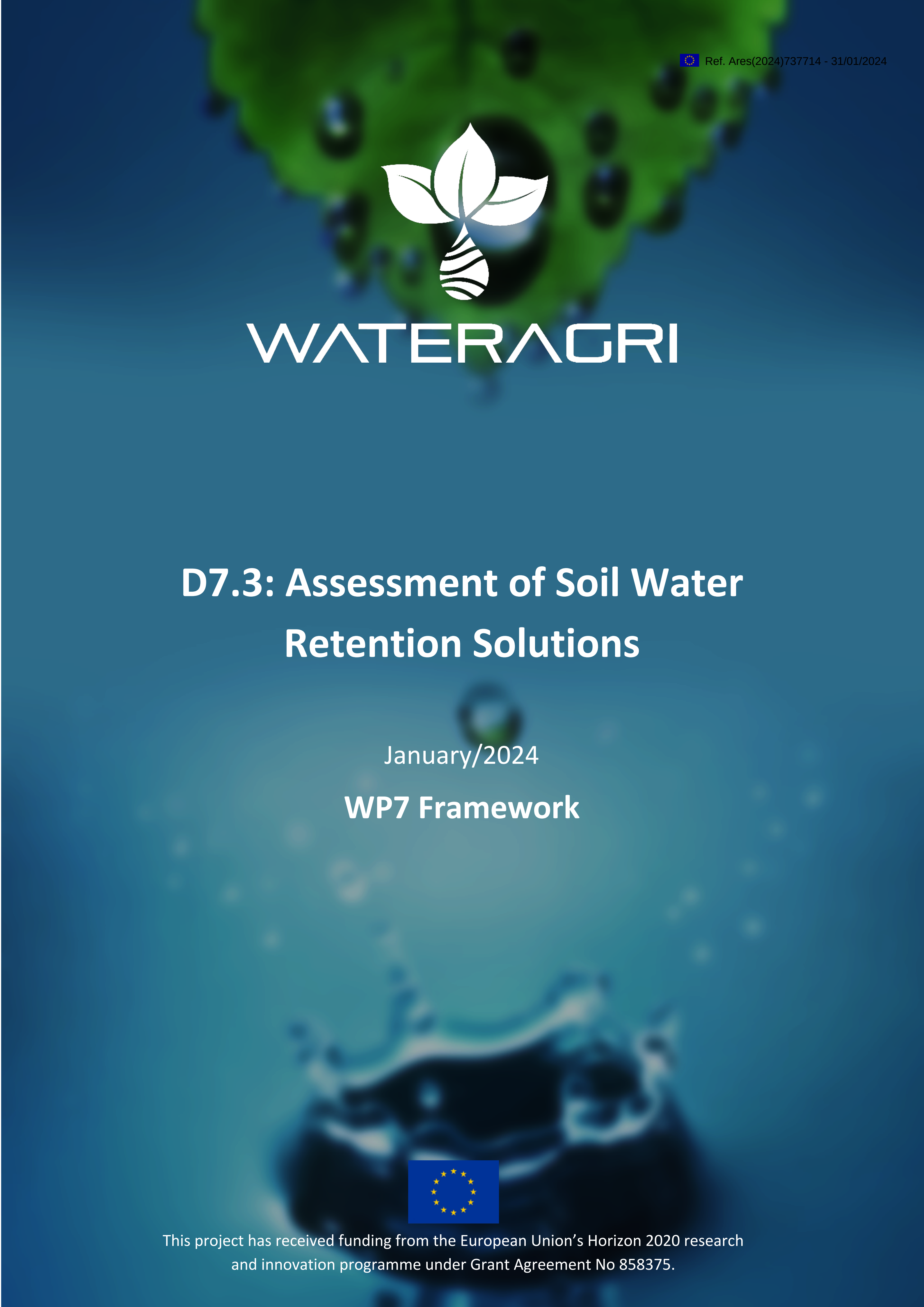

Ref. Ares(2024)737714 - 31/01/2024

WATERAGRI

D7.3: Assessment of Soil Water Retention Solutions

January/2024

WP7 Framework

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 858375.

Author(s)/Organisation(s)	Philip Brunner (UNINE) Qi Tang (UNINE) Arkadiusz Głogowski (UPWR) Yu Wang (USAL) Björn Klöve (OULU)
Contributor(s)	Wieslaw Fialkiewicz (UPWR) Harrie-Jan Hendricks Franssen (FZJ)
Work Package	WP7
Delivery Date (DoA)	31/01/2024
Actual Delivery Date	31/01/2024
Abstract:	D7.3 as part of Work Package 7.3, aimed to assess the impact of the soil Water Retainer on different soil types and catchment dynamics. Initially, the USAL-developed WVSI-WRC model faced limitations, leading to an alternative approach using the HYPROP2 system. Results obtained through the HYPROP2 approach showed no influence of the Water Retainer on soil water retention curves. The more accurate but time-consuming data from the pF Determination Machine approach allowed to identify minor changes to the retention curve, which were further excplored through numerical models to quantify the influence of the water retainer on the water balance. We conclude that the application of the water retainer does not significantly influence a catchments water balance.

Document Revision History			
Date	**Version**	**Author/Contributor/ Reviewer**	**Summary of main changes**
01/11/2023	V0	Philip Brunner (UNINE)	Outline proposed
15/01/2024	V1	Qi Tang (UNINE)	Compiled input from all partners involved
18/01/2024	V2	Philip Brunner (UNINE) Qi Tang (UNINE) Arkadiusz Głogowski (UPWR) Yu Wang (USAL)	Written full draft
19/01/2024	V3	Wieslaw Fialkiewicz (UPWR) Björn Klöve (OULU) Harrie-Jan Hendricks Franssen (FZJ)	Comments and feedback
23/01/2024	V4	Qi Tang (UNINE)	Quality check, minor revisions
24/01/2024	V5	Submission to QC	Final draft
26/01/2024	V6	Sebastian Puculek (ULUND)	Quality Check
28/01/2024	VF	Rolf Larsson (ULUND)	Final Revision

Dissemination Level		
PU	Public	X
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential, only for members of the consortium (including the EC)	

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Funding Scheme: Research and Innovation Action (RIA) ● Theme: SFS-23-2019
Start date of project: 01 May 2020 ● Duration: 48 months

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WR	Water Retainer
HGS	HydroGeoSphere

1 Summary and rationale for modifications of the proposed approach

As outlined in the grant agreement, the goal of WP7.3 is to assess how the soil Water Retainer (WR) affects the physical characteristics of the soil (e.g., soil water retention curve) as a basis to understand the implications of the soil WR on the overall catchment dynamics and behaviour. Different soil types were to be analysed. In the grant agreement, the following procedure was proposed:

1) The WVSI-WRC model (A4), developed by USAL, will be applied to predict changes in the physical properties of different soil types, notably the water retention curve. This curve describes the ability of the soil to hold water at different moisture levels, which has a significant impact on plant water availability, water infiltration, drainage characteristics and overall soil structure dynamics.
2) The predicted changes to the soil water retention curve were to be implemented in physically based models available in the project to explore the large-scale influence of the soil WR on catchments.

The proposed approach of USAL was found not to be appropriate for this analysis. The key issue was related to the very large suctions applied. The experimental range of this approach was thus not suited to provide quantitative information on the suctions relevant to soil-plant-water interactions. Consequently, USAL could not deliver quantitative information on how the WR affects the soil water retention curve in the saturation and suction areas relevant to agriculture.

Once this was recognised, UNINE proposed an alternative approach based on measuring the soil water retention curve of different soil types to nevertheless provide information on how the WR affects the soil water retention curve. The modification was discussed and agreed upon at the WATERAGRI meeting in Budapest in April 2023. This approach (using the so-called HYPROP2 system) was jointly carried out by USAL and UPWR. The HYPROP2 system is capable of establishing the soil water retention curve in the range of 0 to -100 kPa range. It is based on employing a continuous evaporation process while observing the weight as well as the suction in the soil sample using mini-tensiometers. The instrument is manufactured by the company Meter Environment. A detailed description of the product is found at https://www.metergroup.com/en/meter-environment/products/hyprop-2-soil-moisture-release-curves.

The methodological implementation at USAL and UPWR is described in the upcoming sections. USAL focused on synthetic soils, while UPWR complemented the analysis with soil samples obtained in the field. In addition to the HYPROP2 analysis, UPWR carried out an additional analysis using the pF Determination Machine approach. As compared to the HYPROP2 approach, the results are more accurate. However, the time required for the measurements is significantly larger.

The HYPROP2 analysis showed that the WR did not affect the soil water retention curves in a significant way. However, the pF Determination Machine approach allowed us to identify very minor differences. These changes were implemented in 1D, physically based models simulating different soil types. The results showed that very minor changes to the soil water retention function do not have a significant influence on the soil water balance and, therefore, also not on a catchment water balance.

2 Analysis of water retention at USAL

2.1 Detailed measurement approach

In total, three types of soils formulated in the laboratory have been tested:

1) Pure sand, particle size passed sieve size 1.18mm.
2) Clayey sand 1, with 70% sand and 30% clay by weight.
3) Clayey sand 2, with 50% sand and 50% clay by weight.

The formulated soils are the typical soils in agricultural settings of the WATERAGRI project.

The WR was added into deaired water to produce the WR solutions by 0% (no addition of WR), 2%, 3%, 4% and 5% in terms of the water weight.

The experimental procedure was as follows:

1) All formulated soils were put into an oven, which was set at a temperature of 110°C, for 24 hours to achieve full dryness.
2) A specified weight of all the dried soils was taken, measured and loaded into the sample ring of HYPROP 2. The sample rings were fully filled to reach the top level of the ring. Slight compaction was carried out.
3) The fully soil-loaded HYPROP 2 sample rings were thereafter put in a container loaded with the WR solutions. The solution surface in the container was kept at the 2/3 of the height of the sample rings.
4) Setup the pressure sensors and the HYPROP 2 unit following the operation menu.
5) After 24 hours, all soil samples, which were assumed to be fully saturated by the WR solutions, were taken out and installed on the HYPROP 2 to start measurement.
6) Once tests started, the HYPROP2 automatically monitored and recorded the water pressure (tension) in the soils at two heights of the soil sample ring and the corresponding soil sample weight until the test was completed when the instrument ran out of its testing pressure range. Normally, it took 1-2 weeks to complete a test.
7) The water retention curves of the three soil types were presented in the form of normalised water saturation degree vs. suction in the unit hPa. The normalised water saturation degree was the ratio of the water content to the water content at a fully saturated state (i.e., the water content at the start of the tests). The suction is given in the form of pF.

The experimental setup is shown in Figure 1.

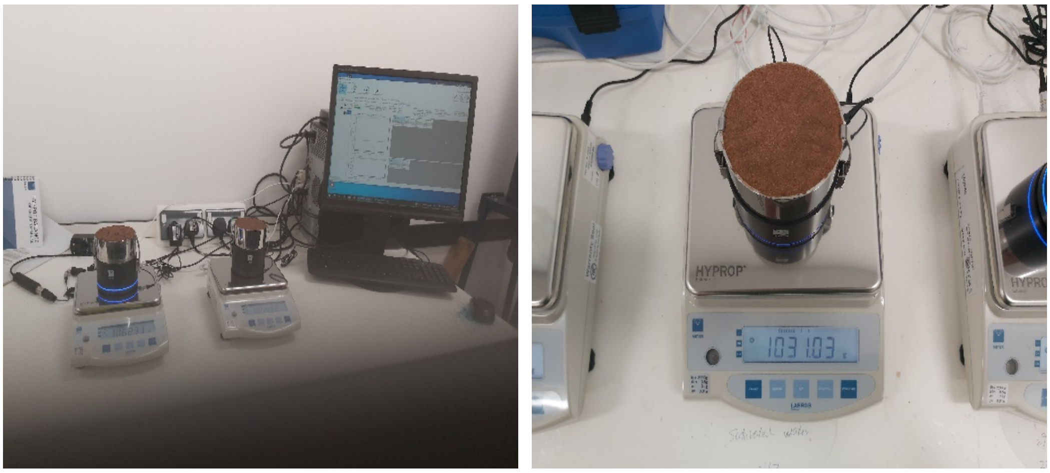

Figure 1: The HYPROP 2 SWRC test.

2.2 Results and conclusions of the USAL analysis

The following figure provides the retention curves for the different soil types using different quantities of the soil WR.

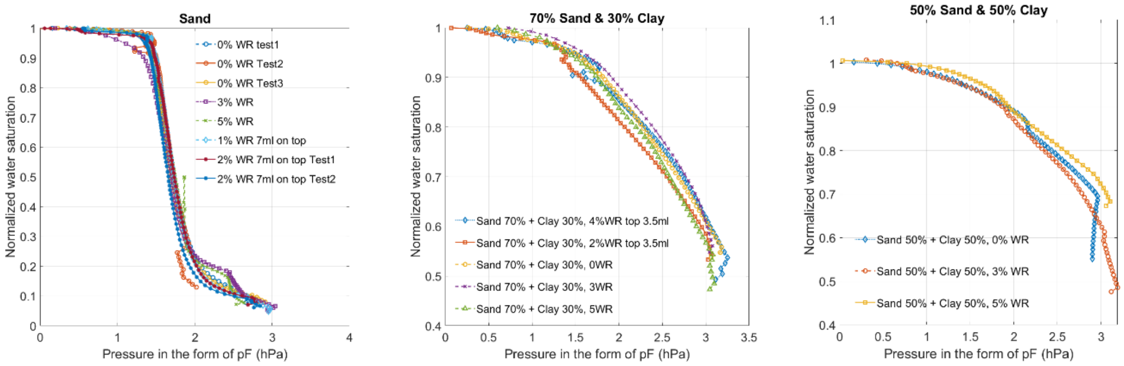

Figure 2: pF vs water saturation degree for the three different soils and different amounts of WR applied. Note the pressure is indicated as absolute values and corresponds to the suction applied. All the water retention curves are almost the same in the tested pressure range. For the sand, there were three identical tests (Test1, Test2 and Test3 in legend) performed for the case 0% WR and two same tests for the case 2% WR on top of the soil in order to validate the repeatability of the HYPROP.

Based on the experimental test results, the following conclusion can be drawn:

1. HYPROP has been successfully employed to assess the WR effect on soil water retention characteristic curves.
2. The curves of measurement have good quality of smoothness which indicates the stability of the tests. The repeating of the tests showed that the results are stable. All the tests have been successfully completed in the capacity range of the HYPROP 2.
3. The WR shows an almost neglectable effect on soil water retaining capacity enhancement in the suction range, pF = 0 ~ 3 for the pressure in unit hPa.

3 Analysis of water retention at UPWR

The analysis of the influence of the soil WR on the retention curve was analysed for soil samples obtained in the field, thus complementing the synthetic soils analysed by USAL.

3.1 Site description of Lower Silesia, Poland

(The text below is largely identical to the text in Deliverables D3.1, D6.2 and D7.2)

The Lower Silesia agricultural case study site is located in South-West Poland around Lubnów village, which is approximately 20 km North of Wrocław. In hydrological terms, the studied farm is located on the border of 2 different hydrological catchments. However, as 90 % of the area of the farm is located in the Ślęganina river catchment, only the Ślęganina River catchment was considered for the fully coupled and physically-based modelling experiments. The Ślęganina river is a tributary to the Odra river, which is Poland's second-largest river. The entire surface area of the catchment is 17.4 km^2, but for modelling purposes, the catchment was limited to 14.6 km^2 to model the catchment outlet in the location of the installed limnigraph (roughly 500 m upstream from the joint of Ślęganina and the Odra rivers). According to the climate classification by Okołowicz (1977) , the climate of the catchment is temperate warm transitional. The modelled Ślęganina river catchment and the currently implemented numerical grid are illustrated in Figure 3.

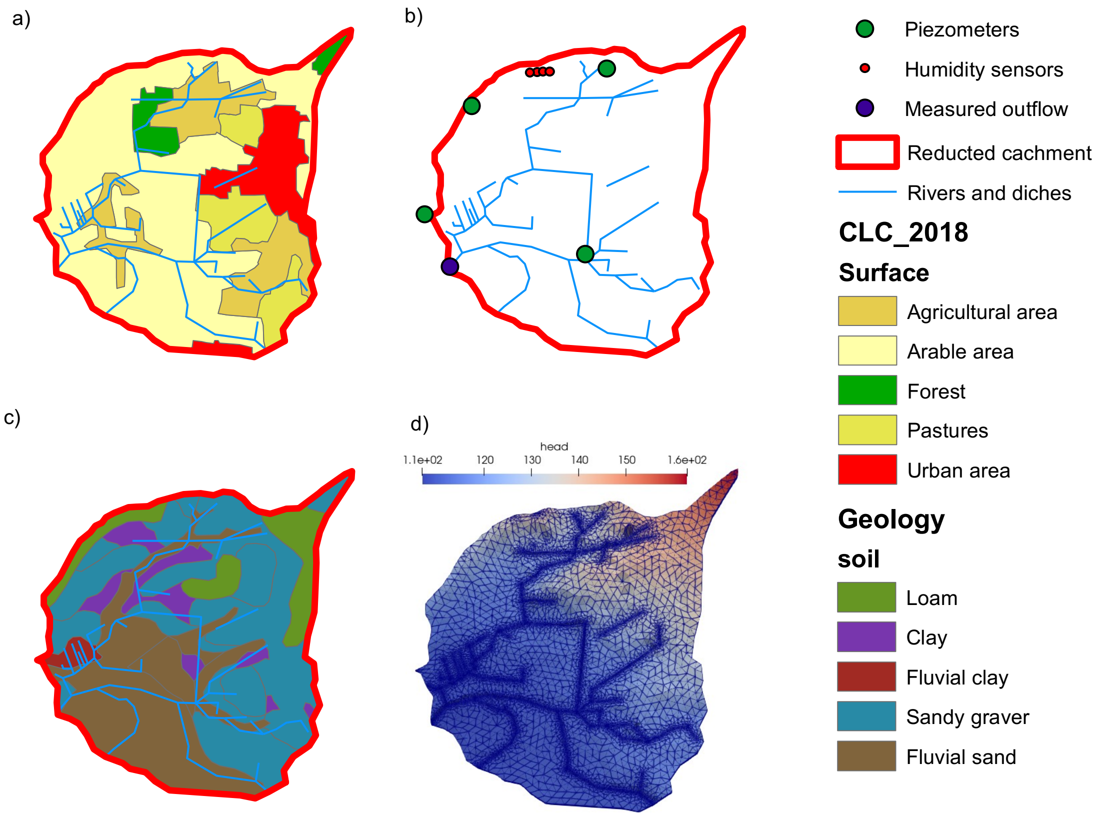

Figure 3: Maps of land cover (a), measurement network (b), soil types (c) and conceptual 3-D model of the catchment generated with HGS (d).

Mean annual precipitation at the study site, measured over the period 1991-2020, was 541 ± 95 mm. Mean air temperature over the same period was 9.7 ± 1 °C. With an average depth to groundwater table of 1-2 m, a significant amount of groundwater resides in the shallow aquifer of the study site. According to the information obtained from 20 boreholes, the shallow aquifer is limited underneath by impermeable bedrock sitting at a depth of 2-5 m, depending on the location within the catchment. The catchment area is covered with the topsoil consisting of loamy sand about 80 %, clay 5 % and silt 15 %. Below the depth of 3-3.5 m, the soil is mainly composed of clay.

3.2 Laboratory and field experimental setup

The analysis of the effect of the WR on the soil water retention curve was made for three different types of soils. The selection of the soils was made based on the granulometric composition, which was taken from one of the case study plots. From the field of 33 ha area, 59 sample points were taken from depths around 0-20 cm with an 80m distance; for each point, 10 sample points were taken (Figure 4). For the WR analysis, locations 13, 21, and 46 (Table 1) were used, and the samples were taken from these points for WR experiment one more time (numbers of sample points will be used further as a reference).

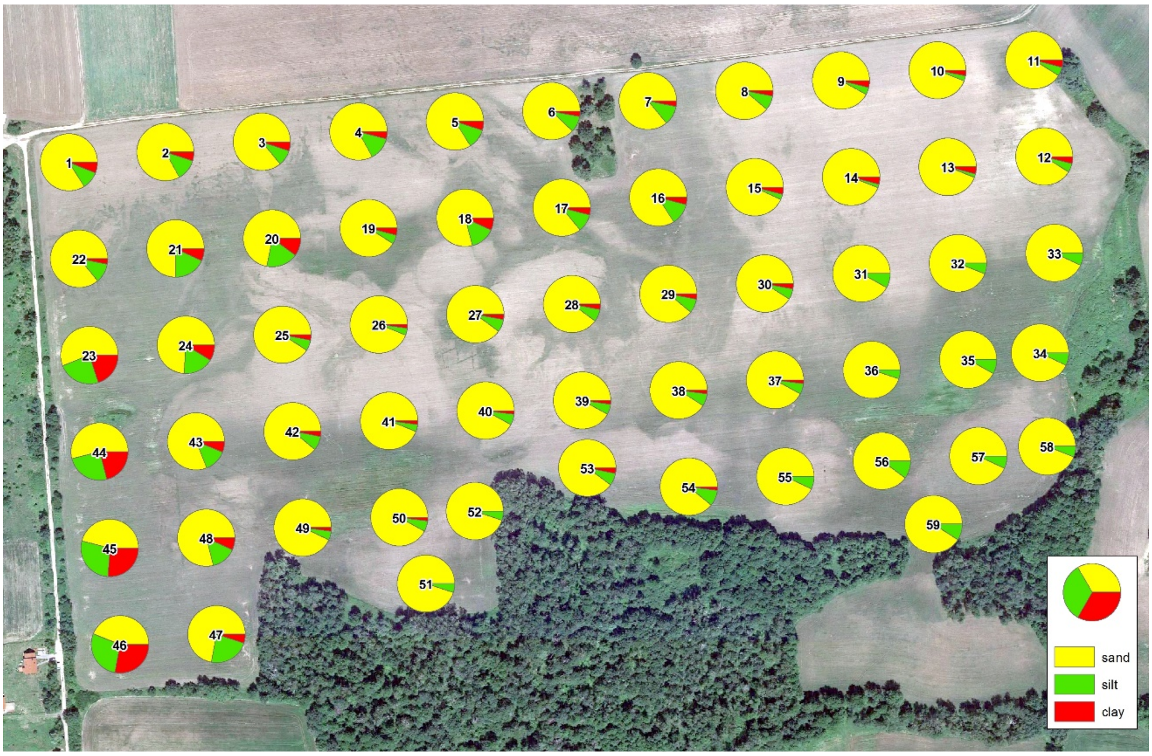

Figure 4: Location of the sample points in the experimental field with a local granulometric composition of soil.

Table 1. Granulometric composition of selected soil sample points

Soil sample point	Sand (2-0.05mm) [%]	Silt (0.5-0.002mm) [%]	Clay (<0.002mm) [%]
13	94	4	2
21	75	7	18
46	44	28	28

The producer recommends applying WR on the field with a concentration of 10 l of the product dissolved in 1000 l for 1 ha. Accordingly, to these recommendations to assess the WR effect on the soil water retention curve, the analysis was made for 4 different scenarios:

1. Without WR
2. 1 dose of WR
3. 3 doses of WR
4. 5 doses of WR

Doses of WR were designated with respect to a three-level full factorial design for the best statistical distribution.

After selecting the soil sample points and scenarios, the soil samples were taken for 2 experimental setups:

1. 36 samples (4 scenarios * 3 soil samples * 3 repetitions) in 250cm^3 (50cm^2 surface) cylinders for Hyprop 2 (Figure 5), which means that 1 dose for 50cm^2 surface is equal to 0.5ml, 3 doses are equal to 1.5ml and 5 doses are equal to 2.5ml. Similarly, as in the first setup, all samples after collection were fully saturated with distilled water. After obtaining a fully saturated state, the doses were applied on the sample surface as described above. The samples were left for a week to allow the Water Retainer to work before the measurements began.

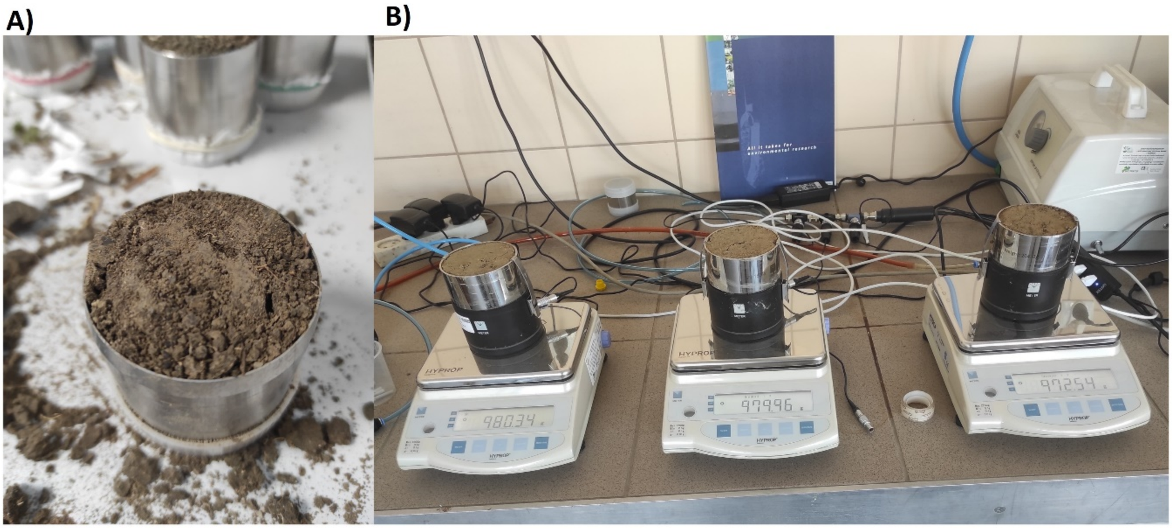

Figure 5: Example of 250cm^3 sample soils (panel A) and measurements on Hyprop 2 (panel B).

2. 72 samples (4 scenarios * 3 soil samples * 6 repetitions) in a 100 cm^3 cylinder (20cm^2 surface) for Sandbox pF Determination Machine from Eijkelkamp (Figure 6). This means that 1 dose for a 20cm^2 surface is equal to 0.2 ml, 3 doses are equal to 0.6 ml, and 5 doses are equal to 1 ml. All samples after collection have been fully saturated with distilled water. After obtaining a fully saturated state, the doses were applied on the sample surface as described above. The samples were left for a week to allow the Water Retainer to work before the measurements began.

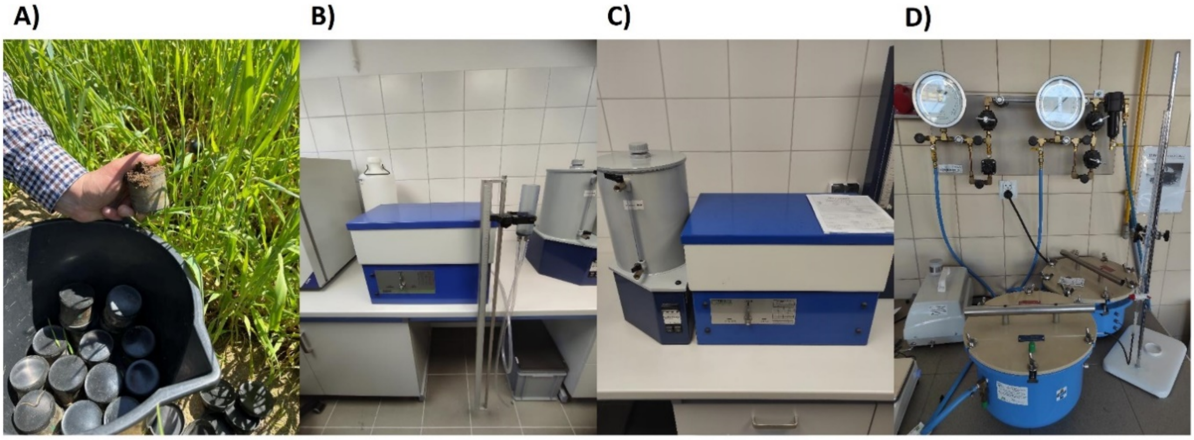

Figure 6: Example of 100cm^3 sample soils (panel A), pF Determination Machines for range 0-2pF (panel B), 2.0-2.7 pF (panel C) and 2.7-4.2 pF (panel D).

3.3 Efficiency of soil water retention of soil samples obtained in the field

3.3.1 First experimental setup (Hyprop 2)

In Figure 7 and Figure 8, all (successful and unsuccessful trials) 36 samples are presented. The unsuccessful trial is a trial for which Hyprop doesn't have data about soil moisture in relation to suction below 2.3 pF (3 points available: 1.85, 2.0, and 2.3). 9 out of 36 samples (25%) were unsuccessful (Table 2). Nonetheless, all results were implemented to analyse the uncertainty (the grey area in Figure 7 and Figure 8 represent the standard deviation) of the result for specific suctions.

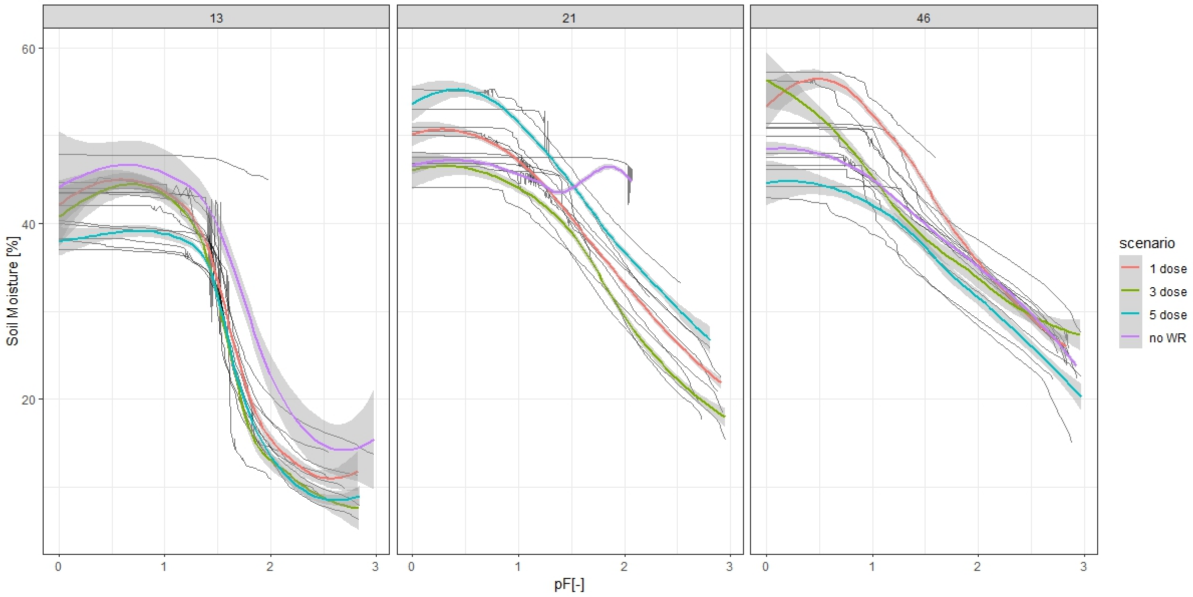

Figure 7: Soil water retention curves made in Hyprop 2 for 3 different soil types (13, 21 and 46) and 4 different scenarios (no WR, 1 dose, 3 doses and 5 doses)

Figure 8 presents a pF range from 1.85 to 2. The uncertainty of measurements does not allow us to take any conclusions as the properties of individual soils and scenarios cannot be determined.

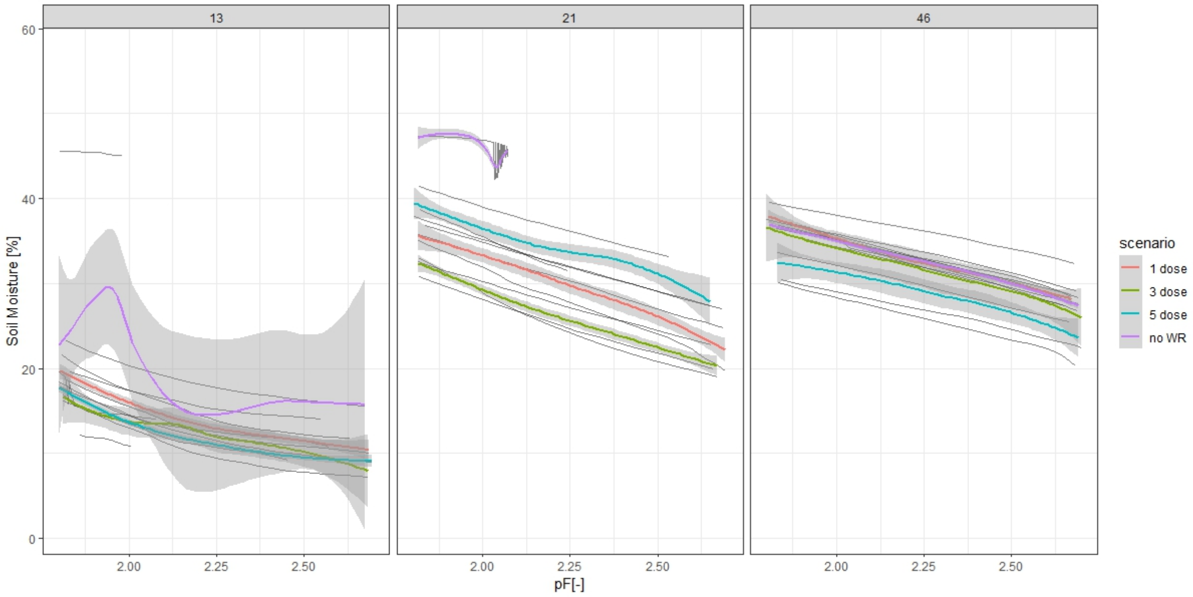

Figure 8: Soil water retention curves made in Hyprop 2 in the range from 1.8-2.85 pF for 3 different soil types (13, 21 and 46) and 4 different scenarios (no WR, 1 dose, 3 doses and 5 doses).

In addition, for soil sample 21 without WR, all 3 samples can be considered as unsuccessful, see Table 2.

Table 2. Unsuccessful trial on Hyprop 2

Scenario	Soil	Sample	Max pF value
no WR	21	12591	1.271
no WR	21	18286	1.386
5 dose	13	11114	1.591
1 dose	46	18282!	1.601
no WR	13	12589	1.980
3 dose	13	16652	2.007
no WR	21	18279	2.071
no WR	13	18278	2.078
5 dose	21	12570	2.242

Removing unsuccessful trials (Figure 9) makes results more understandable, there is nevertheless no clear pattern to distinguish a positive effect of WR by Hyprop 2 measurements.

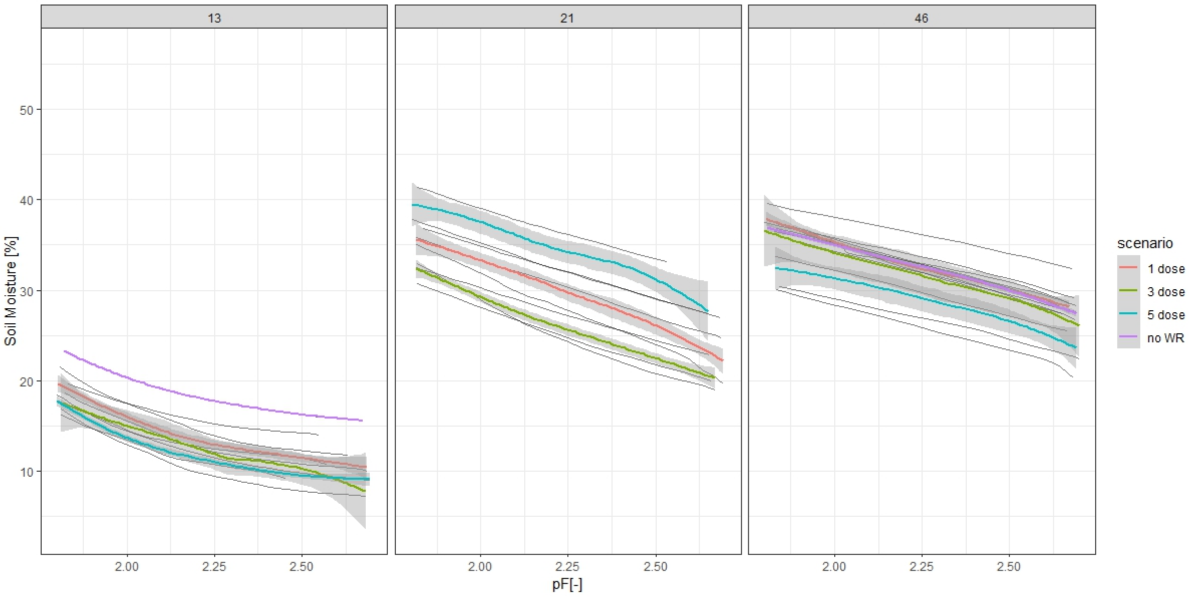

Figure 9: Soil water retention curves made in Hyprop 2 in range from 1.8-2.85 pF without unsuccessful trials.

The Hyprop 2 measurements do not allow us to quantify a significant influence on the retention curve.

Consequently, an alternative approach was employed with the pF determination machine analysing 72 samples.

3.3.2 Second experimental setup (pF Determination Machines)

The results of the pF determination machine are shown in Figure 10.

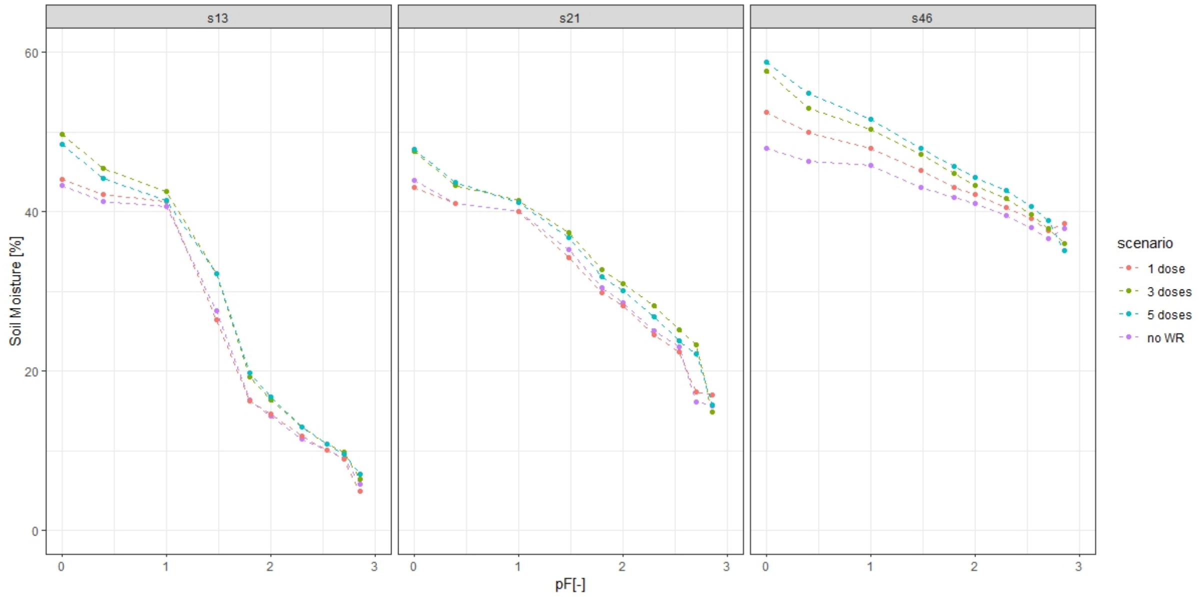

Figure 10: Soil water retention curves in the range from 0 to 2.85 (700 bar) for 3 different soil types (13, 21 and 46) and 4 different scenarios (no WR, 1 dose, 3 doses and 5 doses)

As a result, we can see that increasing the concentration of WR affects the soil water retention curve. The difference is not very pronounced, especially in a range from 1.8 pF, where plants have the best water-air conditions (1.8 pF), to a threshold of 2.85 pF, where plant growth inhibition begins. The water available for plants depends on the scenario and varies from 0.7% to 6.7% (which indicates the difference between pF 2.85 and 1.8 in each scenario). There is only one (out of 9) case where the application of WR has a negative impact in comparison to no application (soil 21 1 dose). In general, the experiment conducted with the standard pF Determination Machines (Figure 6) shows that the WR increases the capability of soil water retention from 2 to 10 % (see Table 3)

Table 3. Thresholds of soil moisture available for plants for different soils and doses match with the total amount of water available for plants

Scenario	Soil	Soil Moisture [%]		Max. relative soil moisture (MS) [%]	Water available for plants in soil (WAPS) [%]	Percentage of water content in the soil [WAPS/MS]
		1.8	2.85			
no WR	13	16.3	5.8	43	11	24%
1 dose	13	16.2	4.9	44	11	26%
3 doses	13	19.3	6.3	50	13	26%
5 doses	13	19.7	7.1	48	13	26%
no WR	21	30.5	15.6	44	15	34%
1 dose	21	29.9	16.9	43	13	30%
3 doses	21	32.7	14.8	48	18	38%
5 doses	21	31.9	15.7	48	16	34%
no WR	46	41.8	37.9	48	4	8%
1 dose	46	43.1	38.5	53	5	9%
3 doses	46	44.8	35.9	58	9	15%
5 doses	46	45.7	35.2	59	11	18%

Based on the results presented in Figure 10, the van Genuchten parameters were determined by fitting them to the minimum value of Summary Root Mean Square Error (SRMSE) of soil moisture in all measured pF points (Table 4). The Van Genuchten parameters allow us to fit the measured points to obtain a full water retention curve. The fitting retention curve for all scenarios has an insignificant change of SRMSE despite the scenario with soil sample 46 and 5 doses where the SRMSE = 235.97. Figure 11 provides examples of fitted curves where the right panel presents the most uncertain match of the fitted retention curve according to measurements. The big SRMSE values are explained by the high difference between a high pf value of 3.9 and the first two pf values of 0.4 and 1.0.

Table 4. Fitted van Genuchten parameters based on measurements from pF determination machines

Sample	Scenario	alpha	beta	SRMSE
13	noWR	0.051	1.75	18.35
13	1 dose	0.052	1.741	20.15
13	3 doses	0.052	1.72	16.45
13	5 doses	0.0642	1.637	14.27
21	noWR	0.028	1.5	26.53
21	1 dose	0.0352	1.425	24.34
21	3 doses	0.0427	1.42	36.03
21	5 doses	0.05	1.345	33.78
46	noWR	0.046	1.234	20.41
46	1 dose	0.0595	1.199	34.31
46	3 doses	0.13	1.163	31.89
46	5 doses	0.031	1.298	235.97

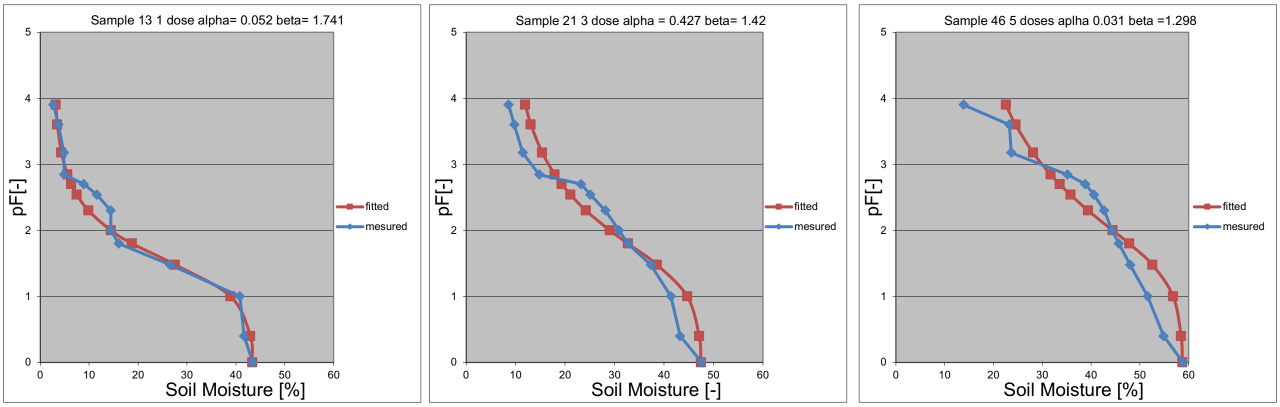

Figure 11: Examples of fitted retention curve according to the measurements based on the pF determination machine.

3.4 Conclusions on the analysis of the Water Retainer on the field samples

The influence of the WR established using the Hyprop 2 approach is negligible. The analysis of the pF determination machine provides better results because the measurements are conducted with more stable conditions and take much more time. Nonetheless, the WR may affect different soil properties than only physical properties such as organic matter, which was not analysed in this case.

4 Exploration of the influence of the Water Retainer on the soil water balance using numerical models

The application of the pF determination machine allowed us to identify changes to the soil water retention curve. Albeit very minor, their influence on the soil water dynamics was nevertheless explored with a physically based model simulating unsaturated flow and evaporation dynamics in the unsaturated zone. For this, the numerical model HydroGeoSphere (HGS) (Aquanty, 2020) was employed. The numerical implementation of this model was described in deliverables D3.1, D6.2 and D7.5 and is thus not repeated here.

4.1 Model setup

To explore how the changes in soil water retention affect soil water dynamics, 1D soil columns were implemented in the numerical framework. This step is based on the fitted retention curves based on the measurements of the pF determination machine.

The simulation strategy was as follows: The models simulate a highly saturated soil column (degree of saturation equal to 80%) exposed to continuous evaporation. The potential evaporation employed is 3cm per day. For different soil types, with and without a WR, we expect the water content in the soil to stabilise at different levels. These properties are conceptualised as van Genuchten parameters (α and β) in the HGS models, and their values are fitted based on the results of the laboratory experiments measured by the pF determination machines. For each of the three soil types, two groups of α and β are determined separately for samples with and without water retention, i.e. six groups in total. The values are provided in Table 4.

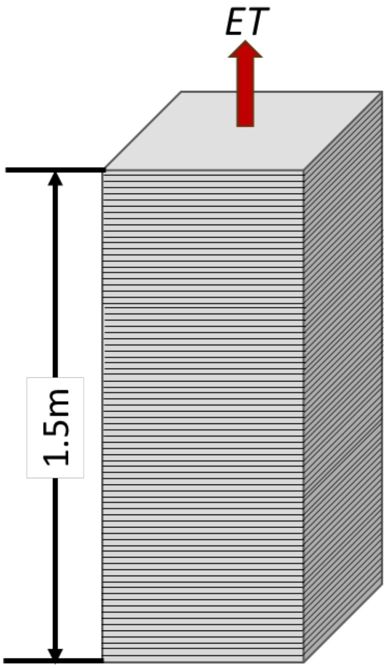

Figure 12: 3-D view of the model domain and model boundary conditions.

The models were set up in the following way: We represent each collum as a single collum in the physically based model HGS. These grid cells have a horizontal area of 1m x 1m and are divided vertically into 150 layers from the surface down to 1.5m, with a constant depth of 1cm for each layer

(Figure 12). The fine vertical discretisation guarantees numerical stability when solving the Richards equation. Potential evaporation is defined as the boundary condition for both the surface and the subsurface domain. For all other outer faces except the top face, no flow boundary condition was set.

4.2 Influence of Water Retainer on simulated soil water saturation

Two examples of soil samples are given here (Figure 13), showing the changes in water saturation over time at a depth of 10 cm below the surface. These examples represent all observed behaviour of all simulations. For both soil samples, we can observe slight differences between the two simulations. For soil sample 13, when a WR is used, a slightly higher saturation is observed in the first 2 days compared to the simulation without a WR, but this is no longer the case in a longer-term effect. For soil sample 46, the conclusion is the opposite. After 12 days, water saturation appears to be higher when a WR is used. However, these simulations are very sensitive to the model parameters (e.g. porosity, ET parameters, etc.). Note also that the fit of the measured data is not perfect (see Figure 11). This uncertainty is likely the cause of the parameters mentioned above. Given the relatively small changes to the water retention curve, these uncertainties are important.

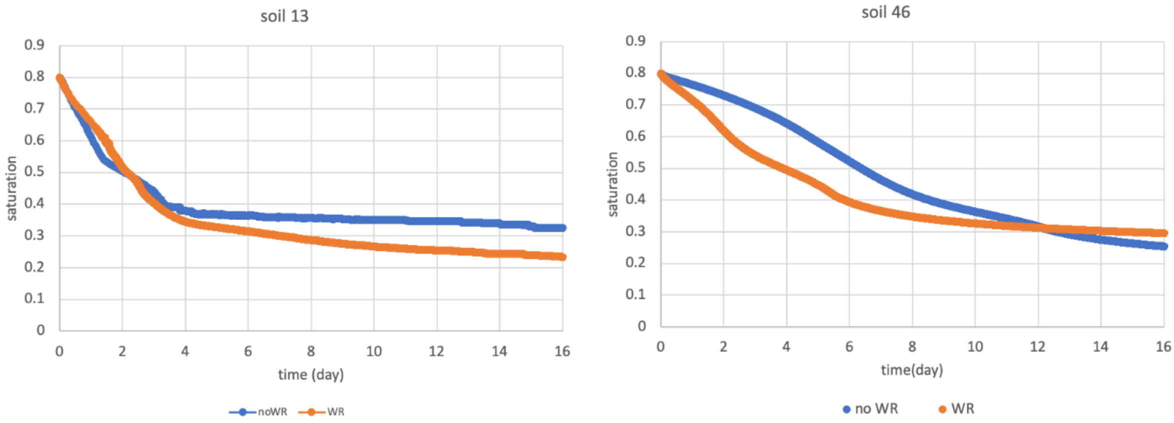

Figure 13: Changes in soil water saturation (possible values: between 0 representing no water content, and 1 representing full saturation) at 10 cm depth as a function of time for (left) soil sample 13 and (right) soil sample 46. The blue lines represent simulations where no WR is used for the soil, while the orange lines represent simulations where the WR is used on top of the soil. For soil sample 13, the WR concentration is 5%, and for soil sample 46, the WR concentration is 3%.

5 Discussion

Two experimental approaches were applied to synthetic and field-based samples. From a methodological point of view, the following points need to be highlighted:

1) Hyprop 2 measures weight changes in the sample automatically and continuously, while pF Determination Machines need to be done manually and on selected pressure points. As such, the Hyprop 2 approach is easier to use and, as such, conceptually well-suited for this analysis.
2) From an experimental point of view, it is very difficult to conduct measurements at a range from 2-2.85 pF on Hyprop 2, especially on sandy soil, which was analysed in this experiment.
3) Measurements in Hyprop 2 are sensitive to surrounding conditions (air temperature and humidity), which have impacts on the results. These uncertainties are small, but given the relatively modest change to the retention curve through the WR they are not negligible. The uncertainties related to the field samples are considerably higher. This is most likely due to

the increased heterogeneity of the soil samples- as opposed to uniform samples analysed by USAL.

4) The pF determination machine is not sensitive to the issues mentioned above and can thus provide slightly more accurate results.

The Hypro2 measurements from USAL and UPWR are coherent and show no significant impact of the WR on the retention curve. Using the pF determination machine, an influence of the WR on the retention curve could be identified. Soil properties of retaining the water increase from 2 to 8 %.

Different degrees of fit of the Van Genuchten model to the measured points were obtained. Some soils could not be well fitted, which explains the unexpected behaviour of the Water Retainer in the numerical models (i.e. the WR seems to have a negative effect on retention in soils 46, see Figure 13). Overall, the WR does not have a very important influence on the wide range of soils tested. We thus conclude that a catchment's water balance is essentially unaffected by the WR, independent of the soil type and doses of the WR.

It is noteworthy that in the field the WR had a positive effect on the crop yield (see D3.2). For an explanation, in all experiments that were conducted on the fields in Poland with the use of a WR, the yield was higher from 7 to even 30% per ha. Note that in this specific case, the effort and the material needed for applying the WR product was so high that the total economical result was not economically beneficial for the local conditions.

6 Conclusion and Outlook

The following conclusions can be drawn:

- We observed a slight increase in water retention after applying the WR. This finding could only be identified by the pF determination machine and not through the Hyprop 2 approach.
- Despite being a versatile and reliable approach, the uncertainties related to the Hyprop 2 approach are of the same magnitude as the potential changes through the WR. For further studies related to the influence of the WR on the soil retention curve, we strongly recommend the application of the pF determination machine.
- The implementation of the modifications to the water retention curve in numerical models strongly suggests that the WR will not significantly affect catchment's water balance. These findings are valid for all the different soil types analysed.
- The WR applied to the field caused a measurable increase in yield. This might, to a certain extent, be related to the observed, in most cases, slight increase in water retention. However, the exact mechanisms of how the increase in yield can be explained remain unclear.

For further assessments on the WR, we recommend testing it on a plot scale. Ideally, monitoring yield and soil water dynamics in two adjacent fields with and without the application of the WR should allow for a full assessment of the efficiency, both in terms of production and also concerning the economic net- benefits.

7 References

Aquanty, I., 2020, HydroGeoSphere: A three ‐ dimensional numerical model describing fully ‐ integrated subsurface and surface flow and solute transport, Waterloo, Aquanty, Inc.