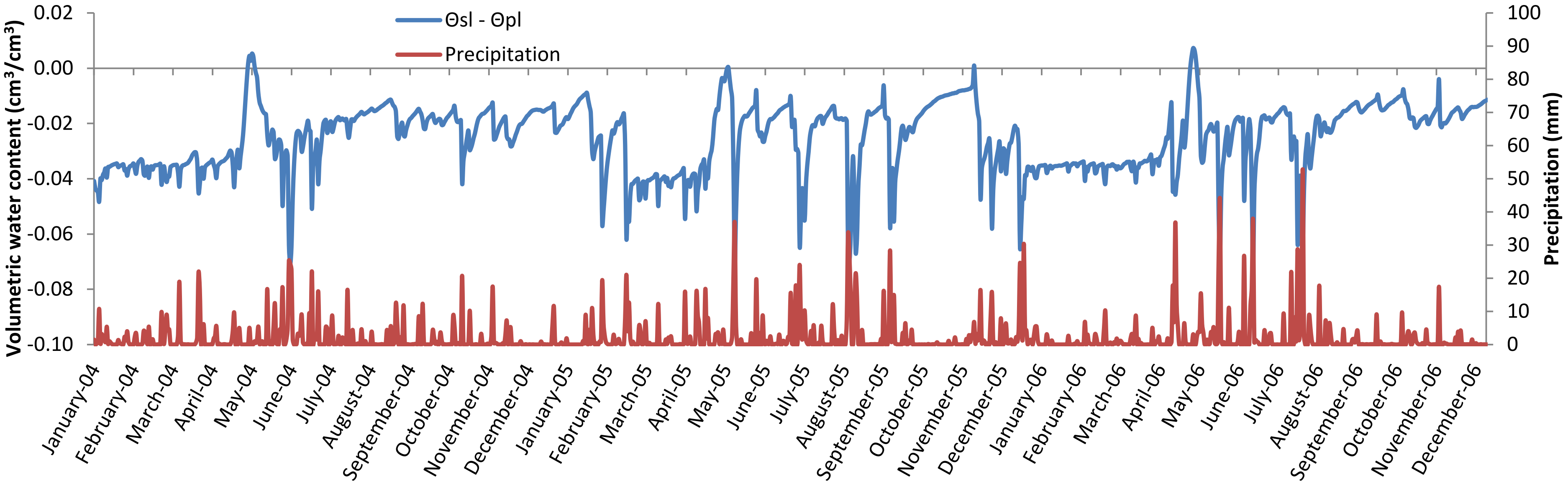

Figure 4-87. Differences in water content between the approaches during 3 years for OP13 (Rosalian Mountains – soil profile 2), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-88, Figure 4-89 and Figure 4-90 show water content of OP23. At depth of 23 cm the K_{sat} of SL is 8766 cm/day and of PL is 1534 cm/day.

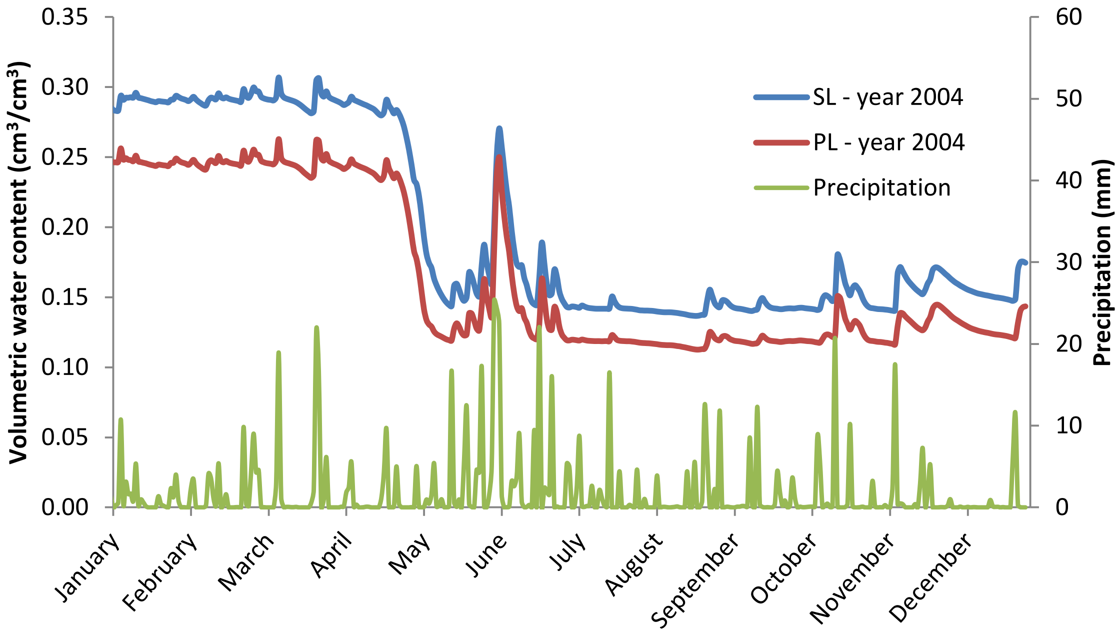

Figure 4-88. Water content data obtained from the water flow simulation at 23 cm depth (OP23) for climatic data from year 2004 – Rosalian Mountains (soil profile 2).

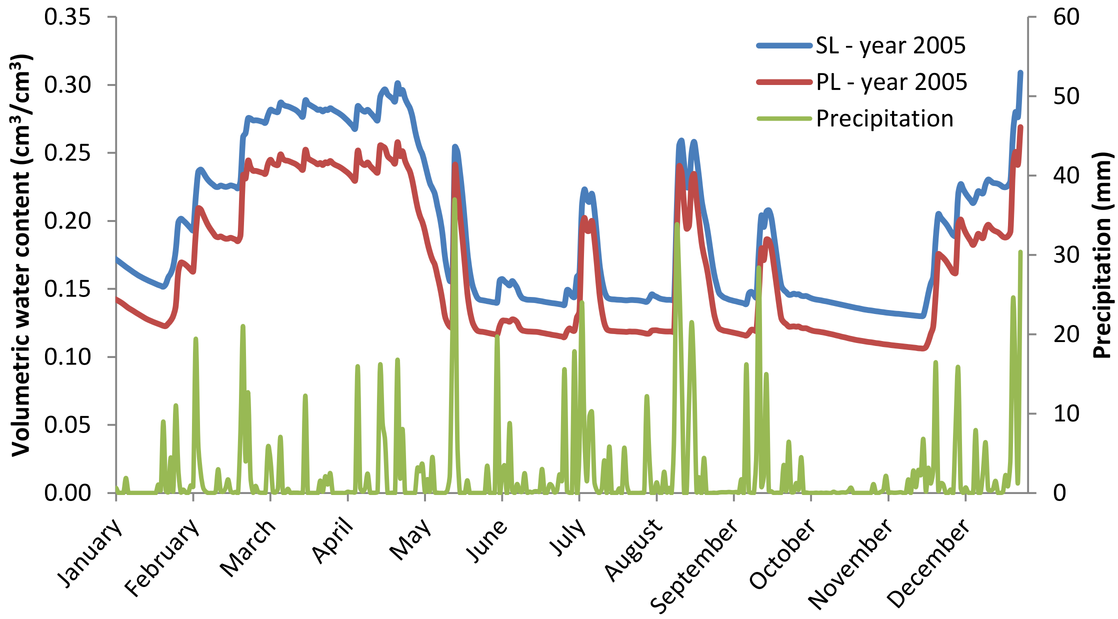

Figure 4-89. Water content data obtained from the water flow simulation at 23 cm depth (OP23) for climatic data from year 2005 – Rosalian Mountains (soil profile 2).

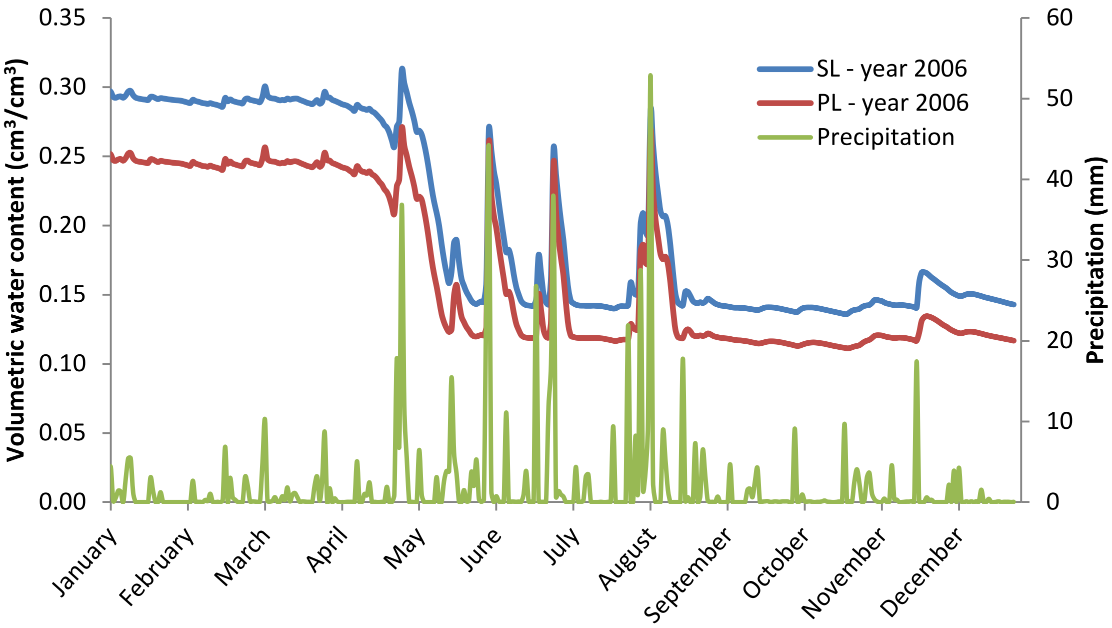

Figure 4-90. Water content data obtained from the water flow simulation at 23 cm depth (OP23) for climatic data from year 2006 – Rosalian Mountains (soil profile 2).

Figure 4-53 shows differences in water content over 3 years. Maximum difference is 0.0545 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0320 cm^3/cm^3. At this depth situation is reversed, water content of SL approach is higher than PL approach. Furthermore, saturated hydraulic conductivity is much higher as well. Although at it is defined for only 5 cm of soil and K_{sat} of both, upper and lower parts of the soil profile, are relatively low, 788 cm/day and 633 cm/day, respectively. Moreover those values are lower than PL's by one order of magnitude. In this situation water do not infiltrate so fast and it is kept at this point.

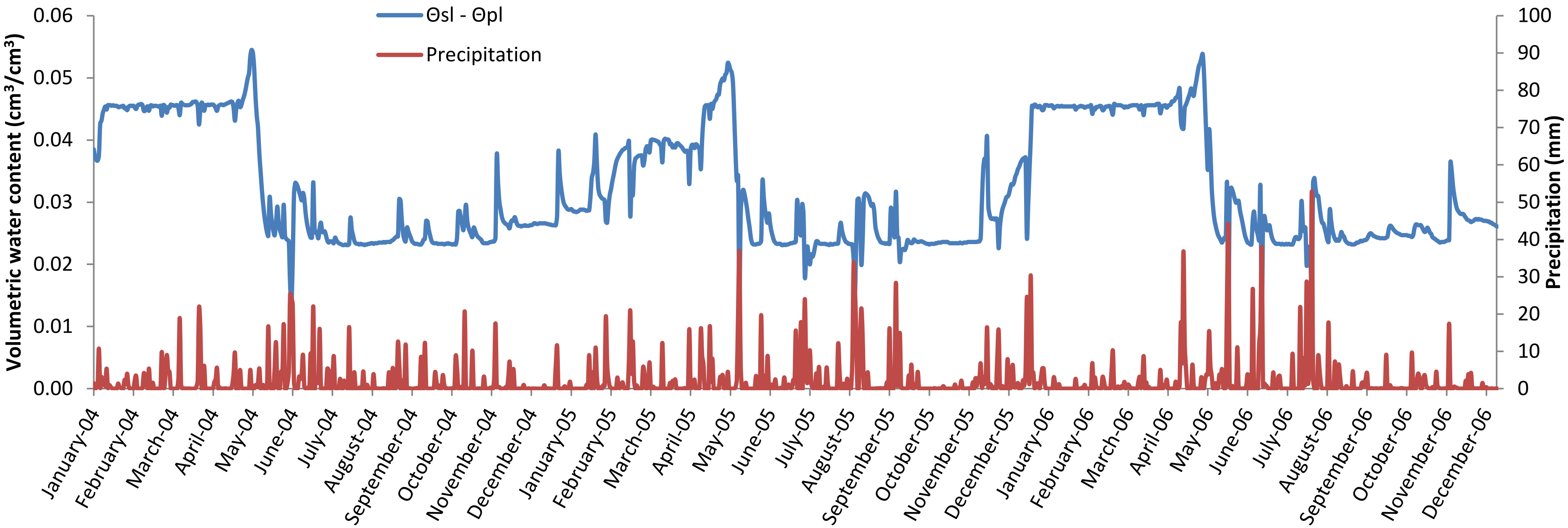

Figure 4-91. Differences in water content between the approaches during 3 years for OP23 (Rosalian Mountains – soil profile 2), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-92, Figure 4-93 and Figure 4-94 show water content of OP43. At depth of 43 cm the K_{sat} of SL is 9407 cm/day and of PL is 9077 cm/day. It is 20 cm deeper than previous Observation Point. As can be seen on all 3 figures the abrupt changes of water content related to precipitation rate ceased.

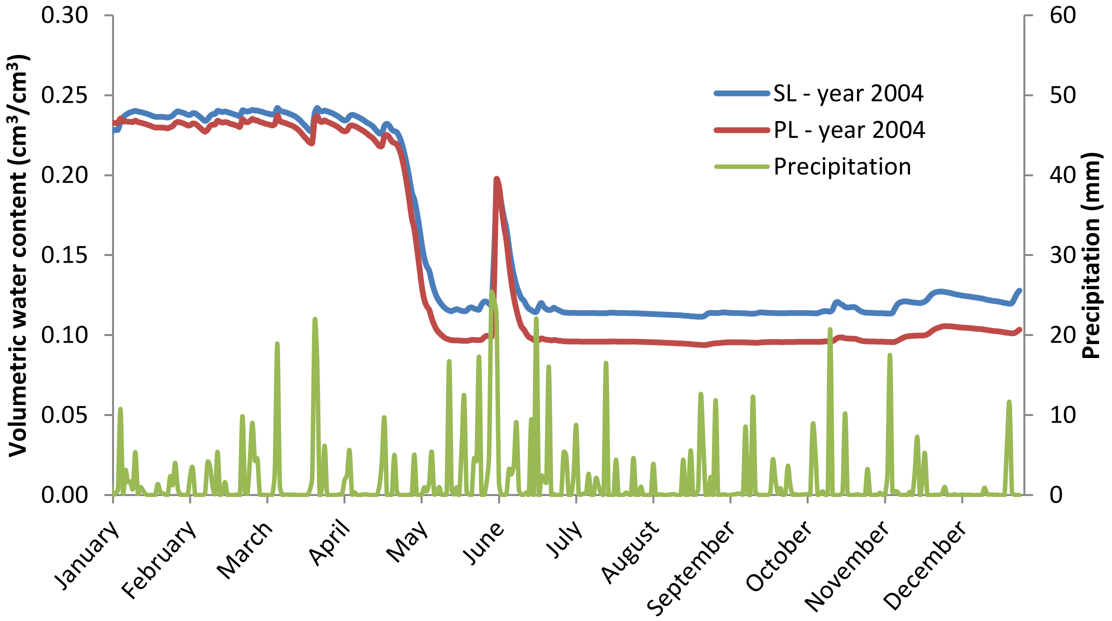

Figure 4-92. Water content data obtained from the water flow simulation at 43 cm depth (OP43) for climatic data from year 2004 – Rosalian Mountains (soil profile 2).

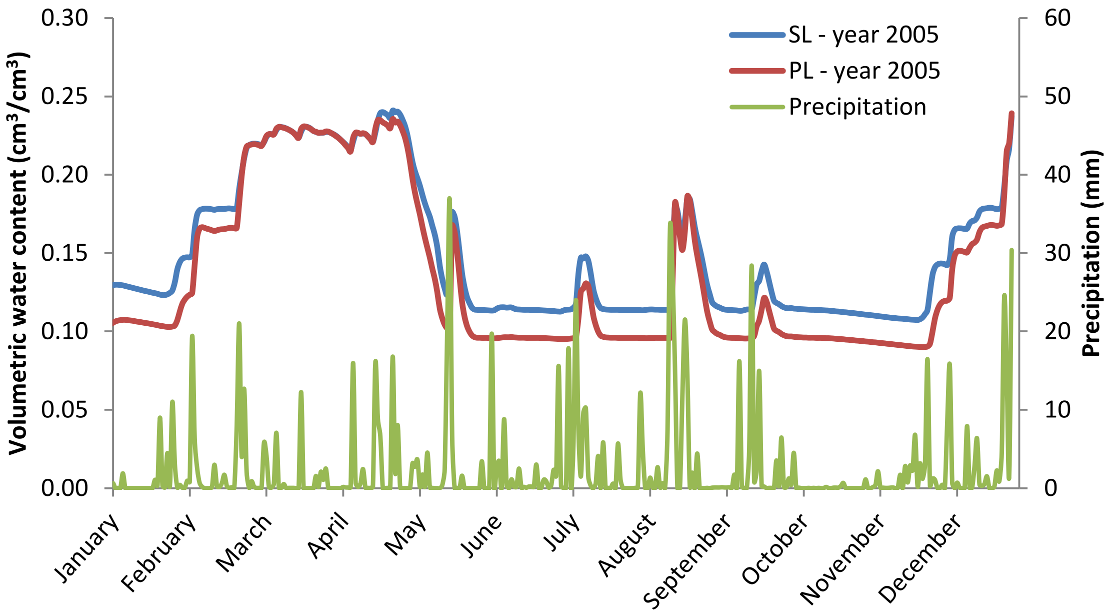

Figure 4-93. Water content data obtained from the water flow simulation at 43 cm depth (OP43) for climatic data from year 2005 – Rosalian Mountains (soil profile 2).

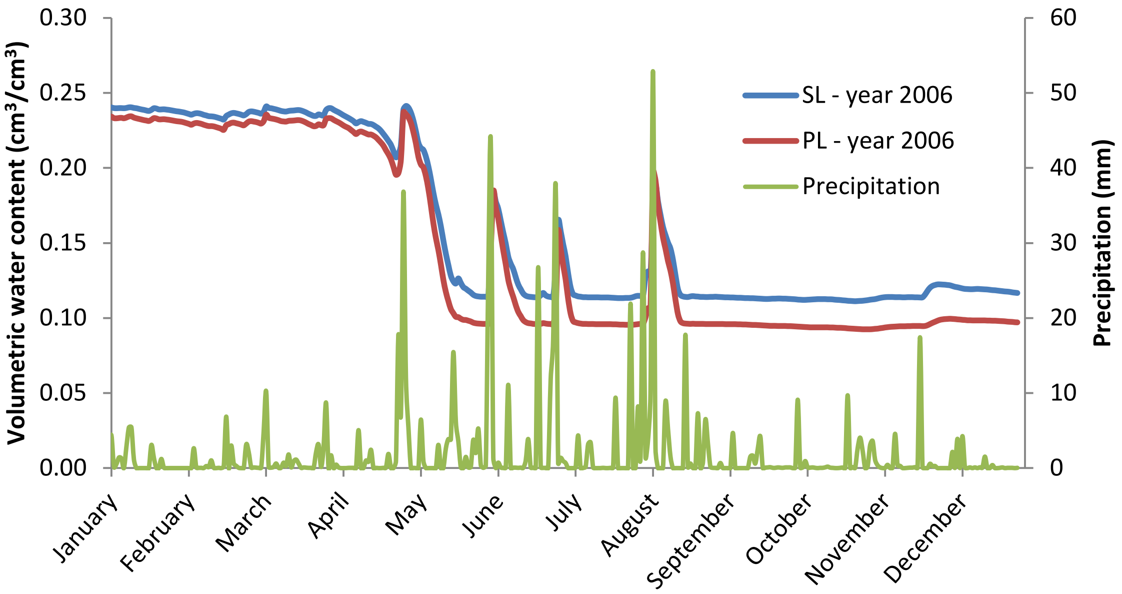

Figure 4-94. Water content data obtained from the water flow simulation at 43 cm depth (OP43) for climatic data from year 2006 – Rosalian Mountains (soil profile 2).

Figure 4-95 shows differences in water content over 3 years. Maximum difference is 0.0363 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0146 cm^3/cm^3. At this depth water content of SL approach is still higher than PL. However the difference between both approaches is lower and even in some periods of time it reverses in favor of PL approach.

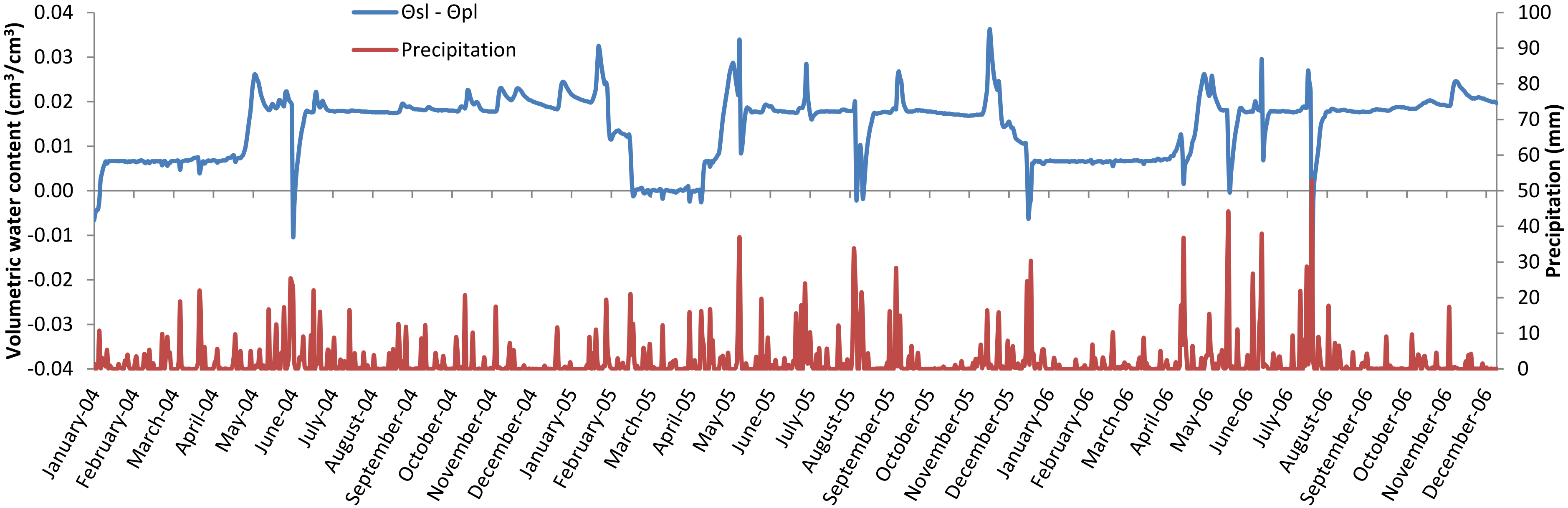

Figure 4-95. Differences in water content between the approaches during 3 years for OP43 (Rosalian Mountains – soil profile 2), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-96, Figure 4-97 and Figure 4-98 show water content of OP53. At depth of 53 cm the K_{sat} of SL is 1352 cm/day and of PL is 9077 cm/day. Alike before the abrupt changes of water content related to precipitation rate also ceased.

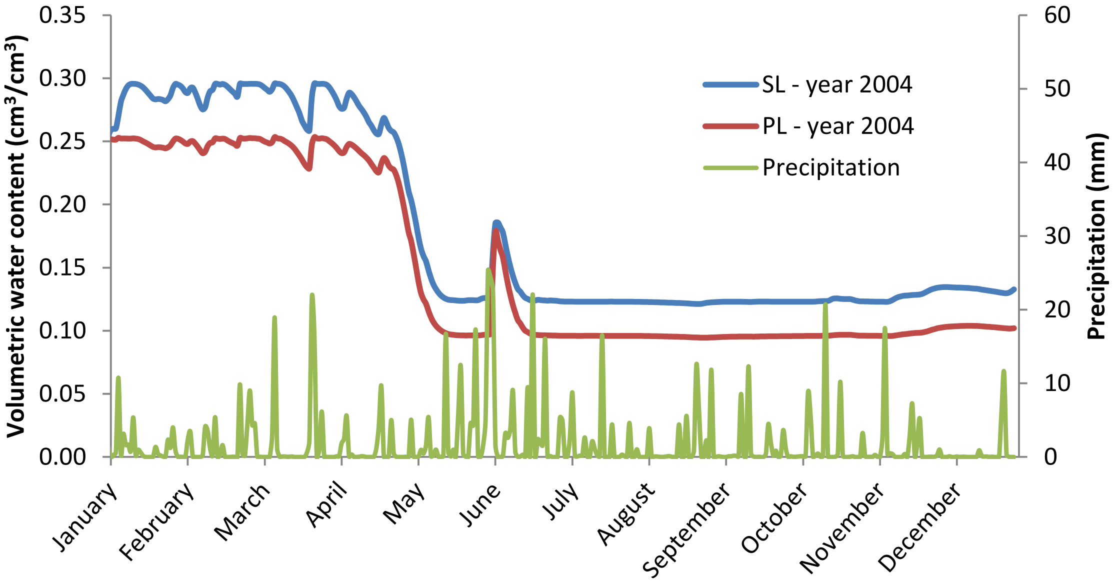

Figure 4-96. Water content data obtained from the water flow simulation at 53 cm depth (OP53) for climatic data from year 2004 – Rosalian Mountains (soil profile 2).

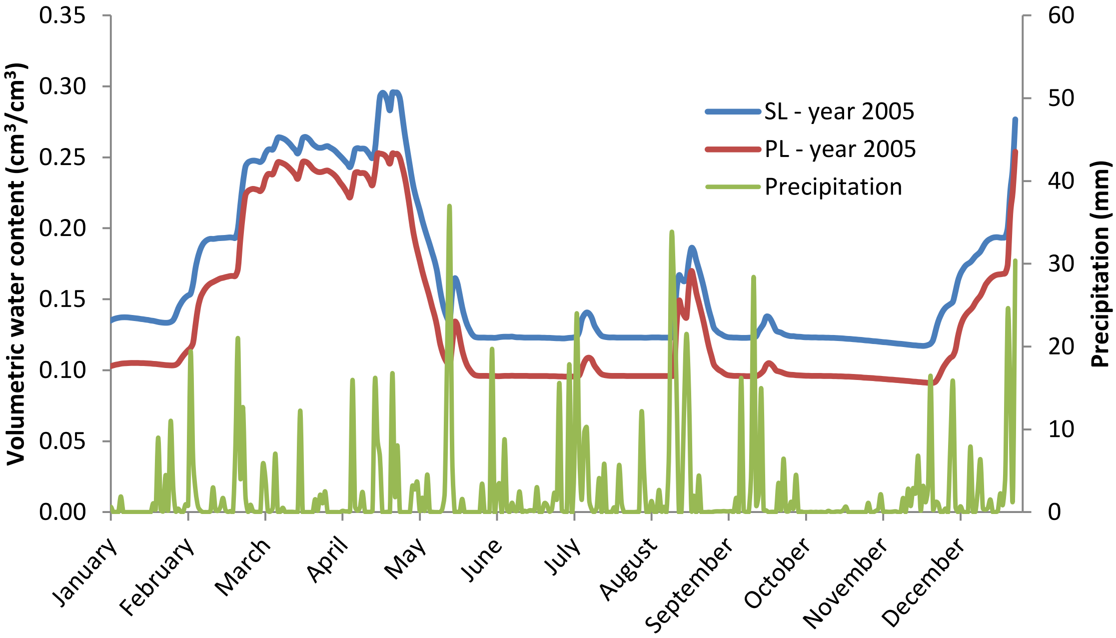

Figure 4-97. Water content data obtained from the water flow simulation at 53 cm depth (OP53) for climatic data from year 2005 – Rosalian Mountains (soil profile 2).

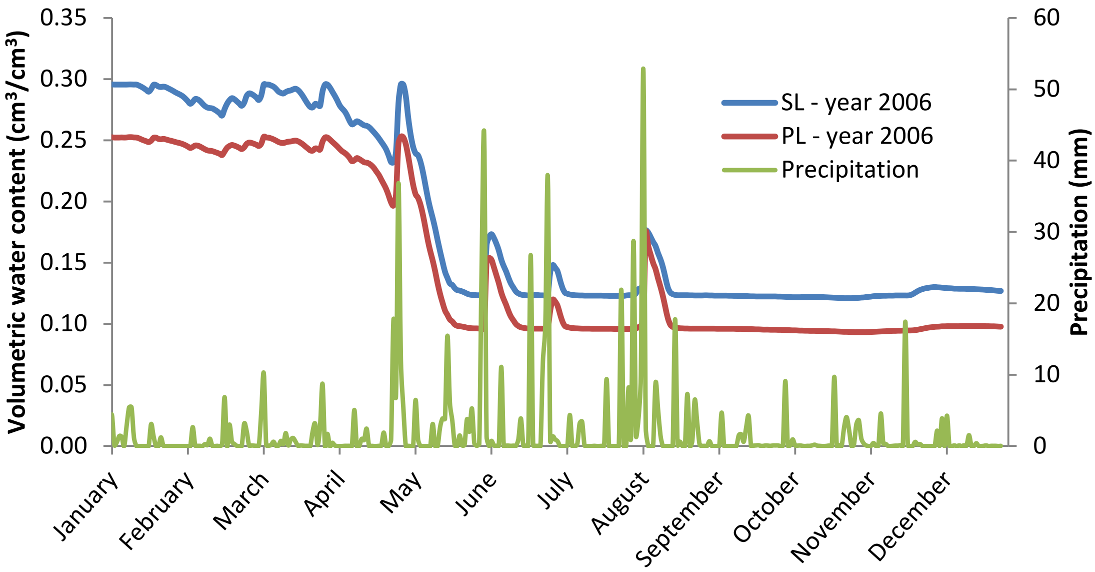

Figure 4-98. Water content data obtained from the water flow simulation at 53 cm depth (OP53) for climatic data from year 2006 – Rosalian Mountains (soil profile 2).

Figure 4-99 shows differences in water content over 3 years. Maximum difference is 0.0434 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0300 cm^3/cm^3. At this depth water content of SL exceeds water content of PL approach during the whole simulation period. It is expected since SL's K_{sat} of this point and adjutant zones are much lower than K_{sat} of PL approach. During the intensive precipitation periods the difference in water content reduces due to the K_{sat} variety.

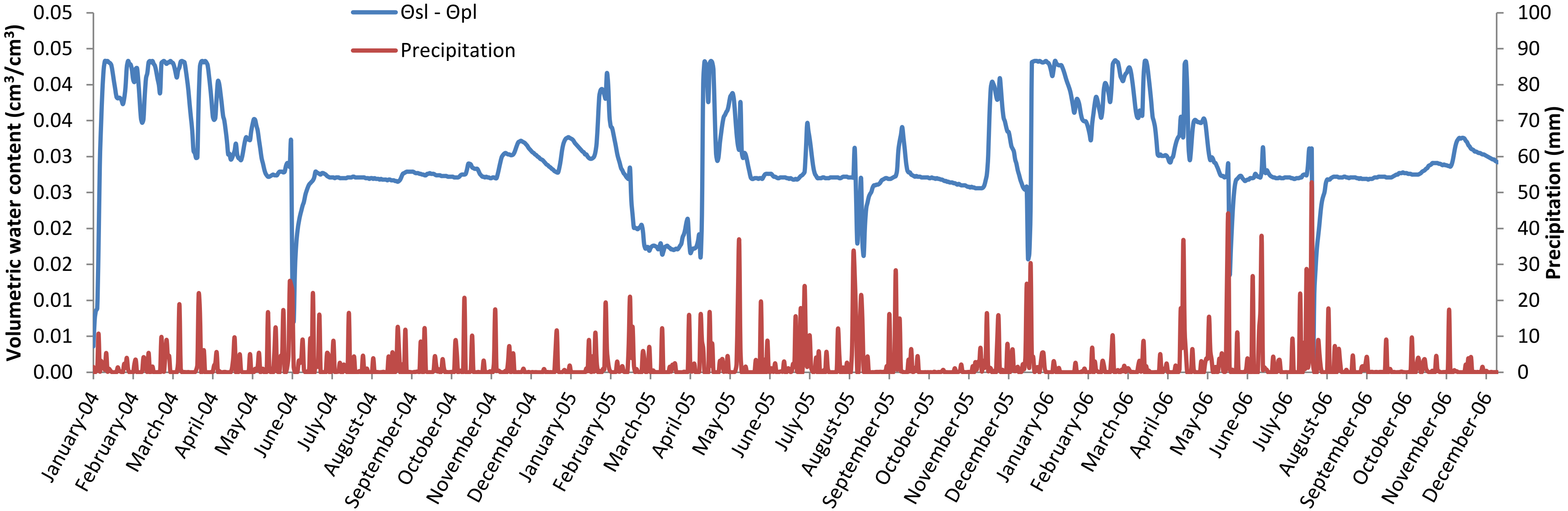

Figure 4-99. Differences in water content between the approaches during 3 years for OP53 (Rosalian Mountains – soil profile 2), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

Figure 4-100, Figure 4-101 and Figure 4-102 show water content of OP63. It is the deepest Observation Point in this soil profile. At depth of 63 cm the K_{sat} of SL is 261 cm/day and of PL is 9077 cm/day. Alike before the abrupt changes of water content related to precipitation rate also ceased.

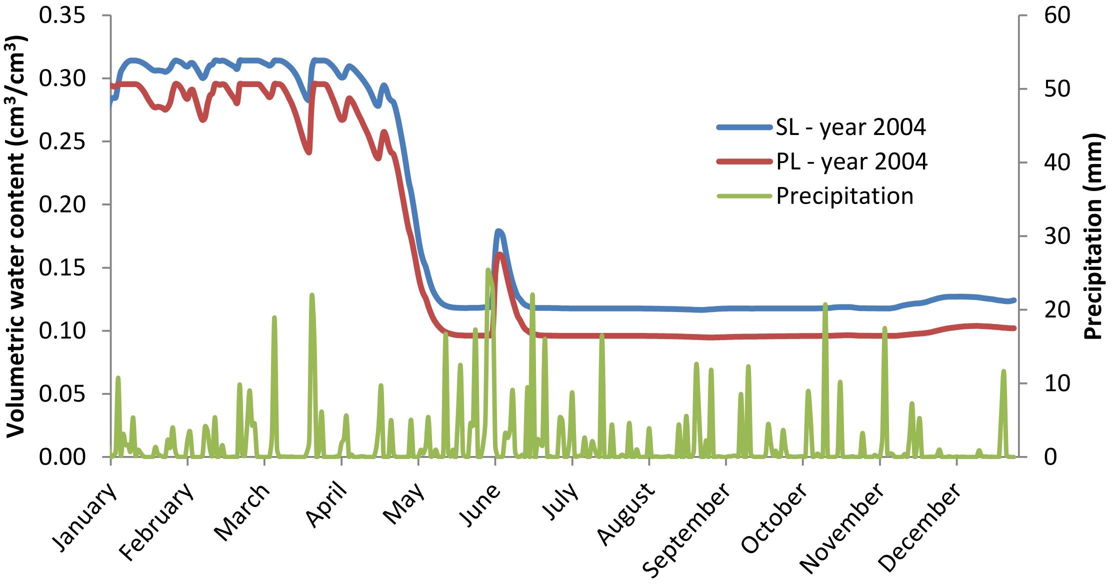

Figure 4-100. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2004 – Rosalian Mountains (soil profile 2).

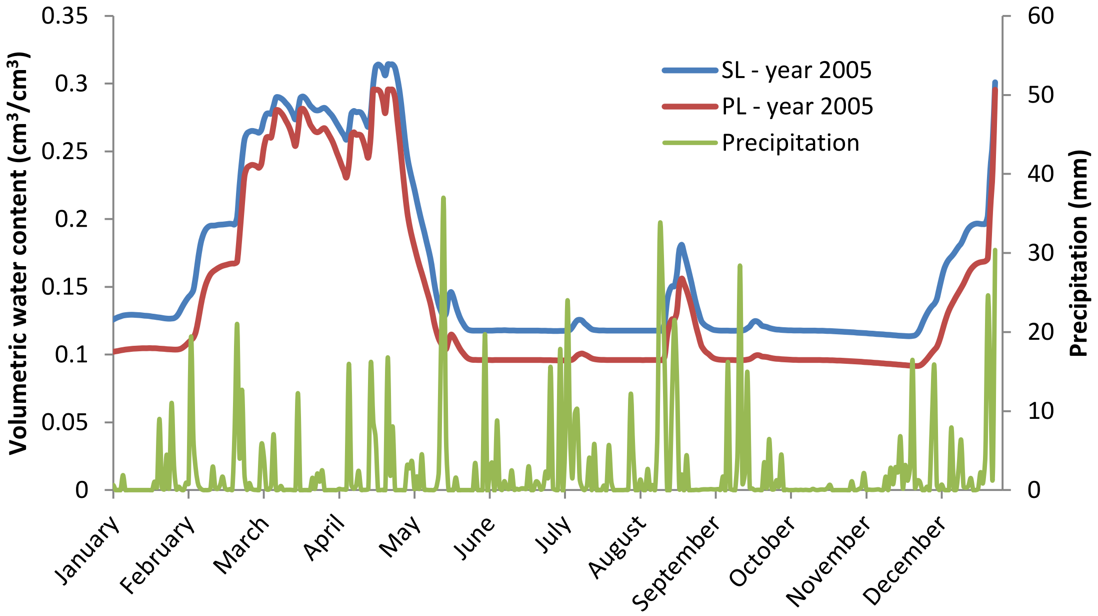

Figure 4-101. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2005 – Rosalian Mountains (soil profile 2).

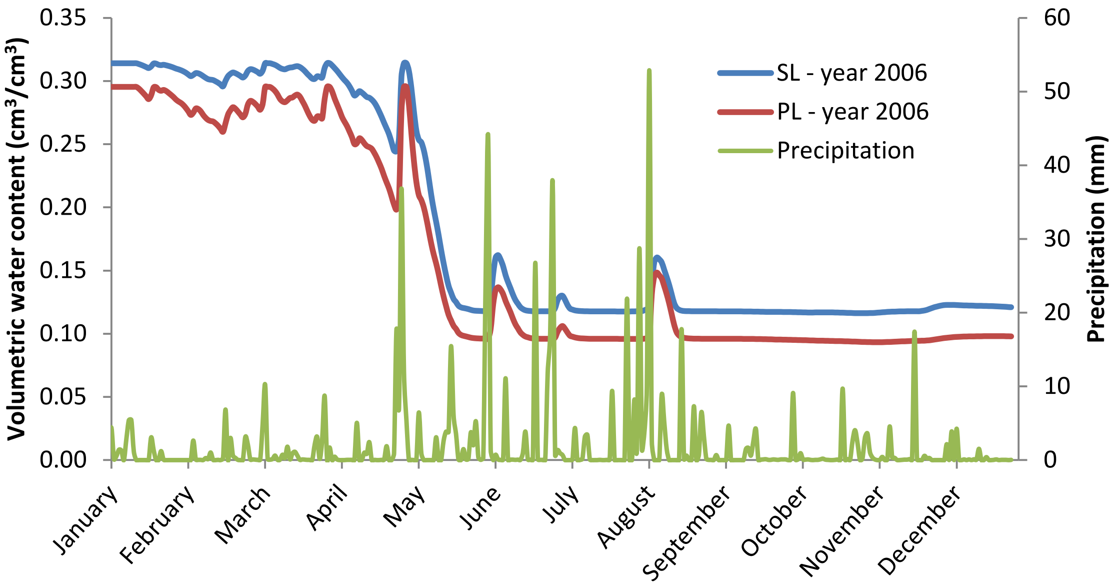

Figure 4-102. Water content data obtained from the water flow simulation at 63 cm depth (OP63) for climatic data from year 2006 – Rosalian Mountains (soil profile 2).

Figure 4-103 shows differences in water content over 3 years. Maximum difference is 0.0484 cm^3/cm^3. Moreover, average difference of absolute value during those 3 years is 0.0240 cm^3/cm^3. At this depth water content of SL also exceeds water content of PL approach during the whole simulation period. It is expected since SL's K_{sat} of this point and adjutant zones are much lower than K_{sat} of PL approach.

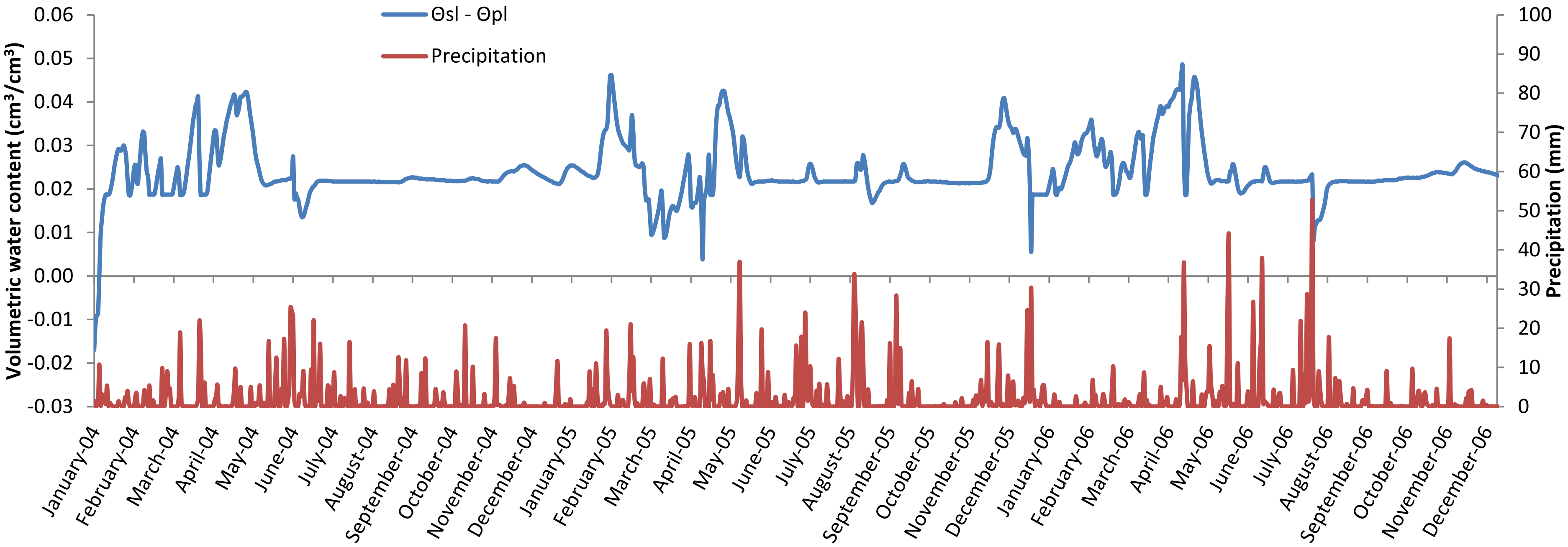

Figure 4-103. Differences in water content between the approaches during 3 years for OP63 (Rosalian Mountains – soil profile 2), where: Θsl – Θpl is a difference of water content between Single Layers and Pedological Layers.

4.3.7 Summary

Two approaches were compared together based on the analysis of the first soil profile from Forest demonstration center in Rosalian Mountains. Hyprop measurements provided information about water retention and hydraulic conductivity of single samples. Comparison of those data shows variety of properties within 3 individual soil horizons. However the variety is not as high as it was in 1st soil profile from the Forest demonstration center. It is true for both retention like a hydraulic curves. Moreover, data analysis established saturated hydraulic conductivity for every single sample and joint samples. It proved the variety of K_{sat} within a soil profile. Alike in previous soil profile high values of saturated hydraulic conductivities may be explained by high amount of course-size particles in the samples, reaching even 50% of a sample's mass. Organic carbon content in this soil profile was very low.

As well here there was found no strong relationship between K_{sat} and organic carbon content or soil particle size distribution.

Unlike the two other investigated soil profiles in this one the soil water simulations showed that there exists difference between two compared approaches. For 3 years the highest average water content difference was 0.0320 cm^3/cm^3 at observation point OP23; the lowest difference occurred at OP43 and it was equal to 0.0146 cm^3/cm^3.

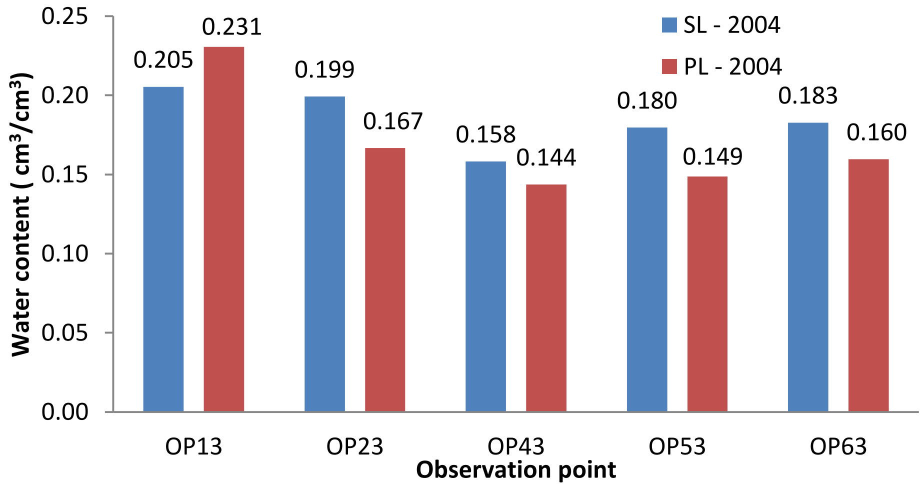

Figure 4-104. Average water content captured for the observation points of soil profile 2 in Rosalian Mountains, y. 2004

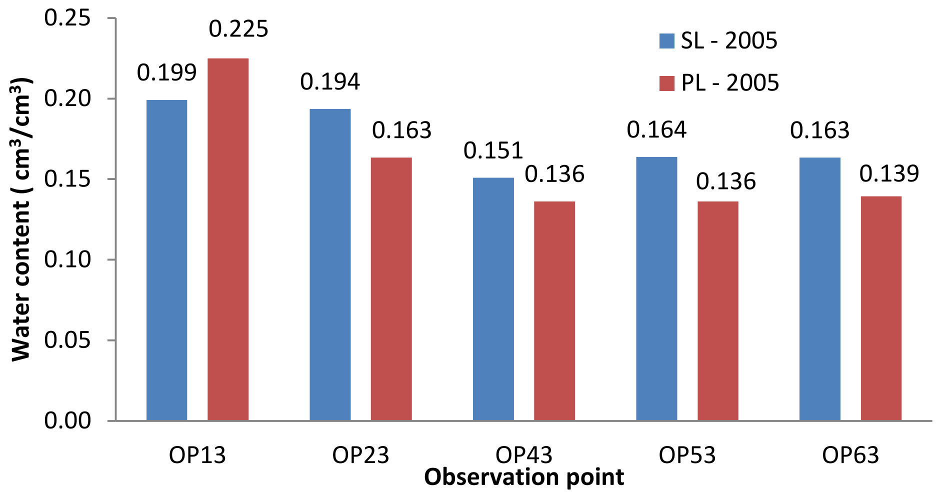

Figure 4-105. Average water content captured for the observation points of soil profile 2 in Rosalian Mountains, y. 2005

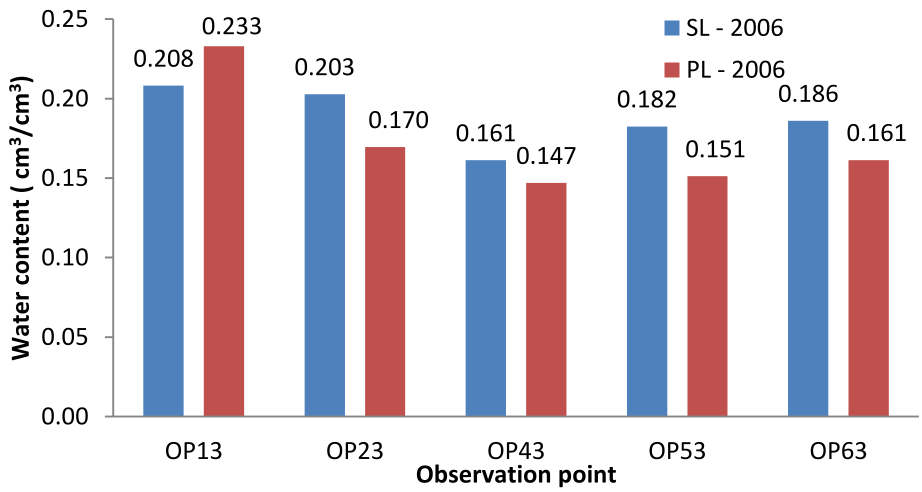

Figure 4-106. Average water content captured for the observation points of soil profile 2 in Rosalian Mountains, y. 2006

Figure 4-104, Figure 4-105 and Figure 4-106 show the average water content in each observation point and both approaches. Distribution of water in this soil profile in some way is similar to other soil profile from Rosalian Mountains. It is reducing from the topsoil and from some point it starts to increase again. Although, water content of SL is higher than other approach except of the shallowest Observation Point located at 13th cm. The main reason of high differences in water content in favor of Single Layers approach is its relatively very low saturated hydraulic conductivity of SL approach that keeps water in soil profile.

Unlike the two other investigated soil profiles, the differences in water content are significant and cannot be neglected.

5 Conclusions

Comparison of two different samplings methods showed that the results obtained by the proposed method vary from the results obtained by standard method. Presented results give a lot of information about complexity of each soil horizon where individual hydraulic properties were recognized and compared.

The conclusions and analysis of this study can be summarized as followed:

(i) Thorough analysis of soil hydraulic properties indicates its high variability in depth. Study proves that single soil horizon is composed of a vary properties set making it difficult to average.

(ii) Soil physical and chemical properties have impact on water holding capacity although there was found no relationship with saturated hydraulic conductivity. Study shows that those properties also vary within single soil horizon which can have a direct impact on the soil hydraulic properties.

(iii) Soil-water simulation of two out of three studied soil profiles showed insignificant difference in water content. Two soil profiles had the same boundary and atmospheric conditions, and root development, however one of them showed significant difference in water content, other did not. It indicates that the distribution of soil hydraulic properties plays a main role, especially properties of the lowest part.

(iv) At single point, water content is not strictly related to K_{sat} but rather is important its distribution within a whole soil profile.

(v) Proposed sampling method gives more information about soil profile in comparison to standard one. It allows gathering thorough data about soil hydraulic properties of the soil.

(vi) Further study of this topic should be carried out in future for better understanding of soil hydraulic properties. Different soil types can be analyzed by Hyprop device, and more accurate results can be obtained by combining this method with some other methods (e.g. Dewpoint potentiometer). Simultaneously analysis can be carried out using standard methods and in the result both methods can be compared.

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