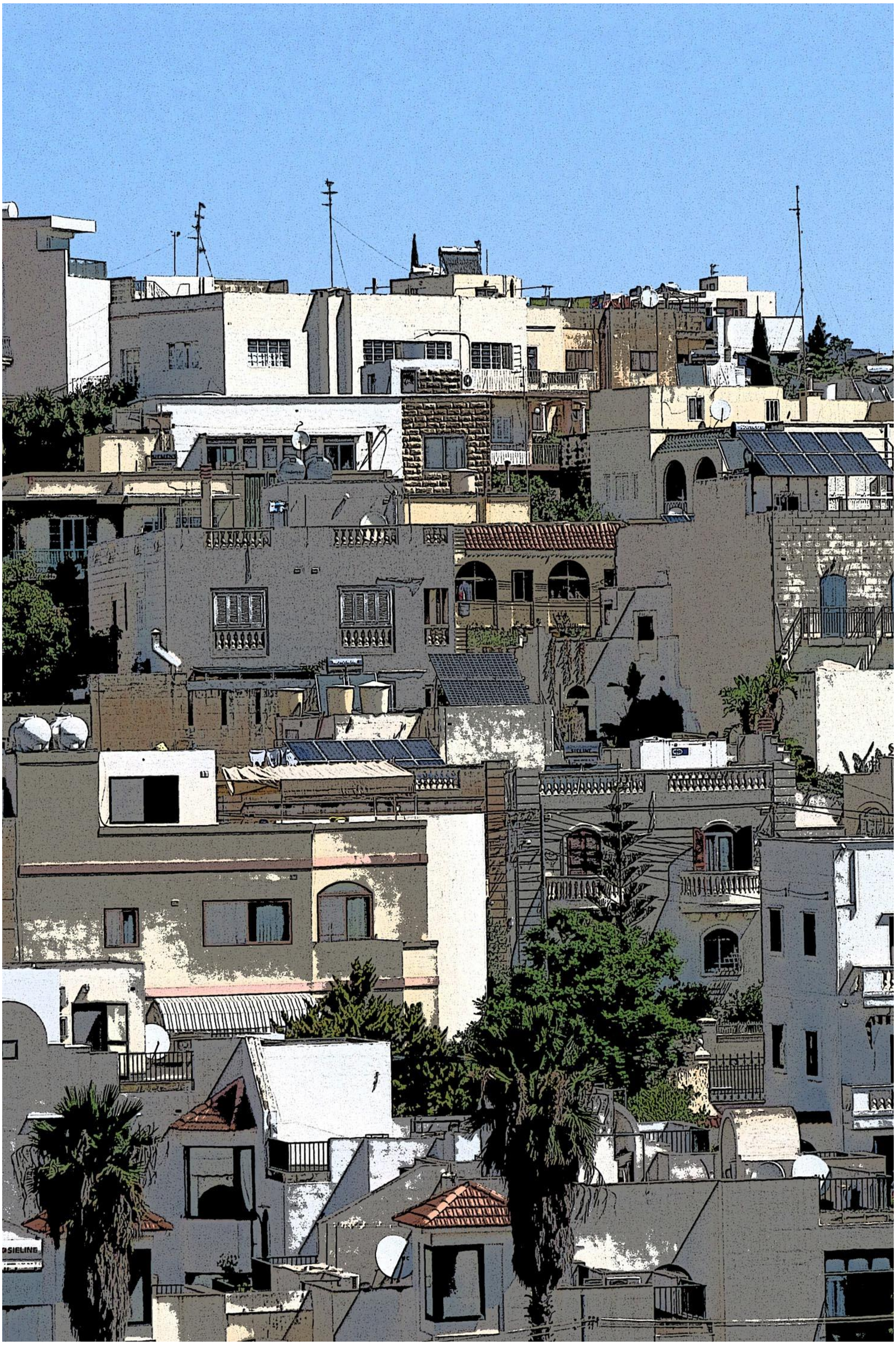


LifeMedGreenRoof Project

Storm water management

LIFE12ENV/MT/000732

LifeMedGreenRoof Project

MEETING ENVIRONMENTAL TARGETS

Table of Contents

List of tables

Table of figures

1. Introduction

Many studies have shown that green roofs provide a number of benefits to urban areas. Benefits can be categorised between 1. those related to the property user/owner, 2. those related to the community and 3. those to the environment. Green roofs provide amenity space and create a welcoming extension to a dwelling or commercial premises. This results in the aesthetical improvement of the roof space and urban landscape. Due to evapotranspiration and the increase in thermal mass, greened roofs reduce heat stress in buildings (Jim, 2014) (Zhao, et al., 2014,). The plants and related structure help to buffer noise (Tolderlund, 2010) (Renterghem & Botteldooren, 2014), improve of air quality (Rowe, 2011), and create habitats for wildlife (Rowe DB, 2012) (Washburn, et al., 2016) to mention but a few. They also provide economic benefits in terms of job creation and increase property value (IchiharaJeffrey & Cohen, 2011) (Tomalty & Komorowski, 2010). Through their insulation properties and decreased exposure to climatic factors, green roofs reduce the carbon footprint of buildings and even prolong the lifespan of damp proofing and structural slab, reducing maintenance costs and maintenance time as well as reducing waste material.

Typical Public and Private Benefits of Green Roofs

Community benefits	**Private benefits**
Aesthetic improvement	Aesthetic improvement
Reduces the urban heat island effect and peak load energy demand	Energy savings
Improves air quality	
Increases biodiversity	Urban agriculture revenue potential
Increases tax revenues	Improves marketability
	Increases property value
Creates local jobs	Reduces employee absenteeism
	Increases employee productivity
Decreases infrastructure costs	Increases roof membrane durability
Improves storm water management - quality and quantity	Meets storm water and green space regulations
Facilitates new recreational/educational opportunities	Facilitates new recreational/educational opportunities
Reduces greenhouse gas emissions	Improves solar panel efficiency (PV panels)
Improves community health and well-being	Improves amenity, health and well-being

Storm water management or flood mitigation is another of the benefits of green roofs. Green roofs absorb and retain precipitation. Both the growing medium and the vegetation have the ability to absorb rain, reducing flooding. By intercepting and retaining water from the early parts of the storm, green roofs limit the release rate of storm water during rain events. Additionally, water is also stored in the green roof depending on the type of drainage module used. Some drainage modules are able to retain a substantial amount of water helping to reduce flooding. Once the green roof system is saturated, the substrate releases the water gently into the drain. The volume of water retained by the substrate depends on the occurrences and intensity of rain events. Research found that the closer the occurrences, the less water is retained. (Berndtsson , 2010) (Stovin, et al., 2012)

The depth of substrate also contributes to the extent by which flooding is mitigated. The deeper the substrate the more water is trapped within it. The make-up of the substrate, the type of drainage layer used, roof slope and vegetation type and density have been found to contribute towards water retention. (Burszta-Adamiak, 2012) (Tolderlund, 2010)

The percentage of water retention is determined by calculating the difference between the volume of precipitation measured and the run-off water volume on an annual average. This leads to the annual coefficient of discharge, the ratio between the annual rain water run-off amount and the annual rain volume.

The **coefficient of discharge** is the quotient of run-off volume and rain volume during block rainfall. Tests are carried out in a non-greening condition of the roof. On the other hand, the **annual water retention** is the difference between precipitation and drainage in % of precipitation amounts.

Coefficient of discharge (C) is calculated using the following formula:

$$= \frac{Runoff\ in\ lt}{rain\ volume\ lt}$$

The annual water retention depends on the type and density of green roof construction. The FFL sets out reference values for % water retention - 60% for extensive green roofs with a course depth of >15- 20 cm and coefficient of discharge / sealing coefficient of 0.40. These figures relate to locations with an annual precipitation of 650-800mm. In regions with lower precipitation as in Malta, water retention was expected be higher. Depth and type of growing medium will affect these figures.

2. Objectives

This report is being drafted as part of action C1 and C2 of the LifeMedGreenRoof project. One of the objectives of this action was to determine the effectiveness of green roofs in mitigating flooding in a Mediterranean environment. As part of the project two demonstration green roofs were constructed and used to establish their performance in terms of water run-off (apart from thermal insulation and plant selection - see relative reports). The performance of both green roofs in terms of flood mitigation will also be examined to establish how climate differences impact green roof behaviour. Even though North Italy and Malta are considered Mediterranean, there are difference in climatic character. North Italy is more temperate with cold winters and fair summers whereas the Maltese climate is more arid, having fair winters and dry summers. Climate change also has an impact on the characteristics of climate. (Galdies, 2011)

3. Methodology

Experimental set up - MALTA

A plot on the demonstration green roof was selected from which precipitation was collect for quantification purposes.

Run-off was quantified utilising a KIPP1000. The KIPP1000 is a tipping counter which measures water flows of up to 75 litres per minute. It has a resolution of 1000ml per tip. It has an integrated counter for stand-alone operation however an external data logger was connected to record the pulses. Because of the resolution of the KIPP 1000, a balance was installed to record run-off inferior to 1 litre. The balance used is a Mettler-Toledo MS32000LE/01. This balance has a maximum capacity of 32kg reading at an accuracy of 1g with a margin of error (at nominal load) of 0.4g.

The area of the plot from which run-off was being monitored has a surface area of 32.61m^2. The plot was infilled with 200mm deep Malta 1 green roof substrate as prepared by Minoprio Analisi e Certificazioni over a layer of screed laid to falls at 2%. Only 1x 50mm drain pipe was installed which was linked to the KIPP1000 tipper counter.

The green roof layers used include a root protection layer FLW-500 manufactured by Diadem above which were laid 25mm high density polystyrene sheets to act as a protection layer. Above these sheets were laid recycled polyethylene drainage boards, type DiaDrain – 40 manufactured by Diadem. These drainage boards have a water retention capacity of 13.4l/m^2. Water flow capacity (i=0.01) of 1.60l/(mxs), and a compressive strength(unfilled) of 125.7kN/m^2. The drainage boards were laid so as not to retain any water within the system.

Figure 1 The green roof plot used to quantify run-off in Malta

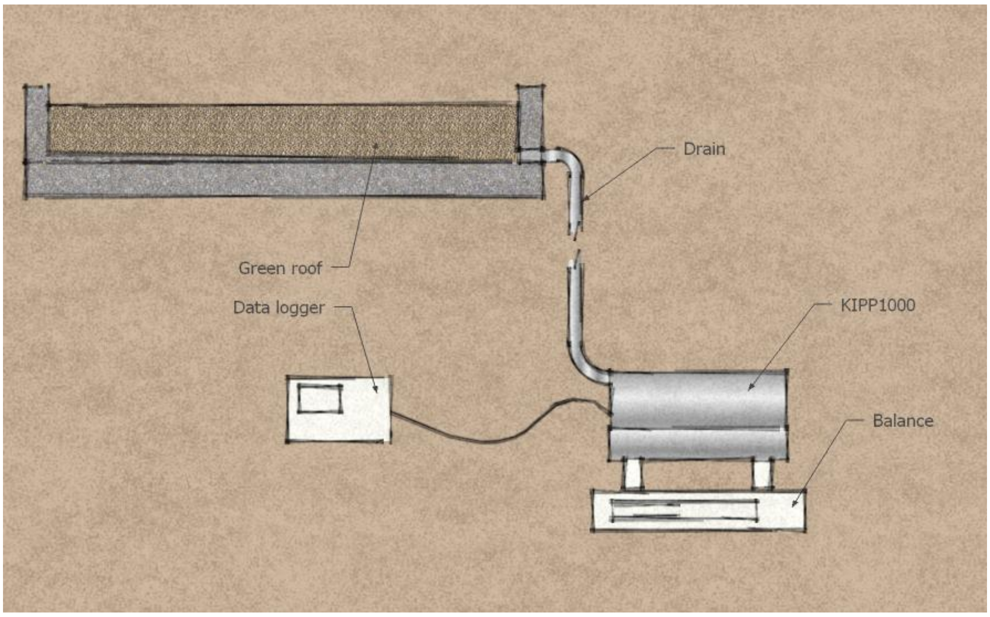


Figure 2 Experimental set-up for measuring the water run-off from the experimental green roof.in Malta

A weather station was set up to measure the prevailing weather conditions. Precipitation was measured using the rain gauge from NESA ANS PL400 – N.

Figure 3 The weather station on the experimental green roof used - Malta

Experimental set up - ITALY

A plot on the demonstration green roof was selected from which precipitation was collect for quantification purposes.

Run-off was quantified utilising a KIPP1000. The KIPP1000 is a tipping counter which measures water flows of up to 75 litres per minute. It has a resolution of 1000ml per tip. It has an integrated counter for stand-alone operation however an external data logger was connected to record the pulses. Because of the resolution of the KIPP 1000, a balance was installed to record run-off inferior to 1 litre. The balance used is a Mettler-Toledo MS32000LE/01. This balance has a maximum capacity of 32kg reading with an accuracy of 1g with a margin of error (at nominal load) of 0.4g.

The area of the plot from which run-off was being monitored has a surface area of 25 m^2. The plot was in filled with 100 mm deep MAC7 green roof substrate as prepared by Minoprio Analisi e Certificazioni over a layer of screed laid to falls at 2%. Only 1x 100mm drain pipe was installed which was linked to the KIPP 1000 tipper counter by a tube of 40 mm ø.

The green roof layers, placed above the waterproof membrane consist in a root protection layer, a drainage layer and a filter fabric. These three layers are combined into a single element board (DP1 – Tenax S.p.A), a combination of drainage cusp shaped membrane and geotextile (see technical data sheet below).

PHYSICAL CHARACTERISTICS	TEST METHOD	UNIT	DP1	NOTES
MEMBRANE POLYMER			HDPE	-
GEOTEXTILE MEMBRANE			PP	-
U.V. STABILIZER			CARBON BLACK	-

DIMENSIONAL CHARACTERISTICS	TEST METHOD	UNIT	DP1	NOTES
MASS PER UNIT AREA	ISO 9864	g/m^2	1400	a
MEMBRANE THICKNESS	ISO 9863	mm	0.5	a
THICKNESS AT 20 kPa	ISO 9863	mm	8.0	a
RESIDUAL THICKNESS AT 200 kPa	ASTM D1621	%	> 85	a
MEMBRANE EDGE		mm	40.0	a
GEOTEXTILE NON-WOVEN EDGE		mm	100.0	a
ROLL WIDTH		m	1.50	a
ROLL LENGTH		m	20.0	a
COVERED AREA		m^2	30.0	a
ROLL DIAMETER		m	0.48	a
ROLL VOLUME		m^3	0.37	a
GROSS ROLL WEIGHT		kg	43.0	a

TECHNICAL CHARACTERISTICS	TEST METHOD	UNIT	DP1				NOTES
HYDRAULIC FLOW RATE		i =	1.00	0.03	0.02	0.01	
σv = 10 kPa	ISO 12958	m^2/s	4.15 E-03	5,83 E-04	4,77 E-04	2,75 E-04	a,b,c
σv = 20 kPa	ISO 12958	m^2/s	4,10 E-03	5,77 E-04	4,71 E-04	2,72 E-04	a,b,c
σv = 50 kPa	ISO 12958	m^2/s	4,04 E-03	5,63 E-04	4,60 E-04	2,65 E04	a,b,c
σv = 100 kPa	ISO 12958	m^2/s	3,97 E-03	5,48 E-04	4,47 E-04	2,58 E-04	a,b,c
σv = 200 kPa	ISO 12958	m^2/s	3,85 E-03	5,41 E-04	4,42 E-04	2,55 E-04	a,b,c
TENSILE STRENGTH	ISO 10319	kg/m	2200				a, b
ELONGATION AT PEAK	ISO 10319	%	60				a, b

GEOTEXTILE CHARACTERISTICS	TEST METHOD	UNIT	DP1	NOTES
MASS PER UNIT AREA	ISO 9864	g/m^2	200	a
OPENING SIZE	ISO 12956	mm	0.10	a

Table 1 Tenax DP1 data sheet

Figure 4 The green roof plot used to quantify run-off in Italy

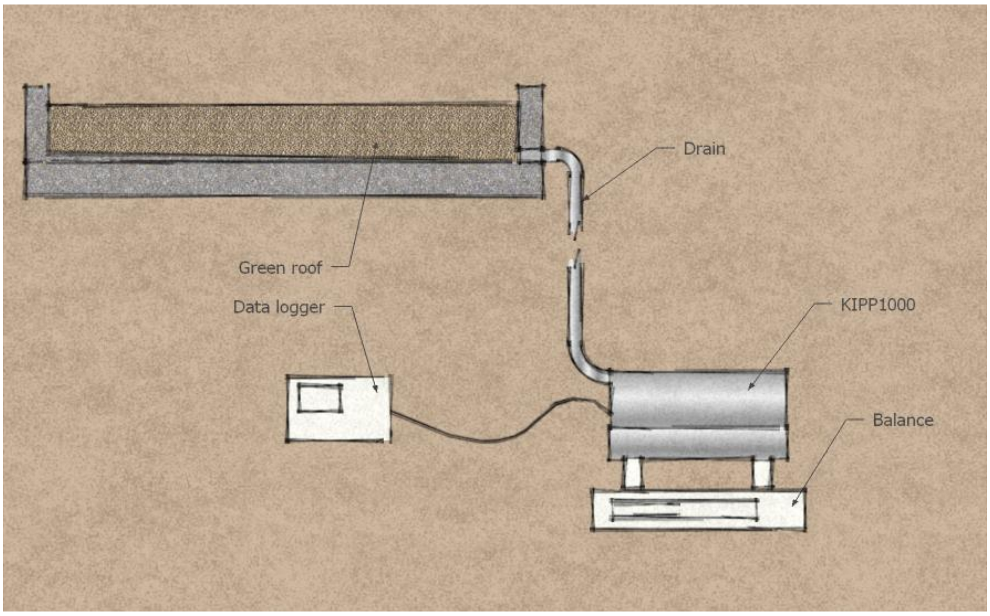


Figure 5 Experimental set-up for measuring the water run-off from the experimental green roof.

A weather station was set up to measure the prevailing weather conditions. Precipitation was measured using the rain gauge from LSI Lastem.

Figure 6 The weather station on the experimental green roof - ItaLy

Substrate Characteristics

Following the results obtained during the preparatory actions and the monitoring activity, 6 different types of substrates have been selected by MAC. Three of these have been used at the University of Malta: MT1 and MT2 have been used on the demonstration green roof whereas MC7 and MT1 have been used in the experimental plots. In Italy four growing media have been used on the demonstration and experimental green roof: MAC7(IT), MAC7/T, MAC7/FC, TA.

In the following table and chart the composition of the selected growing media is being reported.

Table 2 Components and percentages of use (volumetric) for the selected growing media

	MAC7*	MAC7/T	MAC7/FC	TA	MT1	MT2
PUMICE				45	35	30
PUMICE	30	30	30			
LAPILLUS					40	35
EX CRASHED CLAY	40	40	40	30		
peat 0-25	15	20		10	15	10
coconut fiber 0-25			20			
green compost	5	10	10	9	10	10
biochar	10			6		15

* There are two different versions of MAC7: MAC7/IT (in use in Italy) and MAC7/MT in use in Malta. The difference between these substrates is the type of biochar used in the mix. In the Italian version biochar is in pellet form, while in the Maltese version chippings are used.

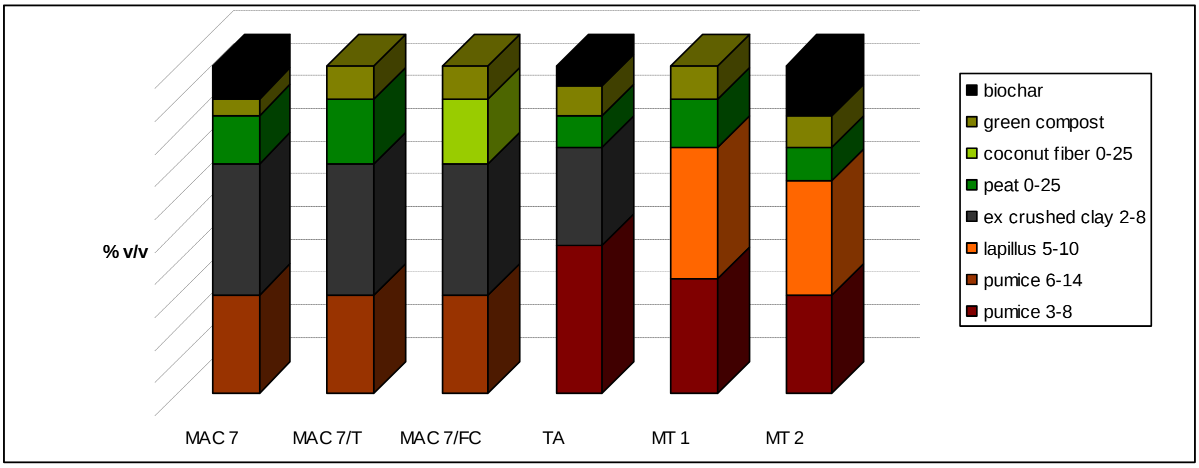


Figure 7 Substrate composition

Chemical and physical properties of the selected substrates have been established following numerous laboratory tests. Tests were conducted in accordance with the Italian and German standards (UNI 11235:2015 and FLL-2008). Below is the report of the average results obtained.

In the first table the particle size distribution was determined. This property influences media performance, such as water retention, bulk density and also the vegetation growth. Data is also shown graphically in the following figure.

All the substrates are in accordance with the Italian and German Standard for green roofs.

Table 3 Particle size distribution for the selected growing media

CODE	PARTICLE SIZE DISTRIBUTION (% w/w)									
	<0,05 mm	<0,15 mm	<0,25 mm	<0,50 mm	<1 mm	<2 mm	<5 mm	<10 mm	<16 mm	<20 mm
MAC 7/IT	0	2	3	8	14	20	64	83	99	100
MAC7/T	0	2	5	13	21	29	84	92	98	100
MAC7/FC	0	1	3	10	17	25	75	84	100	100
TA	0	2	5	10	13	17	74	100	100	100
MT1	0.5	4.5	8.5	14	17	21.5	50	99.5	100	100
MT2	0.5	4.5	9	16	21.5	28.5	58	100	100	100
MAC7/MT	1	3	6	12	16	21	65	90	98	100

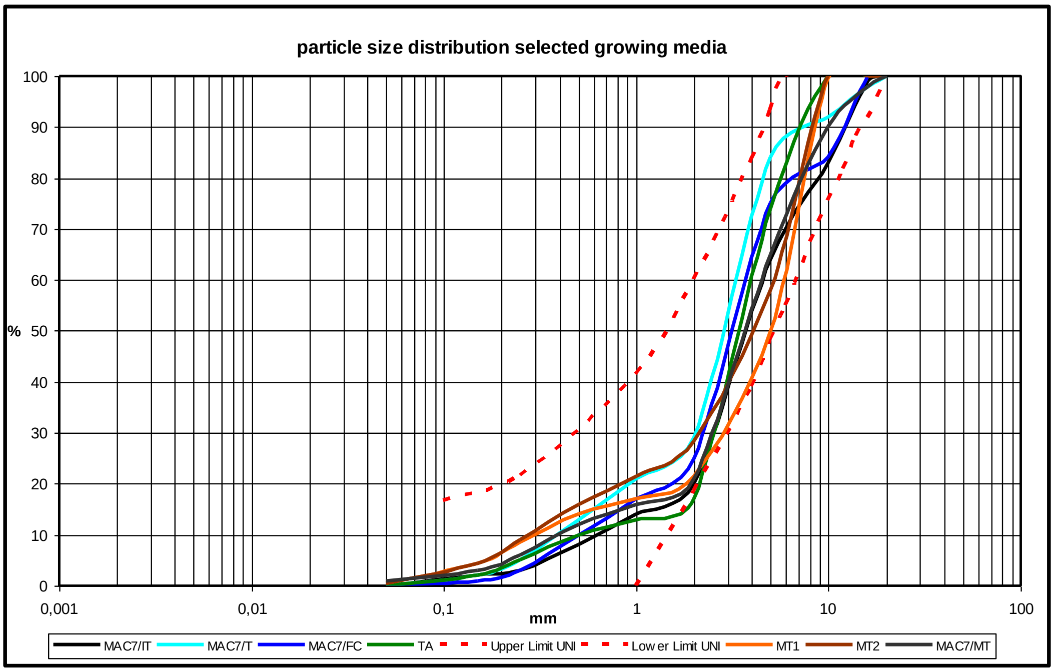


Figure 8 Chart for particle size distribution for the selected growing media

In the following table the main chemical properties are being reported. It is possible to observe that there is a substantial difference between the bulk density of the Italian growing media when compared to the Maltese ones. This was due to the difference in building construction practices. In Italy lighter substrates were needed due to the lower load bearing capacity.

All the substrates have properties in line with the green roof standards. However, MT 2 displays an initial high pH value which was due to the presence of biochar in this substrate. The pH level was eventually reduced after some time when the substrate was used on site.

Because the presence of biochar within a substrate influences the value of organic matter, corrections within the chemical analysis had to be made. As such the last column of Table 4 (organic matter without biochar) is what has to be considered. The level of organic matter had to be corrected proportionally to the presence of carbon from biochar. Cation exchange capacity parameter (CEC) shows high values for all the substrates. CEC is an important indication of the ability of growing media to hold and exchange with plant roots nutrients, thus reducing leaching.

Table 4 Chemical properties for the selected growing media

CODE	CHEMICAL PROPERTIES						
	Compacted bulk density (g/l)	pH (unit)	Salinity (mS/m)	CEC (meq/100 g)	Organic matter % dm	Organic matter g/L	Organic matter without biochar g/L
MAC 7/IT	568	7.8	21.0	42.3	18.89	80.96	34.00
MAC7/T	520	7.6	25.0	45.6	13.26	54.01	54.01
MAC7/FC	532	7.8	23.0	38.8	9.46	36.12	36.12
TA	525	7.7	33.0	30.6	13.79	58.98	32.44
MT1	768	7.8	13.5	34.6	7.18	49.90	49.90
MT2	715	9.1	19.0	20.2	19.61	122.89	67.59
MAC7/MT	449	8.1	25.0	22.1	10.00	44.13	18.60

Table 5 Physical properties for the selected growing media

SUBSTRATE CODE	PHYSICAL PROPERTIES									
	compaction % v/v	dry bulk density kg/m^3 dm	porosity % v/v	H_2O pF 0.7 % v/v	Air pF 0.7 % v/v	H_2O pF 1 % v/v	Air pF 1 % v/v	H_2O pF 2 % v/v	H_2O pF 4.2 % v/v	Available H_2O % v/v
MAC 7/IT	17.92	428.67	81.65	51.42	30.24	46.64	35.01	31.82	16.30	35.12
MAC7/T	18.47	407.33	83.18	52.90	30.29	48.12	35.07	29.67	17.27	35.63
MAC7/FC	17.58	381.67	84.65	42.55	42.10	39.45	45.20	31.15	18.41	24.14
TA	6.32	427.67	82.27	36.13	46.15	35.21	47.06	26.99	11.78	24.35
MT1	11.03	695.00	72.45	46.88	25.57	40.85	31.60	27.56	9.46	37.42
MT2	10.34	626.50	73.17	50.12	23.05	45.45	27.72	30.68	10.91	39.21
MAC7/MT	10.62	441.33	82.15	55.48	26.68	47.59	34.57	25.62	13.77	41.71

In the above table physical properties are reported. Compaction refers to the reduction in volume of the substrate after it has been spread in place. Substrate TA show the lowest compaction value. This is due to its particle size distribution (absence of the fraction above 10 mm). The values obtained are those which are commonly found in materials typical of substrates with similar volume of particle size distribution (between 10 and 20% v/v).

Dry bulk density is also related to particle size of the substrate; such values are lower than the compacted bulk density, because this last parameter relates to fresh matter. Porosity is very high and generally in accordance with the considered green roof standards; Maltese substrates show lower values due to higher bulk density. Air capacity values at saturation (pF 0,7 and/or pF 1) are well within the standard requirements. This is an important property, because low values (< 10-15% v/v) may give problems in terms of root asphyxia, reduction in permeability, which could lead to ponding during rain events. Water retention values give information about the ability for the substrate to retain and release water to vegetation. Water present within the substrate at pF 4.2 (considered the wilting point) is not available for plants. Available water is calculated as the difference between water present at pF 0.7 (or pF 1) and water present at pF 4,2. The substrates proposed possess values above 20% v/v, with MAC7/MT recording the highest values (over 40% v/v). Values expressed in volumetric percentage may be converted in litre/m^2 for every cm of depth of substrate by dividing the percentage by 10; e.g. for a depth of 10 cm of substrate, the given volumetric value corresponds to the l/m^2.

The reason why the values obtained for available water are very high is because water was considered at pF 0.7. During the tests in the rain simulator, evaluation of water content was done to understand better the behaviour of the growing media during a rain event. So, the water retention was determined after saturation. Values are reported in the following table, together with data pertaining to other properties.

Table 6 Other properties for the selected growing media

OTHER PROPERTIES							
CODE	**Permeability mm/min**	**Weight at saturation pF 0.7 kg/m^3**	**Weight at max saturation kg/m^3**	**Weight at saturation h 10 cm kg/m^2**	**Weight at max saturation h 10 cm kg/m^2**	**H_2O at saturation in rain simulator % v/v**	**Available H_2O from rain simulator % v/v**
MAC 7/IT	30.92	942.82	1245.20	94.28	124.52	34.15	17.85
MAC7/T	13.22	936.28	1239.17	93.63	123.92	32.26	14.99
MAC7/FC	17.68	807.17	1228.13	80.72	122.81	33.40	14.99
TA	20.99	788.92	1250.37	78.89	125.04	34.88	23.10
MT1	30.67	1163.80	1419.45	116.38	141.95	31.86	22.40
MT2	18.495	1127.70	1358.15	112.77	135.82	33.32	22.41
MAC7/MT	50.62	996.08	1262.87	99.61	126.29	34.15	20.38

Different and important information was acquired. It was possible to observe that the amount of available water was lower when calculated at max saturation obtained in the rain simulator. After the substrate reached saturation point in the rain simulator, the humidity level of the substrates () was lower than the humidity determined by the laboratory saturation process (H_2O at pF 0.7 or pF 1). The maximum water retention obtained in the rain simulator results between the data obtained in laboratory at pF 1 and pF 2.0 is presented in the charts here under:

Table 6 gives the permeability values of each substrate tested (all values in accordance with green roof standards) and the weight of the substrate when saturated.

Values regarding water retention, air capacity, available water and weight at saturation are also reported in the following charts, so as to give a visual impression of results.

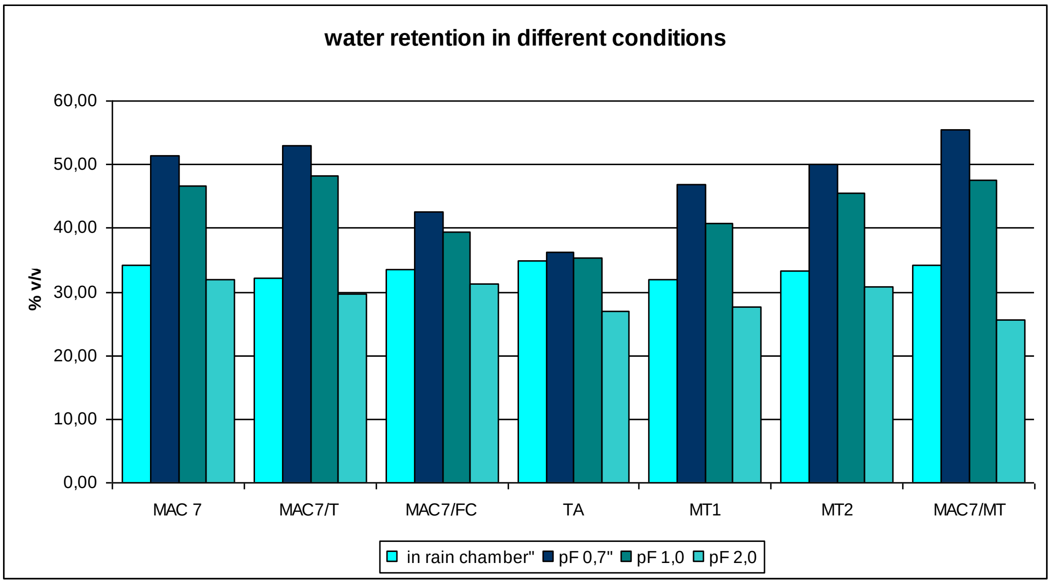


Figure 9 Water retention at different conditions

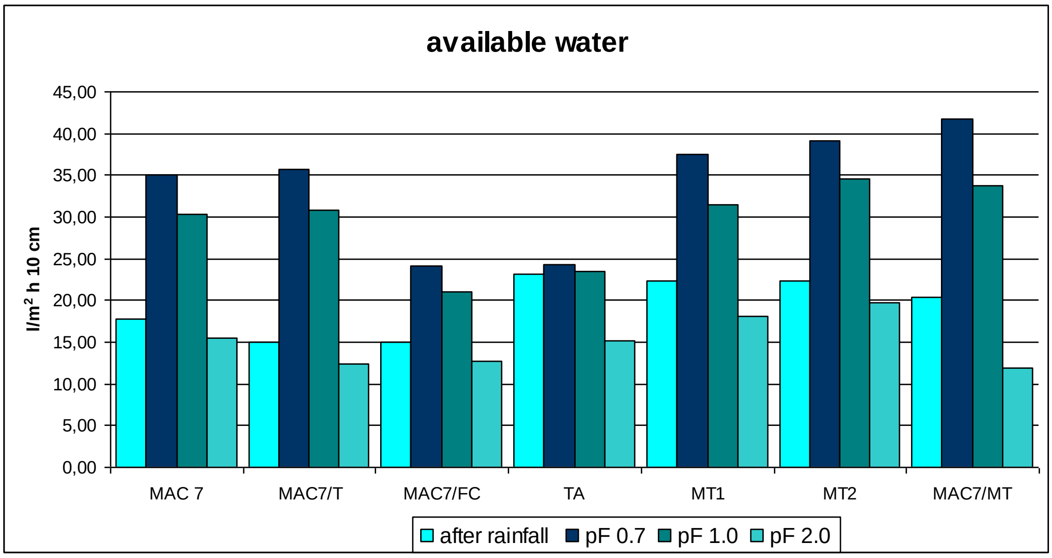


Figure 10 Available water at different conditions

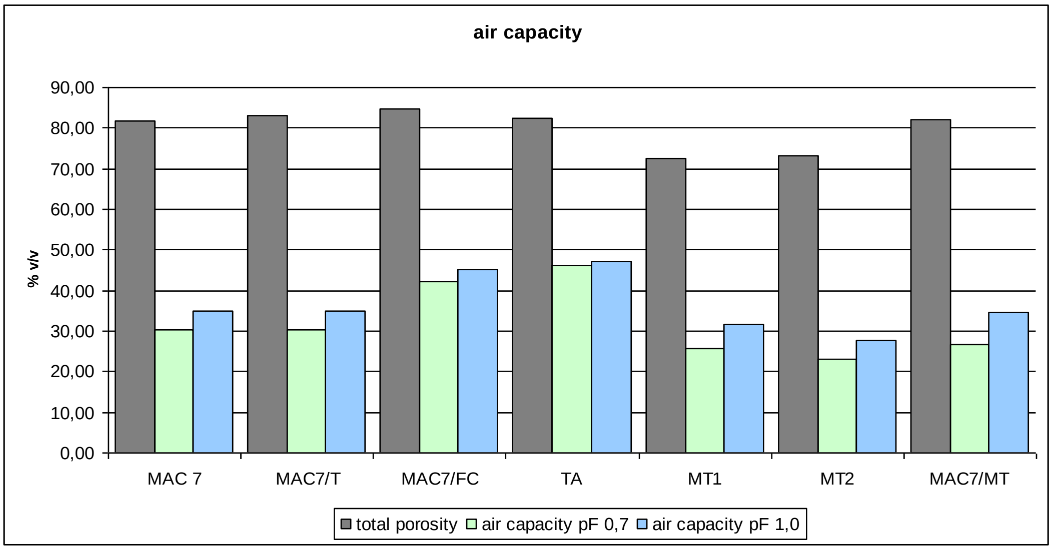


Figure 11 Air capacity at different conditions

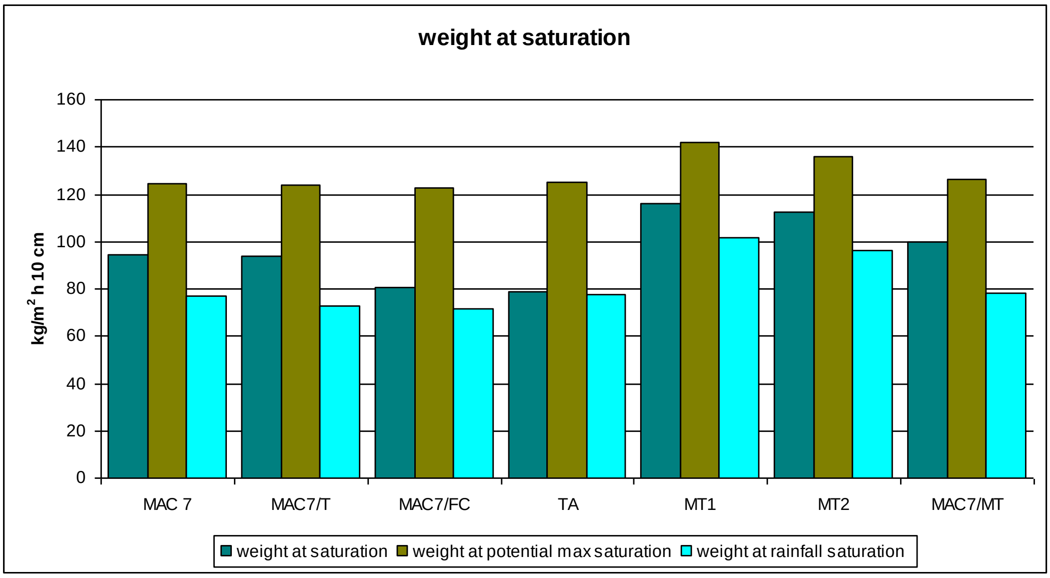


Figure 12 Weight saturation at different conditions

Following an intense search for indigenous materials in Malta earlier on in the project, MAC created 3 experimental mixes utilising the local Maltese materials identified., The search for the new materials was part of the project's preparatory actions (see Table 7 below).

Table 7 Experimental Maltese mix with local components

	MIX1	MIX2	MIX3
Component	% v/v	% v/v	% v/v
sand	30	30	40
coraline limestone 3/8 (< 10 mm)	25	30	25
concrete high grade 4-10 mm	25	30	25
coraline limestone 20 mm	20	10	10

Tests on these samples gave a negative result, especially due to the very low porosity and air capacity values, and high pH and carbonate content values.

The values obtained confirmed that local mineral materials in Malta are not appropriate as components within the growing media.

Monitoring of chemical properties of substrates over time

During the implementation of the monitoring action, some substrate samples were collected from both the Maltese and Italian demonstration green roofs to verify the main chemical and agronomic properties.

Monitoring of Maltese substrates

In August 2015 samples were collected from each single boxes used for the preparatory actions and analysed for pH and salinity levels. This was done to have a quick picture of the basic properties of the substrates.

Results, reported in the below table, show a positive situation, with appropriate values for pH (especially for MT2 substrate) and salinity. The decrease in the pH may have been caused by irrigation that has drained the cations originally present in the substrates in high levels.

Table 8 pH and salinity levels of the various substrates tested

MONITORING MALTA PLOTS SUBSTRATES August 2015					
CODE	**pH unit**	**Salinity mS/m**	**CODE**	**pH unit**	**Salinity mS/m**
M1A	6,9	0,48	**M2A**	7,9	0,43
M1B	7,2	0,6	**M2B**	7,9	0,33
M1C	7	0,67	**M2C**	7,6	0,56
M1D	7,2	0,67	**M2D**	8	0,39
M1E	6,9	0,72	**M2E**	8	0,54
M1F	7,2	0,65	**M2F**	7,9	0,36
M1G	7,6	0,85	**M2G**	7,8	0,5
M1H	7,2	0,31	**M2H**	8	0,31
M1I	7,1	0,55	**M2I**	7,4	0,39
M1J	7,3	0,57	**M2J**	7,3	0,46

In March 2017 a sampling was collected and tested from the demonstration roof. Samples were collected from the different areas of the demonstration green roof.

Results, reported in the following table, show how the pH value is stable, while salinity is very low (no fertilization has been done on this roof), as confirmed also by soluble nutrients level.

No significant difference in these chemical properties were noted between MT1 and MT2 substrates.

Table 9 Chemical properties of Maltese substrates, samples taken from the demonstration green roof - March 2017

CODE	MONITORING MALTA GREEN ROOF SUBSTRATES – MARCH 2017								
	pH	**Salinity**	**N-NO_3**	**N-NH_4**	**P**	**K**	**Ca**	**Mg**	**Na**
	(unit)	**(mS/Cm)**	**mg/l extract**	**mg/l extract**	**mg/l extract**	**mg/l extract**	**mg/l extract**	**mg/l extract**	**mg/l extract**
Area 1 - MT1	8,6	0,10	<1,13	2,62	1,18	14,75	3,55	1,55	8,6
Area 2 - MT1	8,6	0,14	<1,13	1,90	1,42	18,25	4,15	1,13	8,6
Area 3 - MT2	8,8	0,33	<1,13	2,82	1,00	30,53	6,36	2,07	8,8
Area 4 - MT1	8,4	0,11	<1,13	2,18	1,88	20,72	7,82	3,28	8,4
Area 5 - MT1	8,3	0,12	<1,13	1,59	1,88	18,92	5,66	2,63	8,3
Area 6 - MT1	8,6	0,15	1,13	1,25	2,02	23,70	7,83	2,92	8,6
Area 7 - MT2	8,5	0,11	<1,13	1,45	1,00	9,73	7,24	0,97	8,5

Monitoring of Italian substrates

Samples from the Italian green roof were collected during November 2016 (more than 1 year after planting). Samples have been collected from the 4 different demonstration areas. Each area was composed of different substrate type (the first two areas however were composed of MAC7 type substrate). Moreover, the number of samples collected corresponded to the number of plant species cultivated. In the following table each sample is identified by the substrate and plant species code.

Results show no significant agronomic differences between samples. The pH values are within acceptable limits and stable (in accordance with UNI Standard for green roof) and the salinity is very low (maybe too low for vegetation); nitrates and phosphates are very low; this is a positive index for water quality run-off.

Table 10 Chemical properties of the various substrates used taking the plant species into consideration

CODE	MONITORING ITALY GREEN ROOF SUBSTRATES – NOVEMBER 2016								
	pH (unit)	Salinity (mS/Cm)	$N\text{-}NO_3$ mg/l extract	$N\text{-}NH_4$ mg/l extract	P mg/l extract	K mg/l extract	Ca mg/l extract	Mg mg/l extract	Na mg/l extract
MAC7- AR MA	8	0,1	<1,13	2,74	0,96	7,23	11,12	2,15	1,11
MAC7- CE BI	8,3	0,08	<1,13	1,73	0,52	7,15	7,5	1,69	2,78
MAC7- DI CA	8,1	0,07	<1,13	1,87	0,61	6,08	7,26	1,61	3,74
MAC7- PO NE	8,3	0,06	<1,13	2,04	0,37	5,09	5,24	1,09	0,48
MAC7- GR B	8,3	0,06	<1,13	1,61	0,51	4,6	6,72	1,51	0,59
MAC7- GR S	8,2	0,09	<1,13	1,43	0,59	5,29	10,51	1,49	2,77
MAC7- TH SE	8,1	0,07	<1,13	2,22	0,62	6,51	7,91	1,6	1,21
MAC7/T- AR MA	8,1	0,08	<1,13	2,22	0,8	3,53	11,67	1,91	1,41
MAC7/T- CE BI	8,1	0,06	<1,13	1,57	0,59	3,93	7,03	1,62	0,83
MAC7/T- DI CA	8,1	0,05	<1,13	1,73	0,39	2,01	5,32	1,37	0,52
MAC7/T- PO NE	8,2	0,06	<1,13	1,55	0,39	2,69	7,87	1,84	0,69
MAC7/T- GR B	8,1	0,05	<1,13	1,13	0,59	2,12	5,19	1,29	0,43
MAC7/T- GR S	8,1	0,05	<1,13	1,69	0,38	2,21	5,24	1,31	0,69
MAC7/T- TH SE	8,3	0,08	<1,13	1,23	0,4	3,65	10,34	1,88	0,52
MAC7/FC- AR MA	8,2	0,06	<1,13	1,79	0,86	2,56	6,61	1,56	0,55
MAC7/FC- CE BI	8,3	0,08	<1,13	1,57	0,58	6	7,79	2	1,13
MAC7/FC- DI CA	8,2	0,06	<1,13	1,94	0,56	3,4	6,27	1,53	0,76
MAC7/FC- PO NE	8,2	0,06	<1,13	2,16	0,63	2,65	7,19	1,65	1,09
MAC7/FC- GR B	8,2	0,05	<1,13	1,92	0,4	3,39	6,2	1,32	0,95
MAC7/FC- GR S	8,2	0,06	<1,13	1,49	0,54	2,79	7,3	1,59	0,57
MAC7/FC- TH SE	8,2	0,08	<1,13	2,14	0,85	2,61	8,3	2,15	1,11
TA- AR MA	8,3	0,07	<1,13	1,81	2,03	4,54	11,6	2,45	0,84
TA- CE BI	8,2	0,07	<1,13	1,55	1,37	4,63	7,41	1,65	0,48
TA- DI CA	8,2	0,06	<1,13	2,26	1,41	5,32	5,55	1,45	0,53
TA- PO NE	8,1	0,05	<1,13	2	0,87	3,42	4,98	0,94	0,38
TA- GR B	8,2	0,07	<1,13	2,28	1,85	5,13	7,04	1,73	0,47
TA- GR S	8,1	0,07	<1,13	0,81	1,62	4,08	7,51	1,57	0,46
TA- TH SE	8,1	0,07	<1,13	1,63	1,26	6,17	5,87	1,21	0,42
MAC7 GENERAL	8,2	0,08	<1,13	1,79	0,86	4,04	8,59	1,99	0,34

4. Meteorological analysis

MALTA

Test period

Collection of weather records commenced in February 2016, whereas water run-off investigations commenced in May 2016 and ran for a period of one year. A number of issues were encountered with the K1000 during this period. Issues related to power cuts during rain events which effected the data logging. The data logger had to be rebooted following every power cut. This happened on a number of occasions.

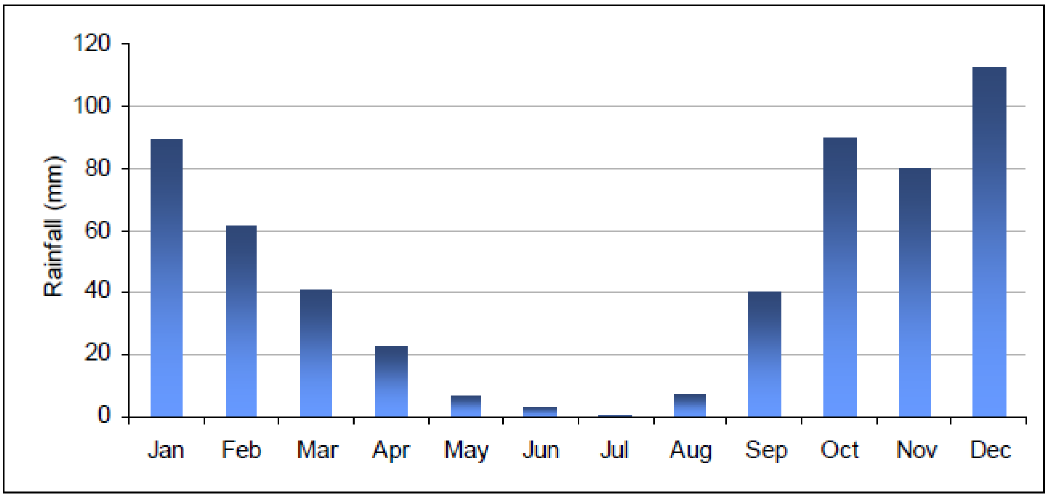
Irrigation was only carried out between April and September using the drip method. The tipper counter on a number of occasions recorded run-off which related to the irrigation. During the rest of the year, the irrigation system was disabled. The set-up was successfully recording run-off between January and June 2017 giving uninterrupted data.

Weather conditions – background information

Data gathered from (Galdies, 2011)

Malta's climate is typically Mediterranean and strongly influenced by the sea. Winters are generally mild with around 5-6 hours of sunshine in mid-season, summers are dry and hot with more than 12 hours of sunshine.

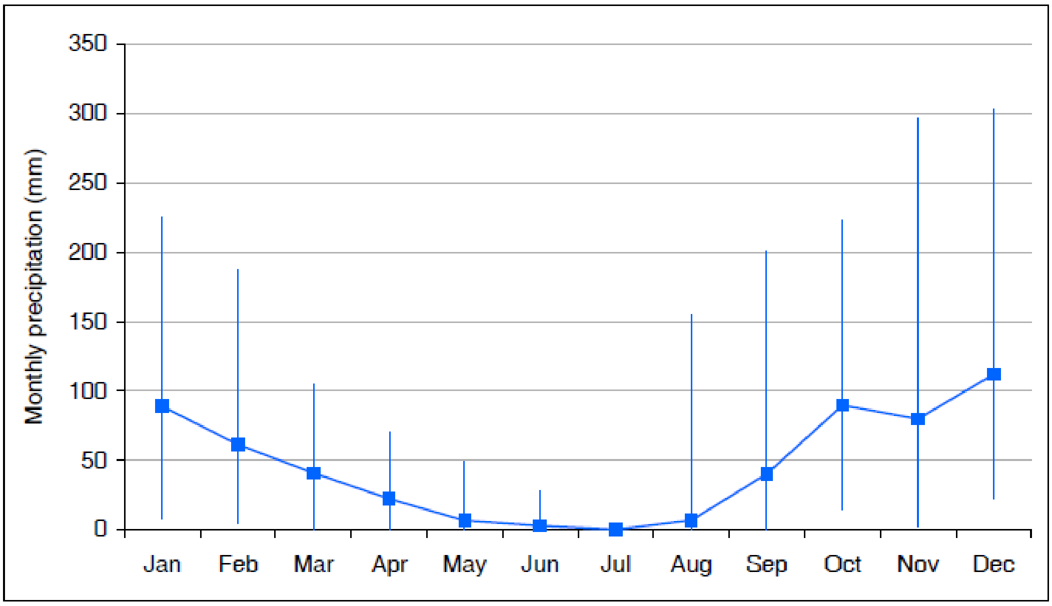
Rain, hail, dew and soft rime are the most common types of precipitation. Average annual precipitation (climate period 1961-1990) is around 553mm with a standard deviation of 156.99mm (Galdies, 2011). Most of the precipitation falls between October and February in a handful of days.



Data collected by the Malta Airport MetOffice

Figure 13 Monthly total annual precipitation (1961-1990) taken from Galdies 2011

According to Galdies (2011), "The total amount of precipitation recorded in 24 hours is a good indicator of the vigour and duration of storms." The figure below shows the trend of the total amount of precipitation recorded in 24 hours. These figures are based on records for a 30-year period between 1961 and 1990. November shows the greatest variability ranging from 0mm to just over 160mm. This variability is "attributed to convective storms triggered by the movement of the continental air mass from the North African region over cooler areas in the Central Mediterranean".



Data collected by the Malta Airport MetOffice

Figure 14 Mean monthly precipitation and variability in 24hrs (1961 -1990) taken from Galdies (2011)

Table 11 Highest precipitation ever recorded on a monthly basis during the period 1922-2010 in comparison with the mean monthly precipitation. Adapted from Galdies (2011)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average monthly precipitation (mm)	87.75	60.53	42.73	22.10	9.92	3.12	0.49	7.31	42.94	86.28	87.73	102.48
Highest monthly precipitation (mm)	248.20	187.90	178.00	118.40	49.10	76.20	18.00	155.50	266.90	476.50	420.30	302.60

Data collected by the Malta Airport MetOffice

July is the warmest month with temperatures averaging at 27°C whereas January is the coldest with temperatures averaging 13°C.

Malta is a windy island. Just like temperature, wind is influenced by the sea surrounding the island as well as by the land masses. Sicily for example can act as a barrier against strong low-level northerly winds. (Galdies, 2011). Short low pressure systems over north Africa can produce strong winds which would hit Malta.

The NW wind is prevailing as can be observed in the wind rose here under. Wind direction frequencies in descending order are: W, WSW, SSW, NNW. Other wind directions show no dominance. The least dominant wind is the Northerly wind. The periods of calm days average around 2% while that of variable winds is around 4.2%.

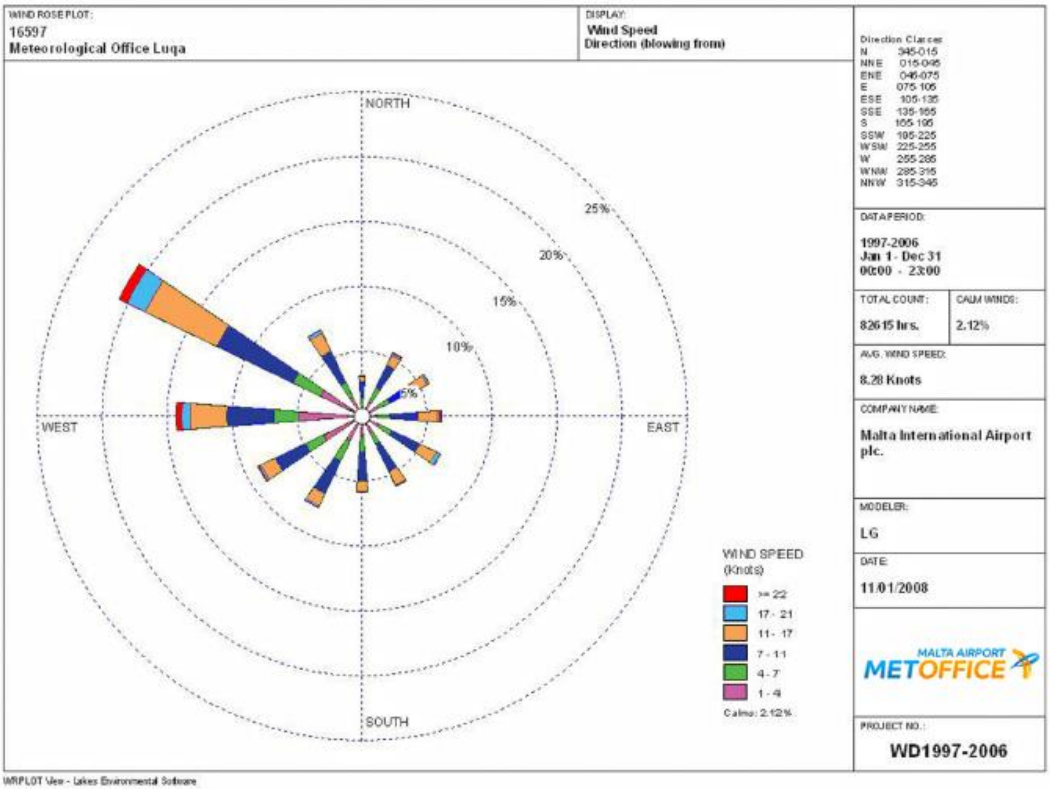
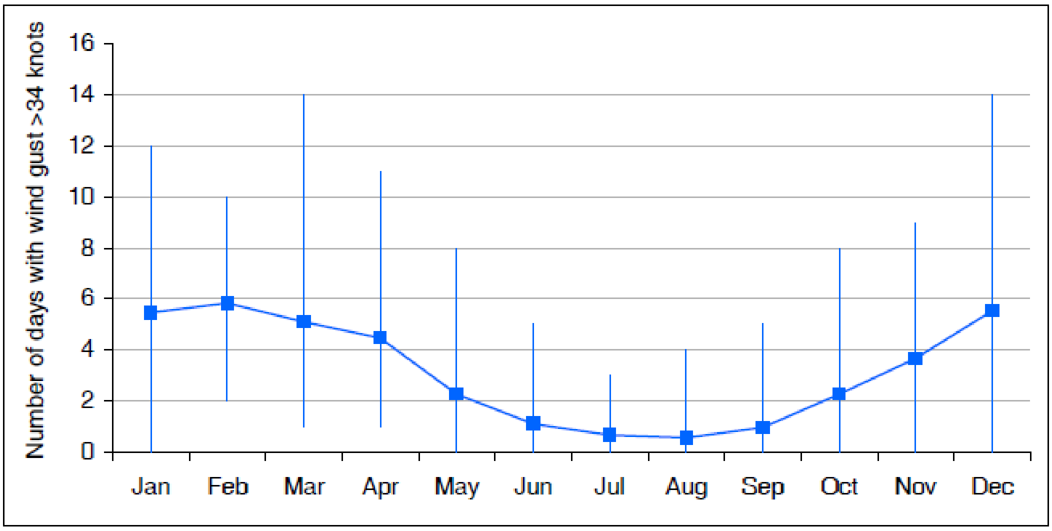


Figure 15 Wind rose for the period 1997 - 2006. Taken from Galdies (2011)

Although observations between 1961 and 1990 show mean annual wind speeds of 8.8 knots, there is considerable variation in monthly averages. The month with the highest variability recorded between 1961 and 1990 was October with wind speeds ranging from 24 knots to 72 knots.

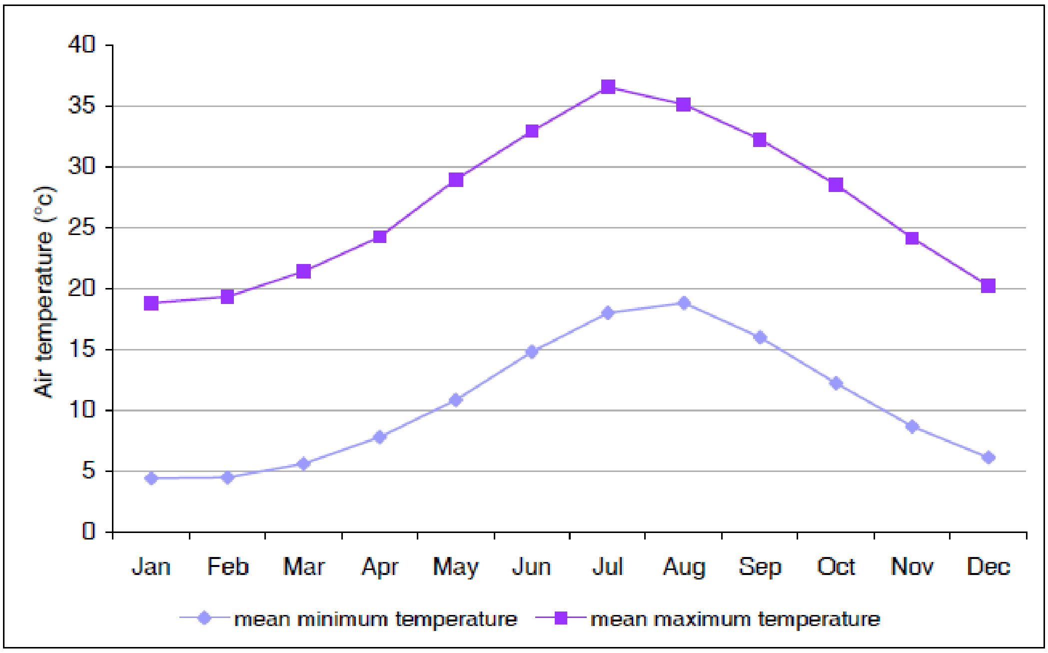


Data collected by the Malta Airport MetOffice

Figure 16 Average wind gusts and variability (1969 - 1990) taken from Galdies (2011)

Temperature variations in Malta is to a large extent related to the central Mediterranean regional weather. The sea also has an influence on temperature especially when considering that the sea tends to have a warming effect in winter and the opposite in summer.

July is the warmest month of the year whereas January is the coldest as can be viewed in the following graph.



Data collected by the Malta Airport MetOffice

Figure 17 Mean maximum and minimum air temperatures in Malta (1961-1990). Taken from Galdies (2011)

Table 12 Average maximum and minimum temperatures, and maximum and minimum temperatures on a monthly basis (1947-2010) Adapted from Galdies (2011)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Maximum temp (°C)	18.72	19.4	21.97	24.67	29.31	33.59	36.38	35.77	32.39	28.64	24.39	20.42
Mean minimum temp (°C)	4.96	4.80	5.89	7.91	11.26	15.19	18.45	19.22	16.53	12.89	9.02	6.48
Highest maximum temp (°C)	22.2	26.7	33.5	30.7	35.3	40.1	42.7	43.8	37.4	34.5	28.2	24.30
Lowest minimum temp (°C)	1.4	1.7	2.2	4.4	8.0	12.6	15.5	15.9	13.2	8.0	5.0	3.6

The table shows that temperatures can vary considerably between seasons with maximum temperatures reaching 43.8°C in August 1999 (being the hottest day on record since 1947) and minimum temperatures as low as 1.4°C (January 1981).

At ground level the temperatures give a slightly different picture. The grass height temperatures generally follow a similar trend as the minimum air temperatures but tend to be lower. The lowest minimum grass-height temperature ever recorded was in February 1983 with a temperature of -5.1°C. The average lowest grass-height temperature is -1.3°C which is the highest frequency of lowest temperature recorded between 1955-2010.

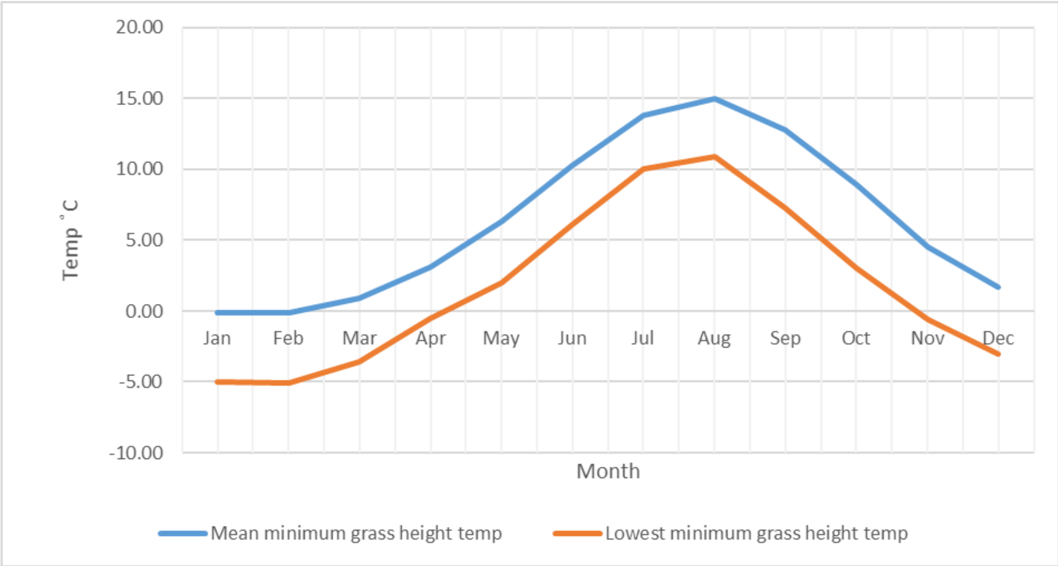


Figure 18 Grass height mean and minimum temperature annual trend

The weather during 2015-2016-2017

During the course of the project period the weather was uncharacteristic for Malta. Winter 2015-2016 was particularly dry, whereas 2016-2017 although not as dry, however the total precipitation was below the annual average.

Climatic conditions have a big influence on the survival of flora and fauna and could be detrimental to the success of green roofs. The following section will give a brief overview of what the weather was like in 2015, 2016, and 2017. Storm water data was collected at the project site between 2016 and 2017. These two winters had an impact on the tests conducted on the green roofs in terms of plant performance and storm water management.

Data for the below was obtained from the Meteorological Office Luqa. (MIA, 2017)

Weather during 2015

The year 2015 was characterised by moderate weather patterns. It began with the lowest recorded temperature for 2015, at 2.1°C in January, reaching a peak of 38.4°C in July. December recorded higher than normal temperatures. The average temperature for the month was 14.4°C with a maximum temperature of 19.8°C and a minimum of 7.8°C. This is unusually high.

December also had unusually high numbers of sunshine hours, 197.9, as opposed to the normal 156.3. Average wind speed for December was 5.1knots, a contrast to the more typical norm of 9.1knots.

The wettest month for 2015 was February with a total of 112.8mm of rainfall and the driest was June with a trace of precipitation. 45.8mm was the recorded total rainfall in December, this is much lower than the normal average of 104.8mm for the month. The annual total rainfall for 2015 was 554.2mm.

The strongest wind gust recorded was 50 knots in November, while the mean wind speed for the year was 8.25 knots.

The winter of 2015-2016 was the driest winter on record with 99.6mm of precipitation. December 2015 was the wettest month of winter; however, this was still significantly less than the average for the month. February was the driest ever recorded since 1923. It was also the driest month of winter (2.6mm precipitation recorded).

Air temperature was higher than usual. The highest air temperatures recorded for each month of winter were close to the maximum temperatures recorded in April and May 2015. February recorded the highest temperature for the month in 93 years. March witnessed the highest temperature (24.6°C) whereas January registered the lowest temperature at 5.9°C.

Days experienced more hours of sunshine that is usually experienced in the winter. "February 19th had a maximum of 10.2 hours of sunshine, which is only 0.4 hours less than the mean sunshine hours recorded for August 2015" (MIA, 2016).

The rest of Europe also experienced such an abnormally warm winter.

Weather during 2016

The year 2016 is considered the fifth driest year since 1923. January had low temperatures but in December, temperatures were marginally above average. Air temperatures varied between 5.9°C as minimum and 37.5°C maximum. December air temperature had an average of 17.1°C which is considered warm. December had 151.6 hours of sunshine recorded, which is considered slightly duller than normal for this month.

November was the wettest month, with 90mm of precipitation and 150.1 hours of sunshine. July was the sunniest and driest month with 370.8 hours of sunshine and 0.4mm of precipitation. Mean wind speed was of 7.2 knots. April was the most windswept month, with mean gusts of 10.9 knots.

Total precipitation for December was 60.8mm, 44mm short of the 104.8mm expected for December. Total rainfall for the year amounted to 324.8mm.

Weather during 2017

From September 2016 till June 2017, the total rainfall recorded amounted to 371.18mm. (MIA, 2017) On average 2017 exhibited temperatures higher than the normal average. January was cooler than normal with temperatures plummeting to 4.2°C on three occasions. Grass height minimum temperature went down to 0.8°C. Mean air temperature for January was 1.2°C lower than normal. Generally, temperatures were warmer than expected for the time of year. Air temperature in February was 1.1°C higher than normal.

The year was drier for this period of year. January had 71.7mm precipitation which is lower than expected and February was rainier than what is generally expected with 62.7mm of precipitation, 5.8mm more than the month's average. April had 14 rainy days with a total of 12.8mm, 8mm lower than average for the month and may recorded 0.6mm most of which was dew. In general, precipitation for the first 5 months of the year was less than the normal average.

Longer hours of sunshine were recorded for April and May. The former had an average of 8.6hrs of sunshine per day with a total of 250hrs for the month. May had 21hrs sunshine more than the norm.

January was windswept with a mean wind at 10.2knots, 1 knot more than expected at this time of year with the strongest gusts reaching 45 knots however February was less windy and brighter than normal.

ITALY

Test period

Collection of weather records commenced in February 2016 until June 2017.

Weather conditions – background information

Italy is a country of extremely varied landscapes and consequently experiences a similarly varied climate. Between the north and south there can be a considerable difference in temperature, particularly during the winter, while in summer such differences are less extreme.

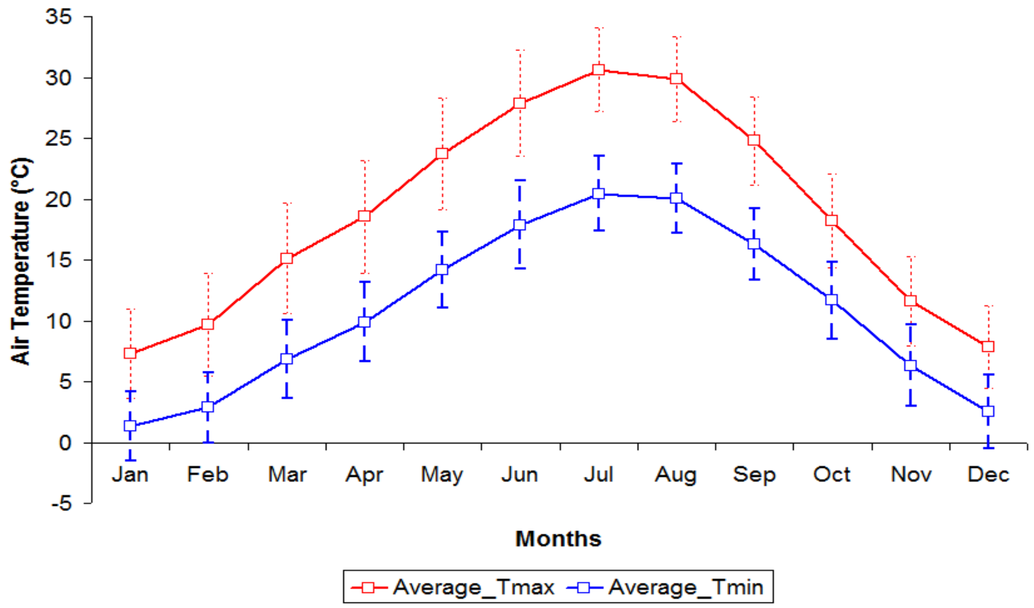
Lombardy has a wide array of climates, due to local variable conditions (presence of mountains, hills and plains, inland water basins, large metropolitan areas).

The climate of the region is mainly humid subtropical (Köppen Cfa), especially in the plains. In addition, there is a high seasonal temperature variation (very cold winter and very hot summer).

In the Alpine foothills, characterised by an Oceanic climate (Köppen Cfb), numerous lakes exercise a mitigating influence, allowing the cultivation of typically Mediterranean crops (olives, citrus fruit).

In the hills and mountains, the climate is humid continental (Köppen Dfb). In the valleys it is relatively mild, while it can be severely cold above 1,500 mt, with copious snowfalls.

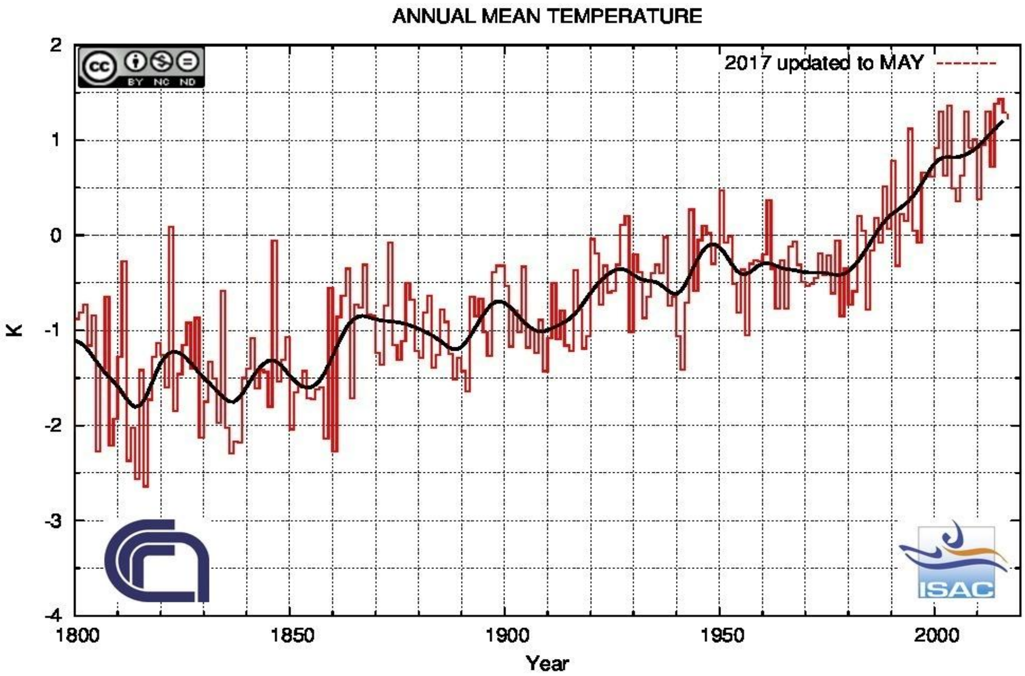
Figure 8 shows the average monthly temperatures including minimum and maximum temperatures for Milan (1978-2007)



Reference: ECA station code:173 MILAN IT
Klein Tank, A.M.G. and Co-authors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatol., 22, 1441-1453

Figure 19 Average monthly temperature in Milan – Lombardy – Italy (1978-2007)

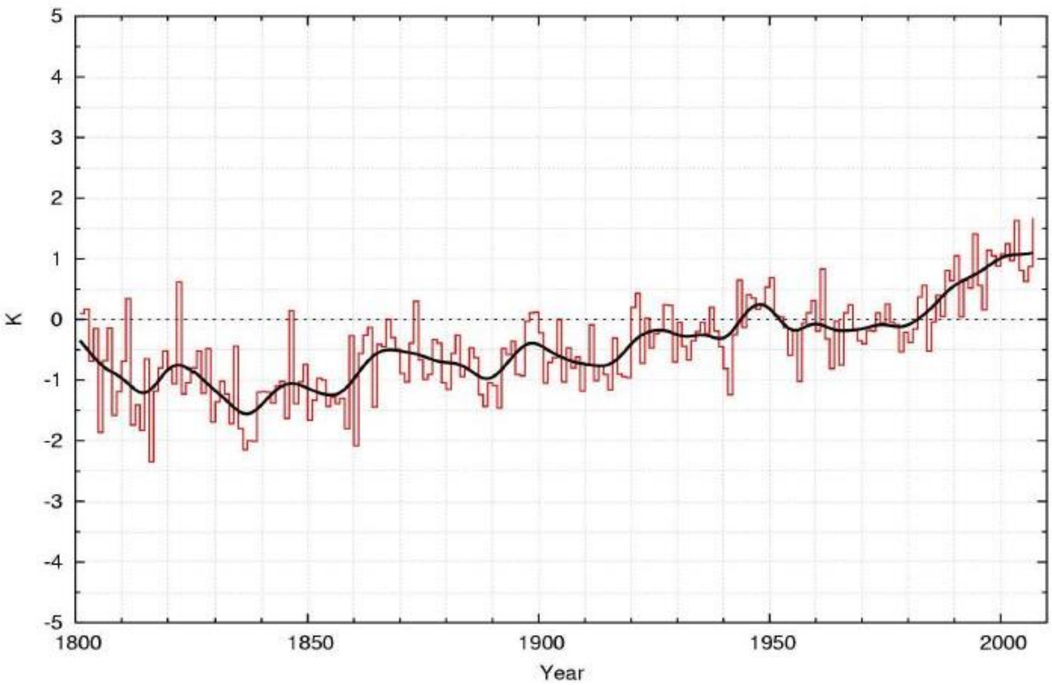
What it is important to annotate is the increase of temperature in the last 30 years, as shown in the figure below (Brunetti et al, 2006). In the last 50 years the maximum temperature trend being stronger than that of the minimum temperature; this has led to a negative trend in the daily temperature range that for the last 40-50 years has become positive.



Reference: Brunetti et al, 2006, International Journal of Climatology

Figure 20 Annual mean temperature variation in Italy in the last 200

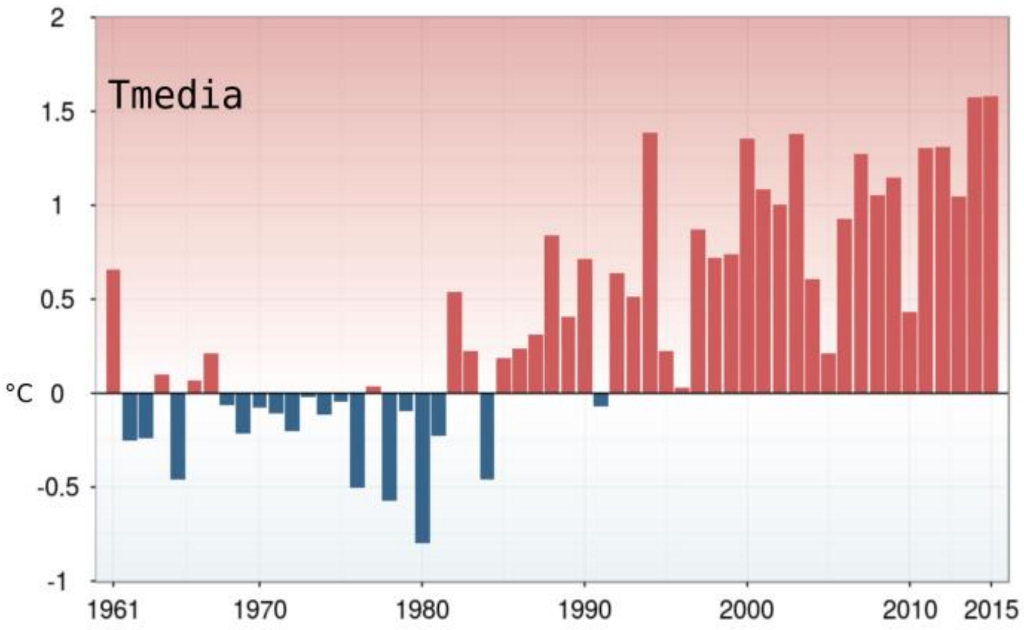
The same chart is reported in the following figure for the Lombardia Region; as it is possible to observe, the trend is the same of the national one.



Reference: Fondazione Lombardia per l'Ambiente, Progetto Kyoto

Figure 21 Annual mean temperature variation in Lombardia in the last 200 years

In figure 12 a similar trend observed for the last 50 years, comparing variations to the normal 1961-1990 values for Italy; it is particularly since 1980 that a significant increase in temperature has been registered. The increase rate is almost 2°C, but the increase above the average value is slightly above 1°C.

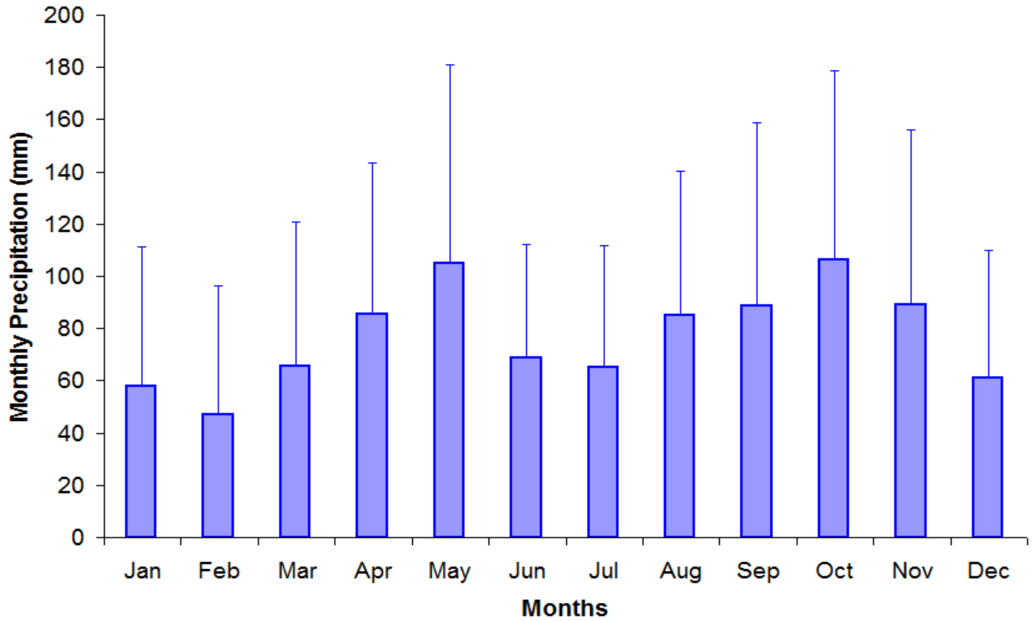


Reference: ARPA Lombardia, Gli indicatori del clima in Italia nel 2015 – 65/2016

Figure 22 Mean average temperature variations compared to normal 1961-1990 values in Italy

The ongoing climate change influences also regional precipitation. In Italy rain is more intense in the Prealpine zone, up to 1,500 to 2,000 mm annually, but is abundant also in the plains and Alpine zones, with an annual average of 600 to 850 mm. The total annual rainfall is on average 827 mm.

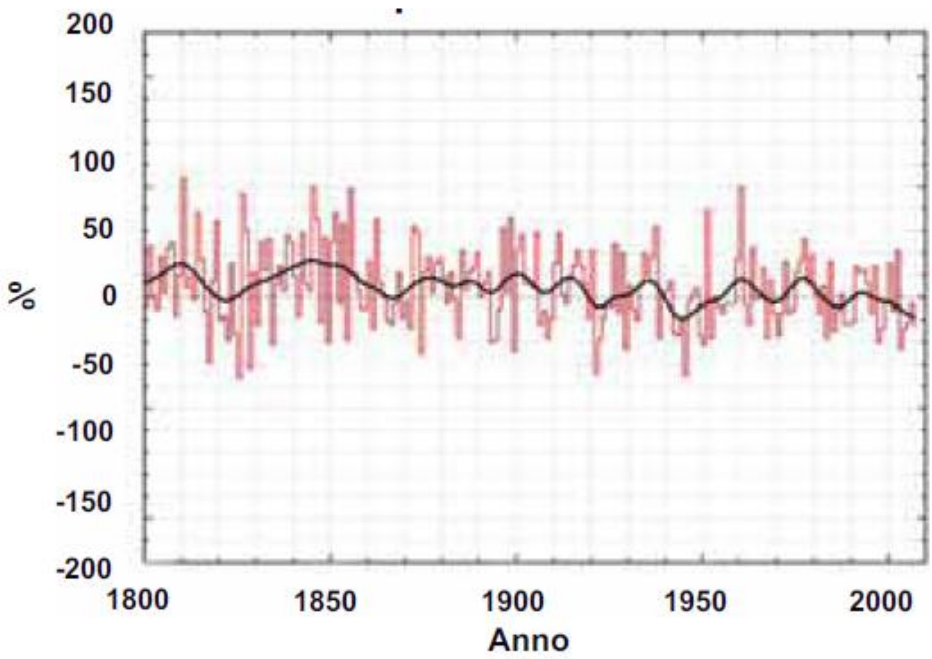
As reported in the following figure (average monthly precipitation in Milan, 1978-2007), there is a significant monthly variability. The rain is mostly present in spring and autumn, while the winter season in generally drier. This was particularly observed during the last years.



Reference: ECA station code:173 MILAN IT
Klein Tank, A.M.G. and Coauthors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatol., 22, 1441-1453

Figure 23 Average monthly precipitation in Milan – Lombardy – Italy (1978-2007)

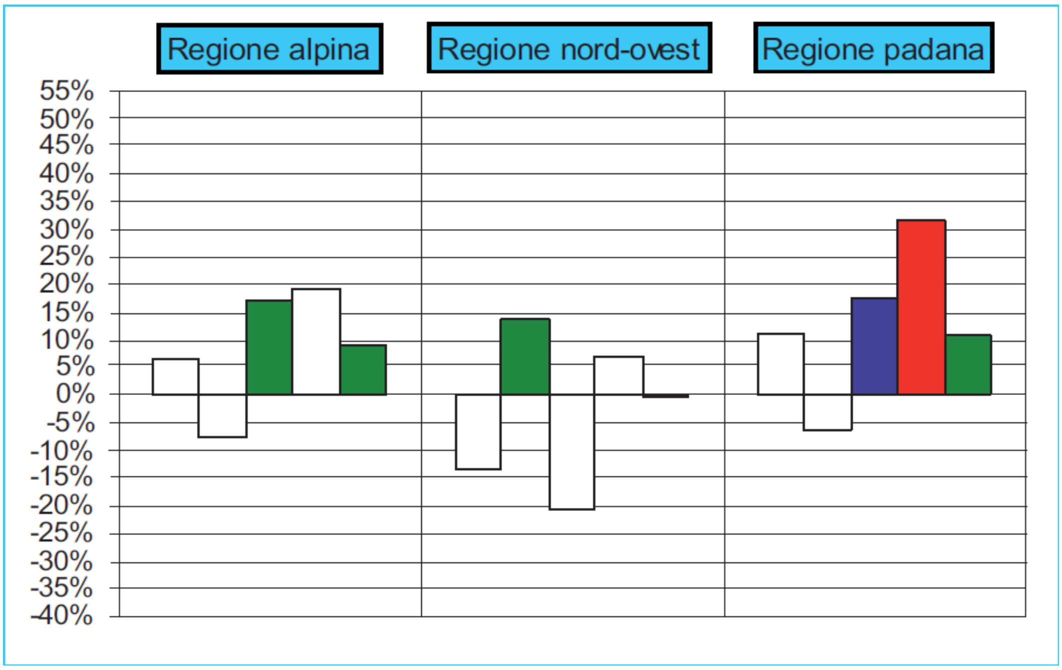
The following graph provides deviations or anomalies in relation to the reference period 1961-1990, referring to the average total precipitation in Lombardia region over the same period (1800-2007). Data is expressed as a percentage of variation compared to the reference period. The vertical bars indicate the values of each single year, the continuous black curve represents the mediated trend over longer periods.



Reference: Fondazione Lombardia per l'Ambiente, Progetto Kyoto

Figure 24 Anomalies referring to average total precipitation in Lombardy (1800-2007)

Lombardia is particularly exposed to alluvial risk, which is related to high intensity precipitation events due to various natural and man-made factors. It is therefore extremely important to verify whether there is also a tendency in Lombardy of increased intensity in precipitation such as is being observed in various other areas globally. Nowadays it difficult to analyse these trends in more limited geographic areas of the entire Padano basin, as the study of intense rainfall is difficult due to the low number of events that are being considered. The figure below shows the trends (period 1880-2004) of the number of events with intense daily precipitation in three macro regions – the definition of high precipitation intensity is taken as being 5% of the whole of the recorded data. For each region (Alpin, North-West, Padana), the first four columns represent the trends for the four seasonal series (in the order, winter, spring, summer and fall), while the fifth shows the trend of the annual series. The values are expressed as percentage changes per century of the frequency of intense precipitation events, compared to the regular average in the 1961-1990 (not significant values are indicated with white columns, while values with significance greater than 90% are shown by coloured columns: green for trends with significance over 90%, blue for trends above 95% and red for trends higher than 99%). Data show that the number of events with high precipitation intensity are increasing, especially in summer and autumn.



Reference: Fondazione Lombardia per l'Ambiente, Progetto Kyoto

Figure 25 Increase in number of event with high intensity precipitation (Lombardy, 1961-1990)

Weather during 2015

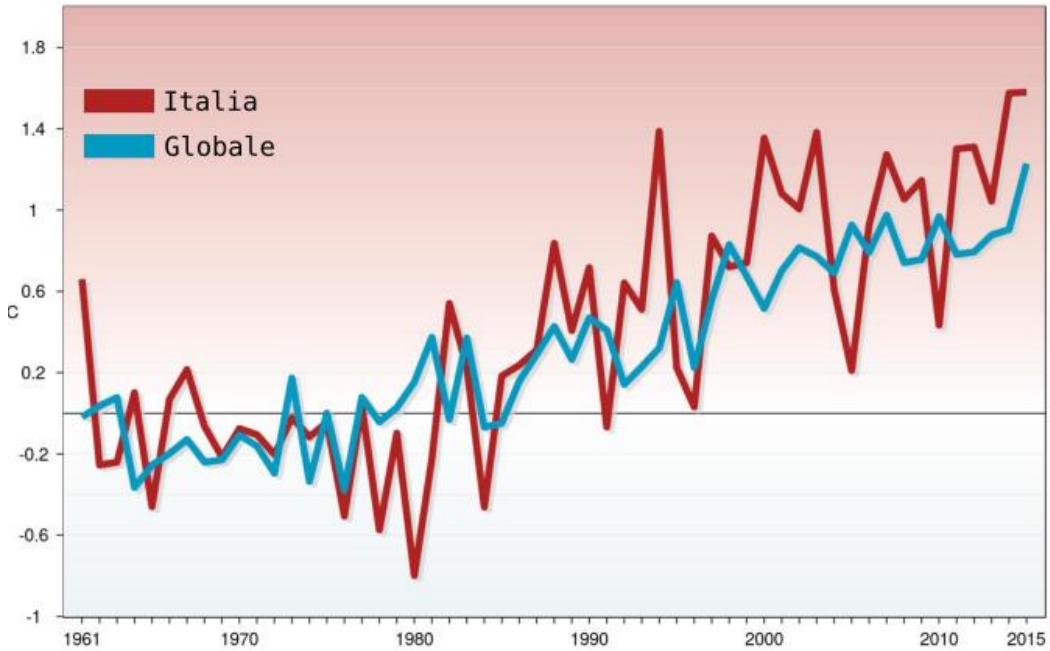
Data was obtained from the annual Report "The climate indicators in Italy" edit by ISPRA (2016)

In Italy, the average temperature value in 2015 was the highest in the whole series since 1961, just above 2014 (old record). The average annual anomaly was + 1.58 ° C and should be attributed to all four seasons, with the most pronounced anomaly in summer (+ 2.53 ° C). The anomaly of the annual average temperature of 2015 is attributed slightly more to the maximum temperatures than the minimum temperatures.

Distinguishing between macro-areas, the mean annual average temperature abnormality was + 2.07 ° C in the North, +1.70 in the centre and + 1.28 ° C in the South and the Islands. All the months of 2015 were warmer than the standard, except for September to the North and February to the South and the Islands. July was the warmest month when compared to the standard, with an average anomaly of + 4.31 ° C to the North, + 4.27 ° C to the Centre and + 2.88 ° C to the South and the Islands. The less warm month than the standard was September to the North (-0.11 ° C), February to the Centre (+ 0.36 ° C) and to the South and the Islands (-0.55 ° C).

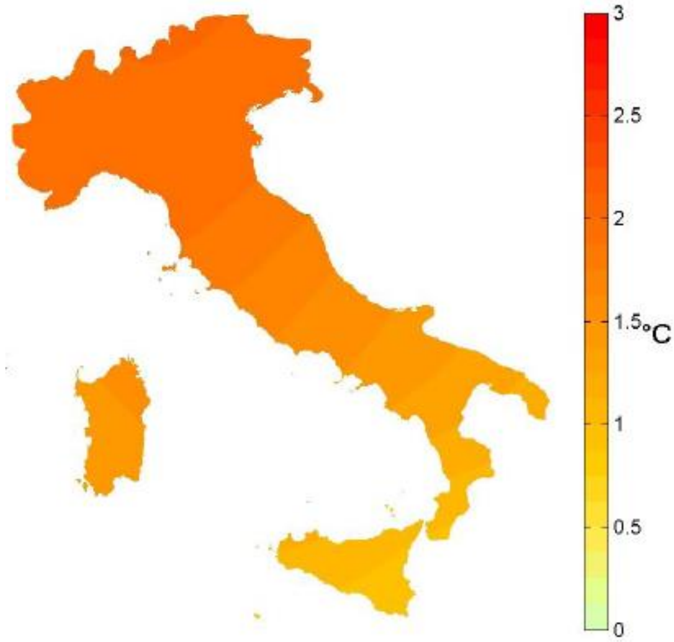
Figure 26 below illustrates the global and national average temperature anomalies, compared with standard value between 1961 and 1990.

Figure 27 below represents temperature abnormalities along the peninsula; as it is possible to observe, the north is the one that has greater major temperature anomalies.



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA.

Figure 26 Series of global average temperature abnormalities in Italy and in the world



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA.

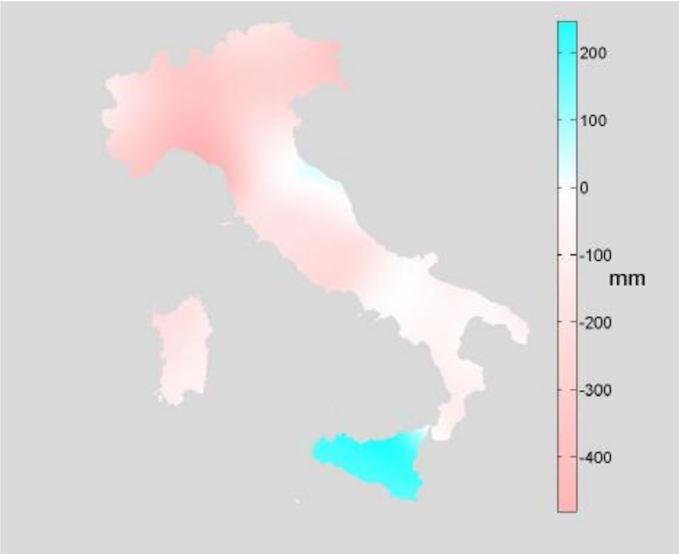
Figure 27 2015 temperature anomalies along the peninsula as compared to 1961-1990 average values.

The annual cumulative precipitation in 2015 was below the average by around 13%. The average annual anomalous value has significant differences between different areas of Italian territory. In the North and in the centre, precipitation in 2015 was significantly lower than the average (-21% and -17% respectively). To the South and the Islands precipitation was very close to the average.

2015 was ranked and the third driest year since 1961.

In the North and centre precipitation was lower than the norm, especially in July, November and December. In December, almost no rainfall was recorded practically throughout the national territory.

In the period 1951-2015, the average values of annual cumulative precipitation have slightly decreased but not in a statistically significant trends.



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA.

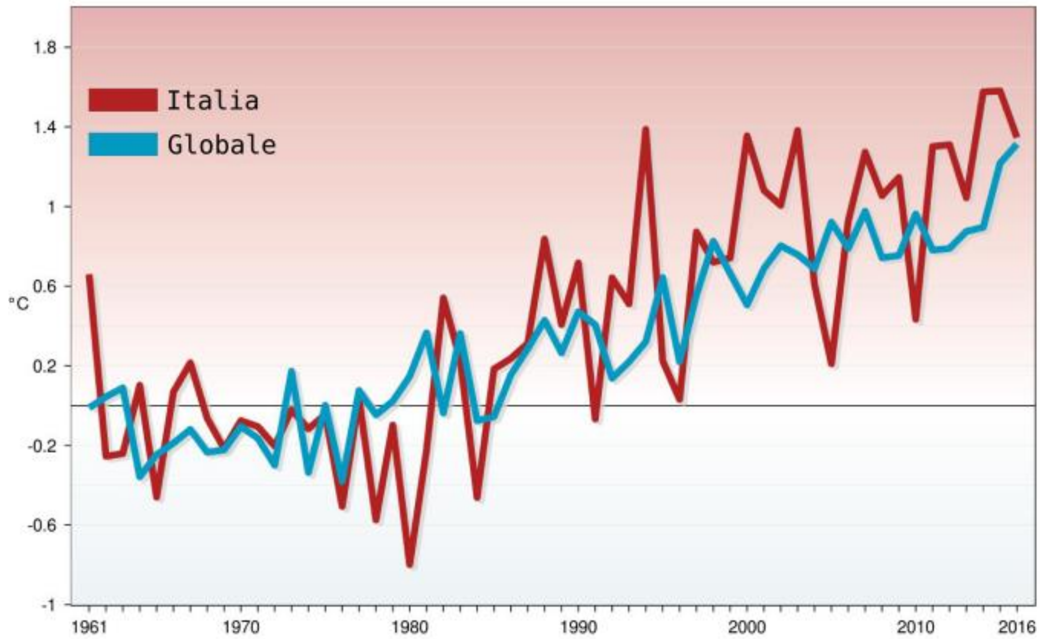
Figure 28 2015 Precipitation anomalies along the peninsula as compared to 1951-1980 average values.

Weather during 2016

Data for the below was obtained from the annual report "The climate indicators in Italy" edit by ISPRA (2017).

For the third consecutive year, 2016 was considered as being particularly warm. The global annual average temperature was +1.31°C above the normal average registered between 1961 and 1990. In Italy, the year 2016 was the sixth hottest year since the start of meteorological observations, with an average anomaly of + 1.35°C over the thirty-year 1961-1990.

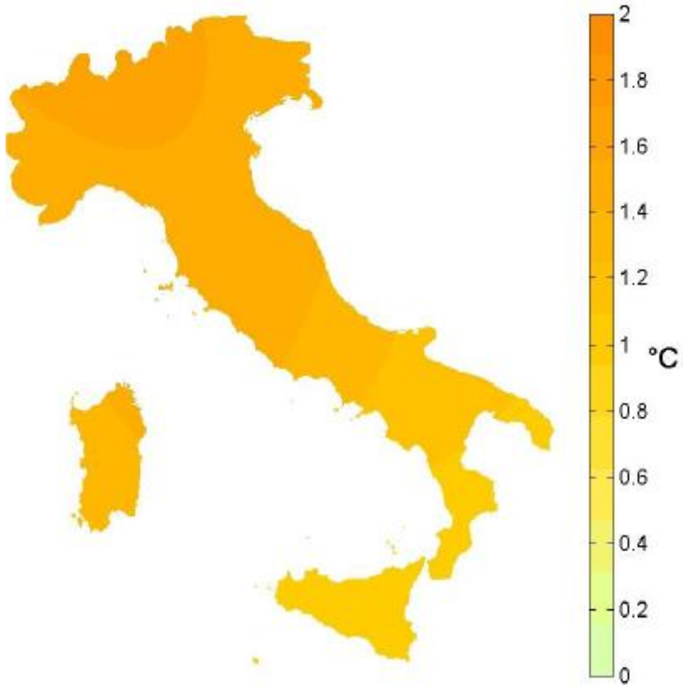
From the analysis of the historical data of the last half century, the period with increased temperatures commenced in the early 1980s. The latest estimate of the rate of variation of the average temperature from 1981 to 2016 is +0.36°C ± 0.06°C / 10 years, that of the minimum temperature being +0.35°C ± 0.05°C / 10 years and of the maximum temperature +0.36°C ± 0.08°C / 10 years. On a seasonal basis, average temperature trends were stronger in spring (+0.45 ± 0.11°C / 10 years) and in the summer (+0.42 ± 0.11° C / 10 years). Winter was the season with the most marked thermal anomaly, with a national average value of + 2.15°C.



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA.

Figure 29 Series of global average temperature abnormalities in Italy and in the world

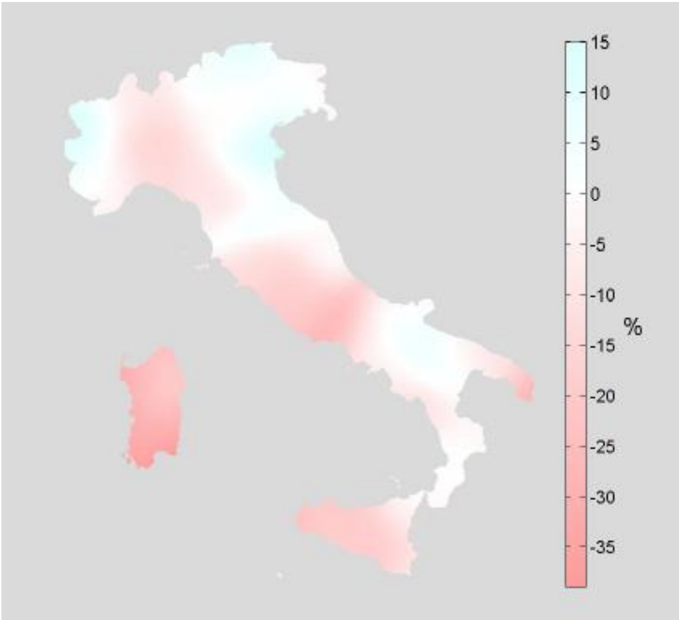
Below is the representation of temperature abnormalities along the peninsula; as it is possible to observe, the north is again the one that has greater major temperature anomalies.



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA.

Figure 30 2016 temperature anomalies along the peninsula compared to 1961-1990 average values.

In 2016 there were no intense precipitations, even prolonged events such as those that hit Liguria and Piedmont in the third decade of November. However, the most significant meteorological event in 2016 was perhaps the persistence of drought conditions, partially alleviated by spring rains that facilitated the management of water resources. The second part of 2016 was characterized by prolonged periods of shortage or even lack of rainfall over several areas of the national territory, which at year's end have reported water resources generally at very low levels. The annual cumulative precipitation of 2016 in Italy was overall lower than the standard average by around 6%. For the second consecutive year, no rain events were present during December. Rain in May and June were more frequent than the normal average, almost throughout the Italian territory.



Reference: NCDC / NOAA and ISPRA. Processing: ISPRA

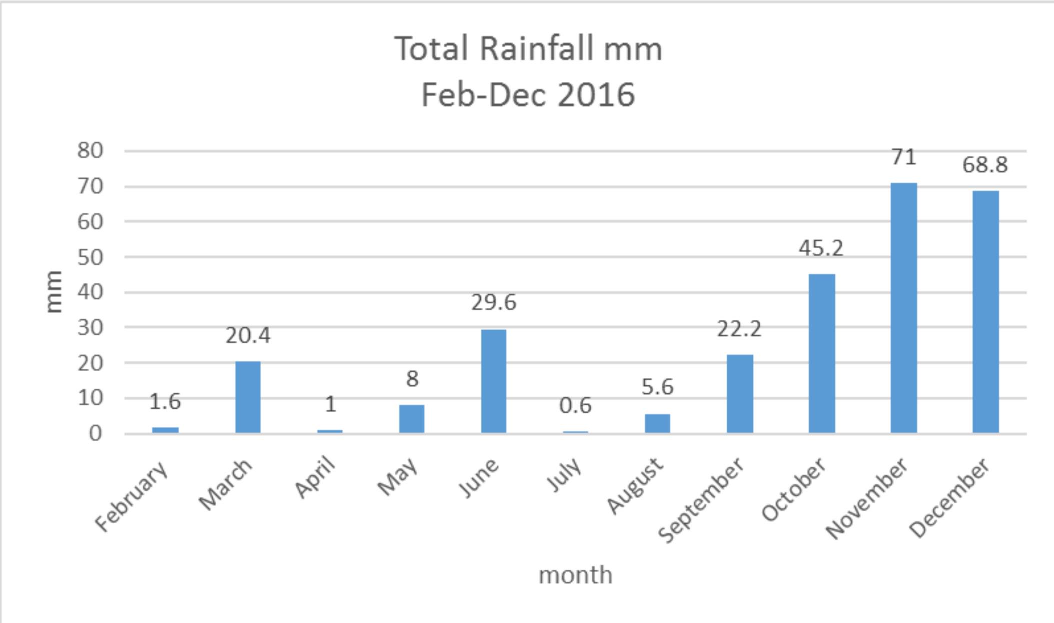
Figure 31 2016 precipitation anomalies along the peninsula compared to 1951-1980 average values.

5. Data analysis

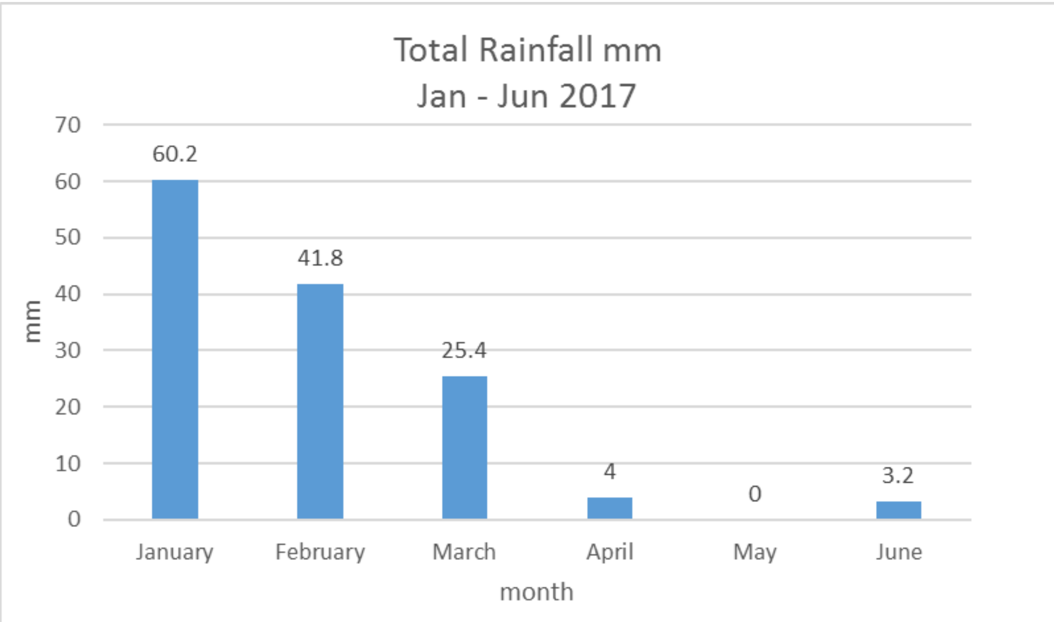
MALTA – University of Malta

Precipitation

Data from the weather station at the University of Malta was collected for the duration February 2016 till June 2017. The total precipitation recorded for the period February 2016 – December 2016 was of 274mm.



November was the wettest month with 71mm of precipitation while July was the driest.



The total rainfall for the period January 2017 – June 2017 was 134.06mm. January was the wettest month with 60.2mm of precipitation registered at the University while no rain was recorded for May.

The table below illustrates the precipitation as recorded during the period. It also indicates the run-off recorded. The figures in red are dubious as they relate to run-off from the irrigation system. These figures and the associated precipitation quantities shall not be used to analyse the effectiveness of the green roof in managing storm water. The white cells indicate missing data.

The following table summarizes data related to rain events taken from Table 13 below:

	2016 **February-December**	**2016** **August - December**	**2017** **January - June**
	mm	mm	mm
Max rainfall	30	30	33.80
Min. rainfall	0	0	0
Min. rainfall recorded	0.20	0.20	0.20
Average rainfall	0.85	4.26	0.74
No. of rainy days	74	50	35

Figure 32 Views of the experimental green roof

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2016	January	**Precipitation**																															
		Run-off																															
	February	**Precipitation**												0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
		Run-off																															
	March	**Precipitation**	1.00	0.00	0.80	2.20	0.00	0.00	0.00	0.00	0.40	2.00	5.80	7.40	0.20	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00
		Run-off																															
	April	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	
		Run-off																															
	May	**Precipitation**	0.00	**0.20**	**4.20**	0.00	0.00	0.00	**1.00**	**2.20**	0.00	0.00	0.00	**0.20**	0.00	0.00	**0.20**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Run-off													11	0.4	0.6	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	1.4	0
	June	**Precipitation**	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	0.00	27.80	0.00	0.00	0.00	0.00	0.00	0.00	
		Run-off	1.6	0	1.6	0	0	1.5	0	3.56	0	3.63	0	0	4.1	0	37.6	0	2.41	0	0	2.2	0	0	0	26.5	0.1	0	0				
	July	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	August	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	4.80	0.00	0.00	0.00	0.00	0.00	0.00
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	September	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	2.80	0.00	9.00	0.60	0.00	9.00	0.40	0.00	
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0.1	0	0.4	0.3	0	0	0	0	
	October	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	10.20	1.00	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.20	0.00	0.00	0.00	0.00	0.00	0.00	5.60	12.00	4.00	0.00	8.20
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.3	0.06	0	0	0	0	0	0	0	0	0	0
	November	**Precipitation**	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	9.60	1.80	0.00	6.00	0.00	0.00	2.60	1.00	0.60	30.00	9.20	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.40	5.20	0.00	
		Run-off	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0														
	December	**Precipitation**	0.00	0.00	1.20	5.40	0.00	0.20	5.40	10.80	1.60	0.00	0.00	0.40	0.00	0.00	11.20	6.80	16.40	0.40	0.40	2.20	0.40	5.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
		Run-off					0.1	0.8	0.03	2.88	0.06	0	0	0	0	0	3.81	5.6	11.8	1.88	0.1	0.8	0.03	2.9	0.1	0	0	0	0	0	0	0	0
2017	January	**Precipitation**	0.00	0.20	0.20	3.20	1.80	0.20	0.20	0.00	0.00	1.20	0.00	0.00	0.20	0.60	0.40	1.40	0.80	0.40	0.20	0.00	0.00	8.80	0.00	0.00	1.00	0.00	0.00	3.00	33.80	2.60	0.00
		Run-off	0	0	0	0.1	0	0.1	0.03	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0.47	2.3	0.1
	February	**Precipitation**	0.00	0.00	0.00	0.20	0.00	3.60	12.40	2.00	12.20	3.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.80	3.20	0.00			
		Run-off	0	0	0	0	0	2.28	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0			
	March	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.80	5.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00
		Run-off	0	0	0	0	0	0	0	0	0.19	0.03	0	0	0	0	0.13	0	0	0	0	0	0.88	0	0	0	0	0	0	0.88	0.06	0	0
	April	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.60	0.80	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
		Run-off	0	0	0	0	0	0	0.03	0	0.03	0.19	0	0.1	0	0	0	0	0.09	0	0	0	0.03	0.03	0	0.09	0	0	0	0	0	0	
	May	**Precipitation**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	June	**Precipitation**	0.00	0.00	0.00	0.00	0.00	3.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
		Run-off	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 13 Precipitation and run-off as recorded between May 2016 and June 2017

Storm water run-off

The data used for calculating the storm water retention of the green roofs spans between July 2016 and June 2017; a period of one year which encompasses the whole of a rainy season in Malta. The total precipitation resulting during this period is of 348mm. Due to the fact that the tipper counter did not function during the period November 18th till December 4th, the period November 18th till December 9th was not considered when calculating precipitation and run-off. The period has been extended till December 9th because it is the last day of run-off and precipitation before 5 days of no run-off. (refer to table 1 above).

The total precipitation for the period considered amounts to 276.4mm with a run-off of 37.39mm. Table 2 illustrates the total precipitation and run-off on a monthly basis. There did not seem to be a relationship between the amount of precipitation experienced and the run-off. This indicates that there are other factors at play. Studies have shown that both the climate and the substrate composition together with plants cultivated have an influence on the water management of green roofs. (Vijayaraghaven & Frnklin, 2014) (Beecham & Razzaghmanesh, 2015) (Fioretti, et al., 2010)

The winter between 2016 and 2017 was particularly dry with 74 days of rain. This allowed ample time between rain events for the evaporation of the water trapped within the growing medium. The hydrological behaviour of the green roof was initially analysed on a month by month basis (refer to Annex). Specific rain events which produced run-off were then identified for further analysis. Of the 74 days of rain, 8 days produced run-off. Run-off volumes varied between 0.03mm and 11.84mm.

Table 14 Total precipitation and run-off per month

	2016						2017					
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
precipitation	0.60	5.60	22.20	45.20	24.00	44.20	60.20	41.80	25.40	4.00	0.00	3.20
run-off	0.00	0.00	0.78	0.40	0.03	27.01	3.77	2.56	2.17	0.67	0.00	0.00
coefficient	0.00	0.00	0.04	0.01	0.00	0.61	0.06	0.06	0.09	0.17	0.00	0.00

Table 3 shows the characteristics of storm water run-off of the experimental green roof. Antecedent dry period was determined as those days with precipitation inferior to 0.99mm. The retained volume was calculated as the percentage difference between the volume of rain event and the water run-off. Water retention ranges between 40% and 100% with a mean figure of 90%. The delay between the run-off is the difference in time between the start of the rain event and the first run-off event recorded.

From the results of the experiments conducted, it can be comfortable said that green roof in Malta can contribute significantly to reducing storm water run-off and mitigate localised flooding. Applying the results achieved to an urban watershed would give a clearer picture of the amount of flood mitigation green roofs can contribute to and the amount of green roof area needed to be effective. This was outside the remit of this study but highlights possible future studies.

Table 15 Data pertaining to the performance of the experimental green roof in terms of water management.

Rain event date	Rain depth (mm)	Antecedent dry period* (hrs)	Run-off vol (mm)	Retained vol (%)	Delay in run-off ** (hrs/min)
23.9.2016	2.80	624	0.03	98.93	2 hrs
25-26.9.2016	9.60	24	0.62	93.54	2hrs 30min
19-20.10.2016	1.00	144	0.40	60.00	-
9-10.11.2016	11.40	120	0.03	99.74	37hrs
02-07.01.2017	5.80	216	0.21	96.38	50hrs 10min
10.01.2017	1.20	48	0.03	97.50	22hrs 50min
13-19.01.2017	4.00	48	0.19	95.25	33hrs 20min
22.01.2017	8.80	48	0.47	94.66	5hrs 30min
25.01.2017	1.00	48	0.03	97.00	36hrs 40min
28-30.01.2017	39.40	48	0.28	99.28	7hrs
04.02.2017	0.20	96	0.00	100.00	-
06-10.02.2017	33.80	24	2.37	92.99	40min
26-27.02.2017	8.00	360	0.19	97.63	6hrs 40min
07-08.03.2017	6.00	168	0.35	94.17	19hrs 20min
21.03.2017	17.20	288	1.76	89.77	1hr 20min
29.03.2017	2.20	168	0.12	94.55	1hr 40min
10.04.2017	1.00	264	0.25	75.00	18hrs
16.04.2017	0.20	120	0.12	40.00	7hrs 40min
20-22.04.2017	2.80	72	0.21	92.50	36hrs 10min

* until a cumulative rain event > 0.99mm

** Delay calculated from the initial rain recorded to the initial run-off recorded.

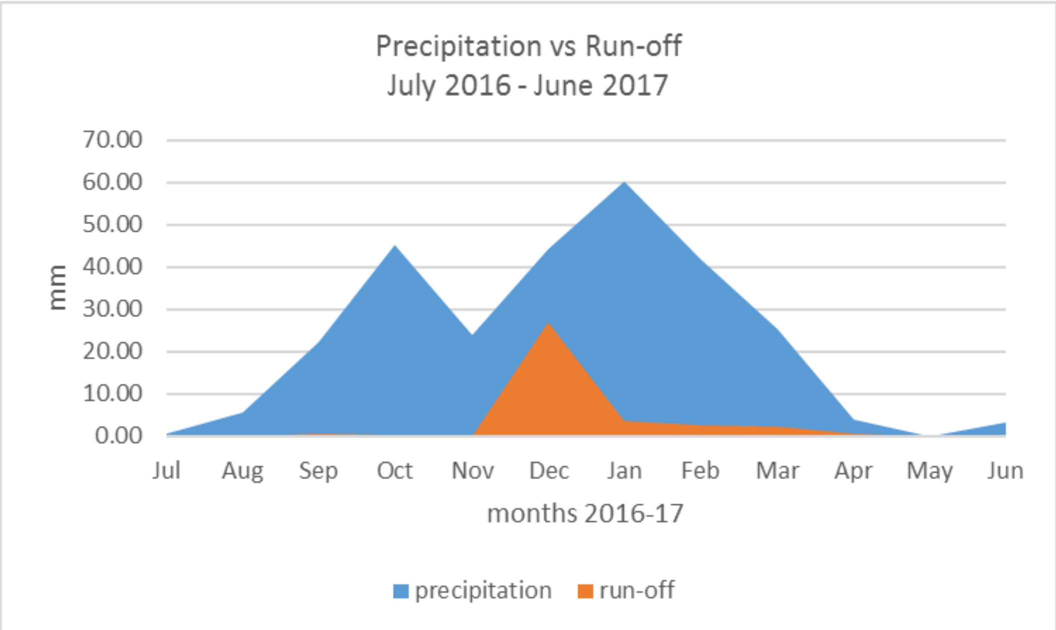
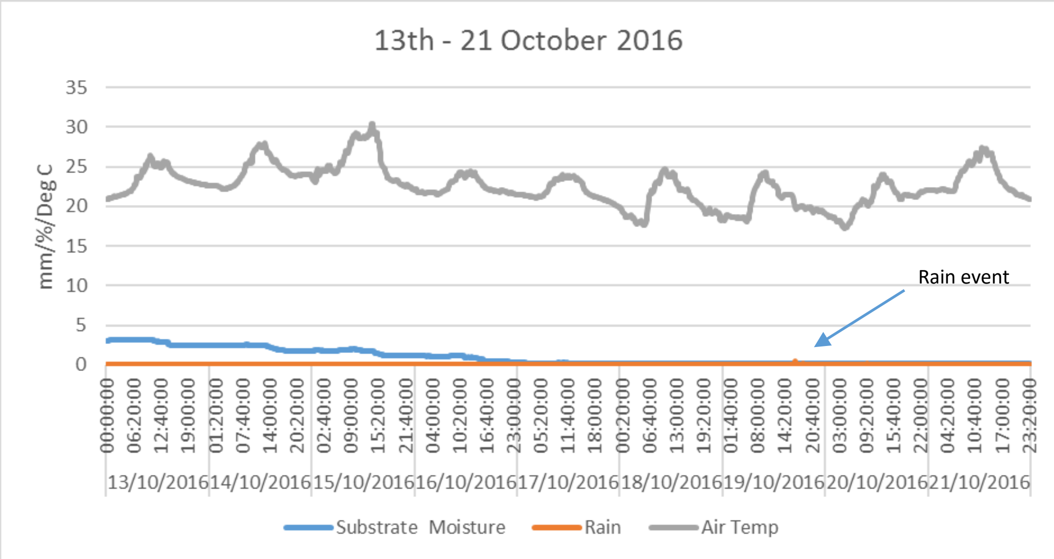
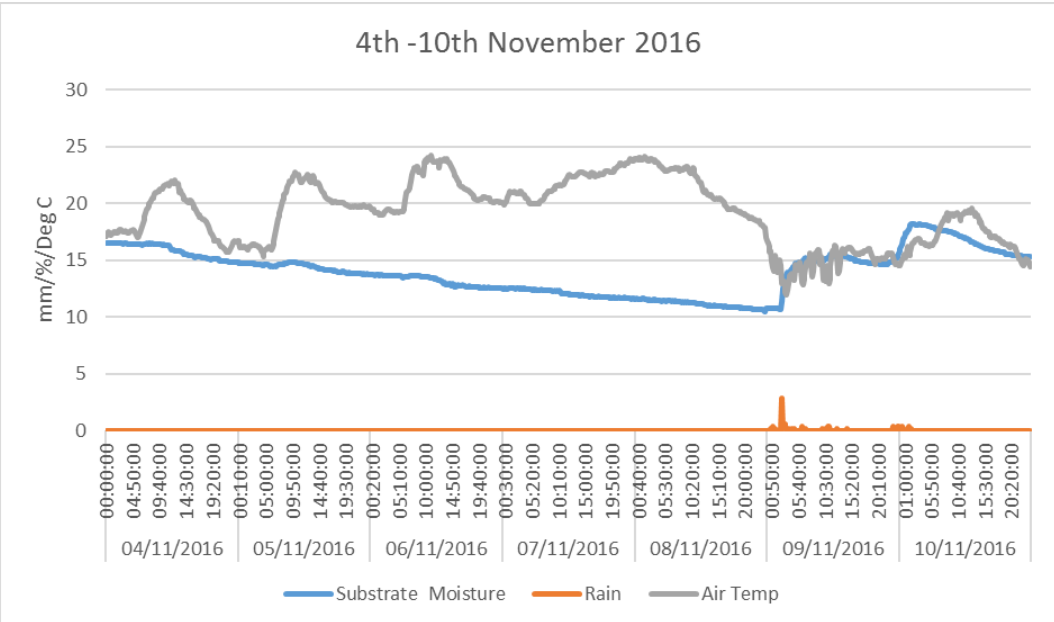


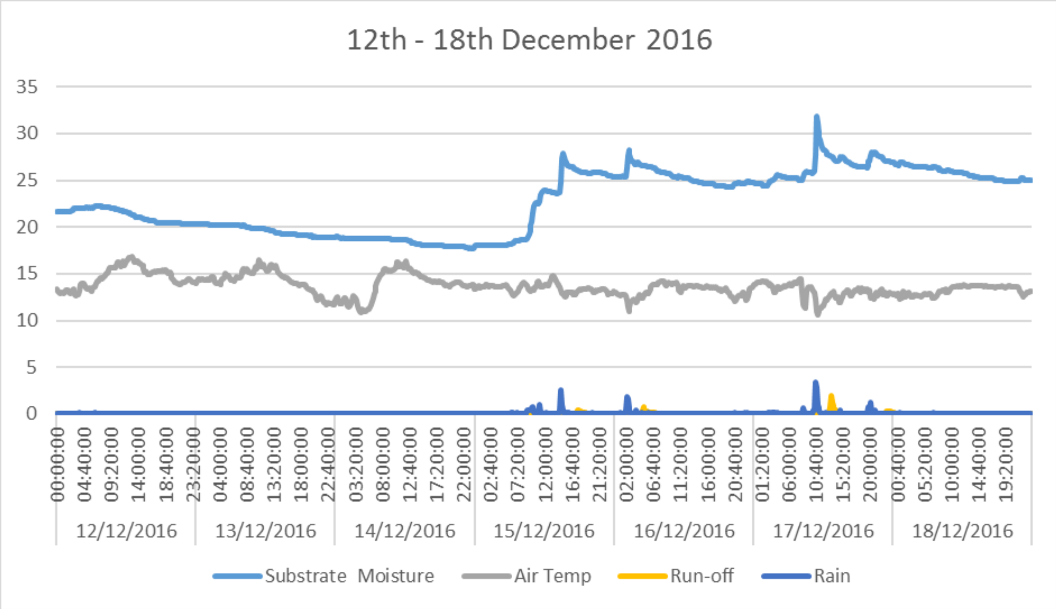
Figure 33 Comparison between precipitation and run-off over an annual period

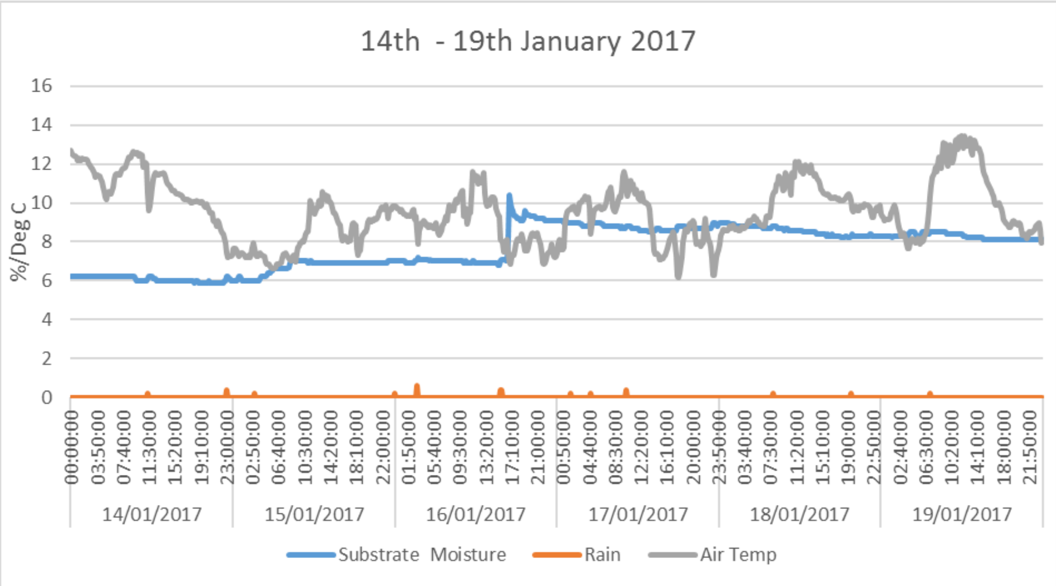
The data gathered was further analysed for the relationship between the moisture level of the substrate and precipitation. Three instances are being illustrated here under. These are 13th – 21st October 2016, 4th – 10th November 2016, 12th – 18th December and 14th – 19th January 2017.

These graphs clearly indicate that a period of no precipitation will result in the reduction of the moisture levels within the substrate. This allows subsequent precipitation to be absorbed by the substrate reducing run-off and delays peak flows.






12th - 18th December 2016
35
30
25
20
15
10
5
0
00:00:00
04:40:00
09:20:00
14:00:00
18:40:00
23:20:00
04:00:00
08:40:00
13:20:00
18:00:00
22:40:00
03:20:00
08:00:00
12:40:00
17:20:00
22:00:00
02:40:00
07:20:00
12:00:00
16:40:00
21:20:00
02:00:00
06:40:00
11:20:00
16:00:00
20:40:00
01:20:00
06:00:00
10:40:00
15:20:00
20:00:00
00:40:00
05:20:00
10:00:00
14:40:00
19:20:00
12/12/2016
13/12/2016
14/12/2016
15/12/2016
16/12/2016
17/12/2016
18/12/2016
Substrate Moisture
Air Temp
Run-off
Rain


14th - 19th January 2017
%/Deg C
16
14
12
10
8
6
4
2
0
00:00:00
03:50:00
07:40:00
11:30:00
15:20:00
19:10:00
23:00:00
02:50:00
06:40:00
10:30:00
14:20:00
18:10:00
22:00:00
01:50:00
05:40:00
09:30:00
13:20:00
17:10:00
21:00:00
00:50:00
04:40:00
08:30:00
12:20:00
16:10:00
20:00:00
23:50:00
03:40:00
07:30:00
11:20:00
15:10:00
19:00:00
22:50:00
02:40:00
06:30:00
10:20:00
14:10:00
18:00:00
21:50:00
14/01/2017
15/01/2017
16/01/2017
17/01/2017
18/01/2017
19/01/2017
Substrate Moisture
Rain
Air Temp

ITALY – Fondazione Minoprio

Data analysis and storm water run-off

Data from the weather station at Fondazione Minoprio was collected for the duration February 2016 till June 2017 (collection data is still ongoing)

This report considers the whole data referred to a solar year between July 2017 and June 2018, so as to have a yearly evaluation.

Below are the monthly average values for temperature and precipitation in this period (table and chart).

Table 16 Average temperature and precipitation values (July 2016- June 2017 – Fondazione Minoprio (IT)

MONTH	°C	mm
07/16	23.1	184.6
08/16	22.3	50.8
09/16	20.1	122.9
10/16	11.6	106.7
11/16	7.3	124.2
12/16	4.5	0.0
01/17	1.3	4.3
02/17	5.4	66.7
03/17	11.0	40.6
04/17	13.1	42.8
05/17	17.0	115.5
06/17	22.2	104.0
Average °C/Total mm	13.2	963.1

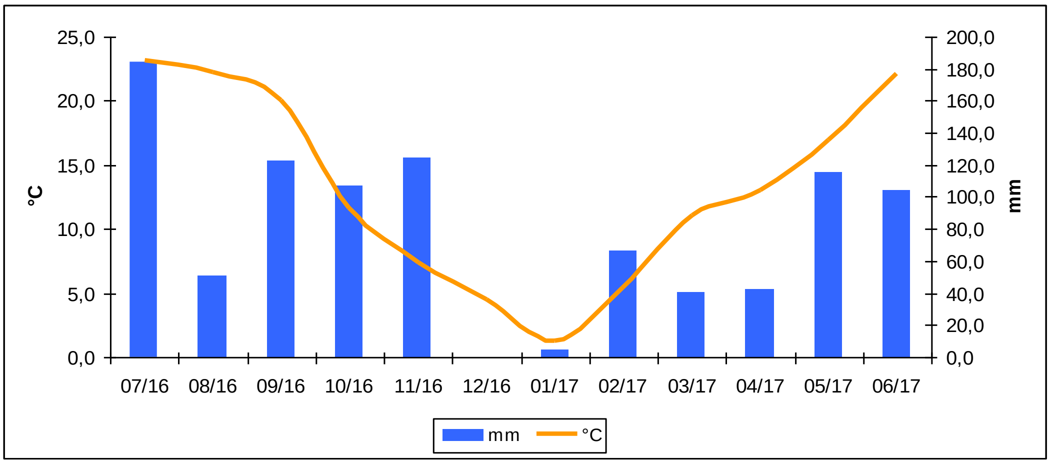
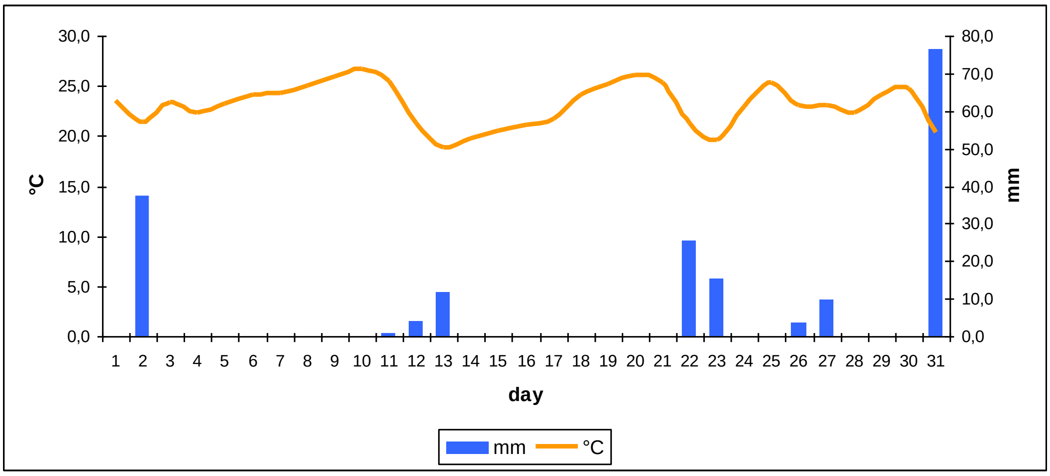
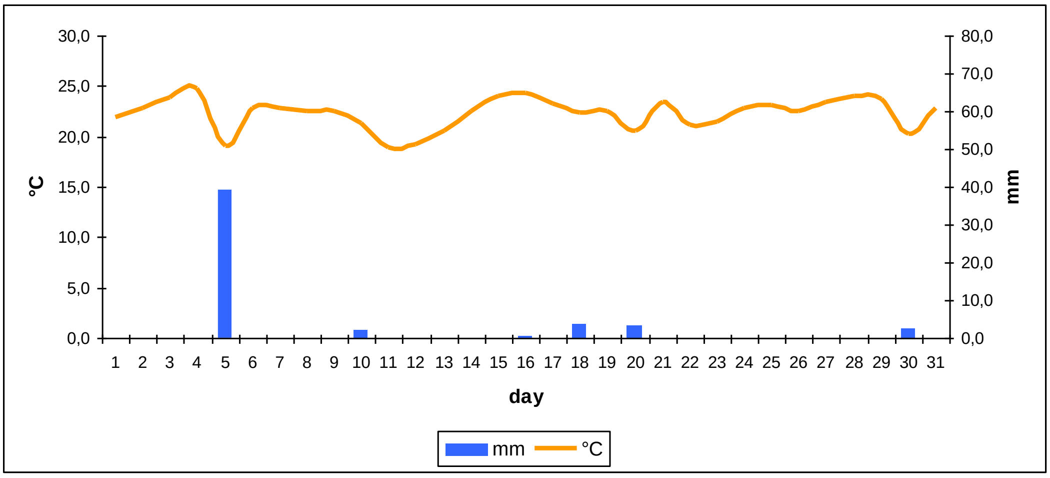


Figure 34 Average temperature and precipitation values (July 2016 - June 2017 – Fondazione Minoprio (IT)

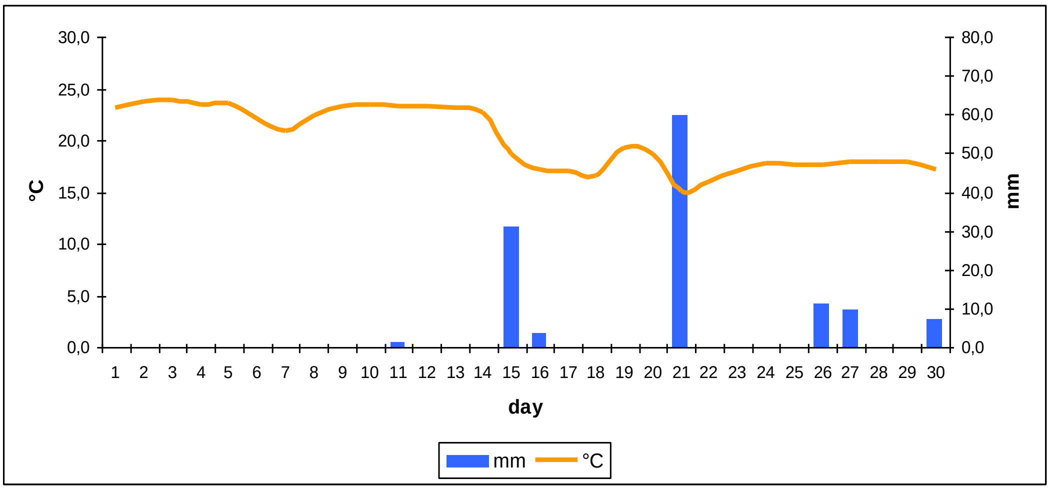
Figure 35 Monthly Precipitation and temperature charts for July 2016 to June 2017



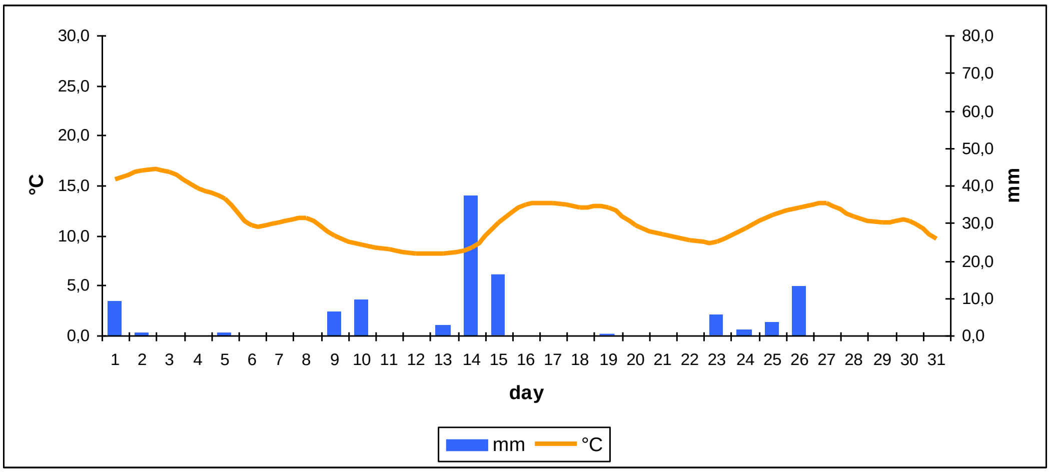
July 2016



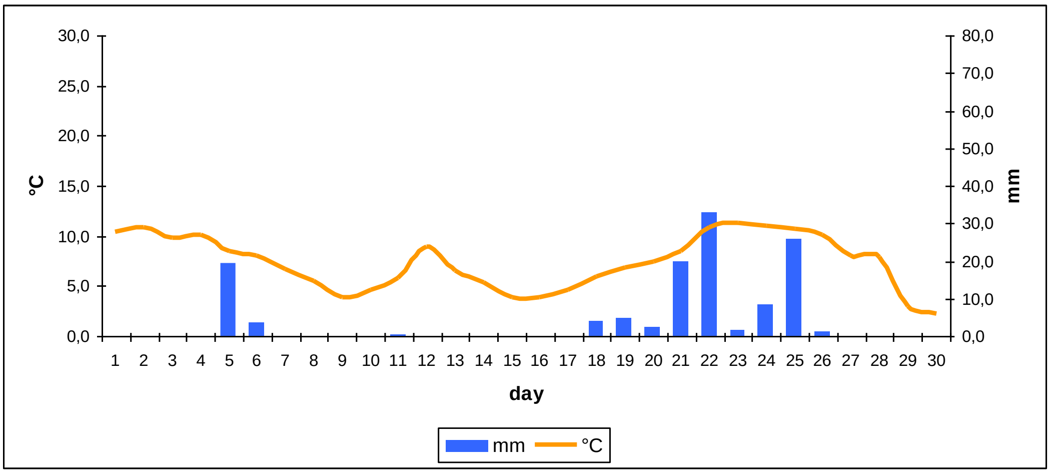
August 2016



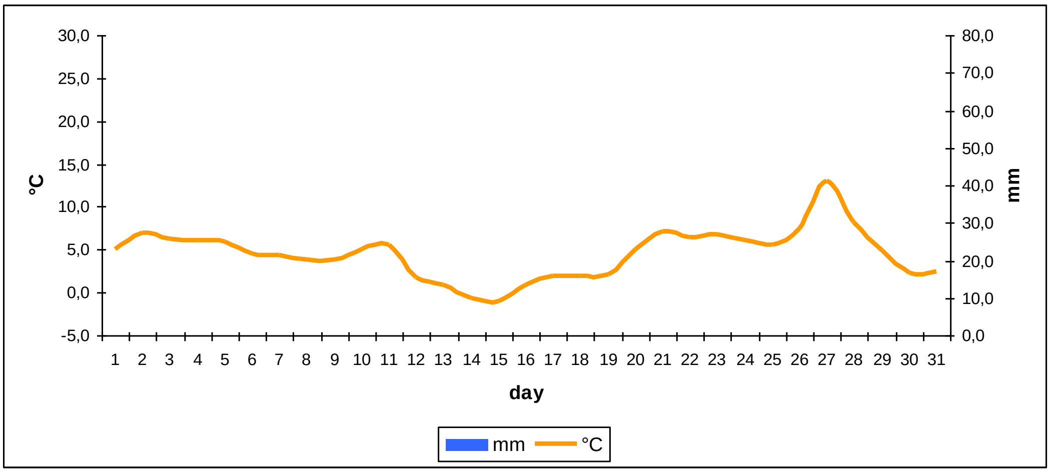
September 2016



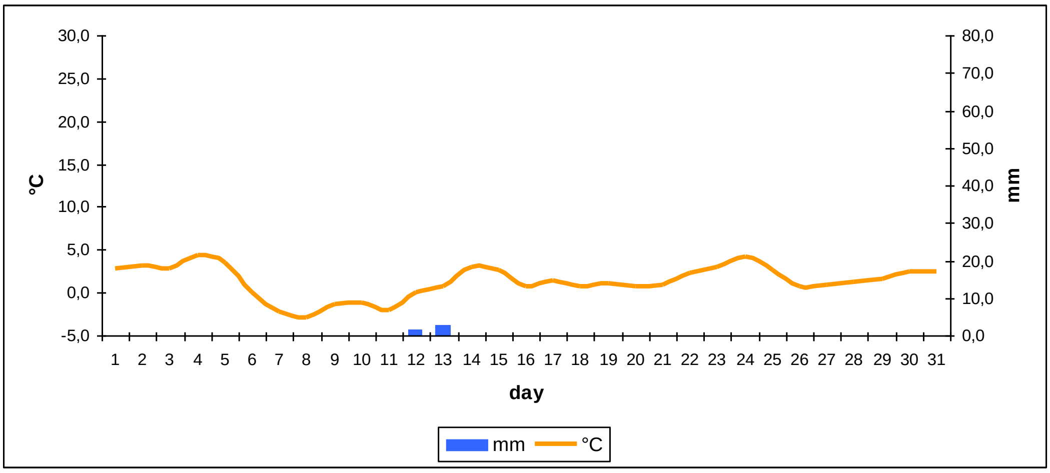
October 2016



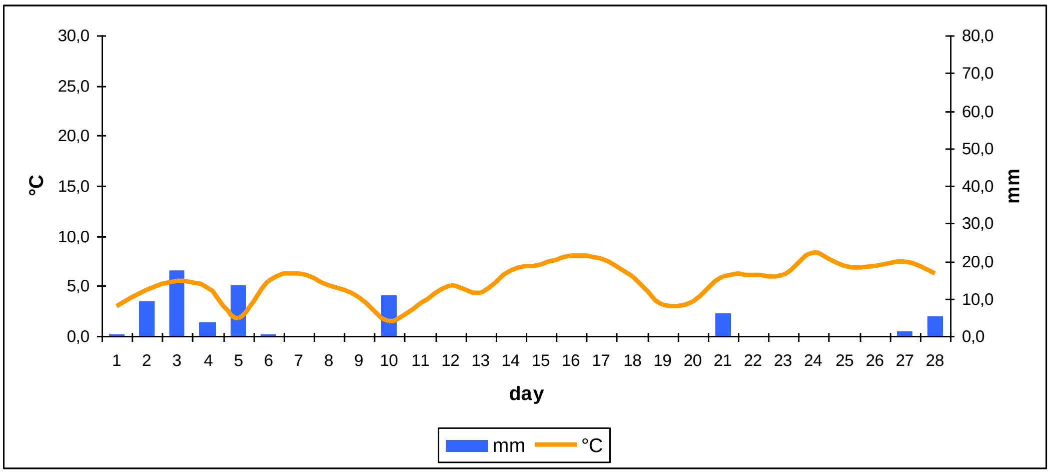
November 2016



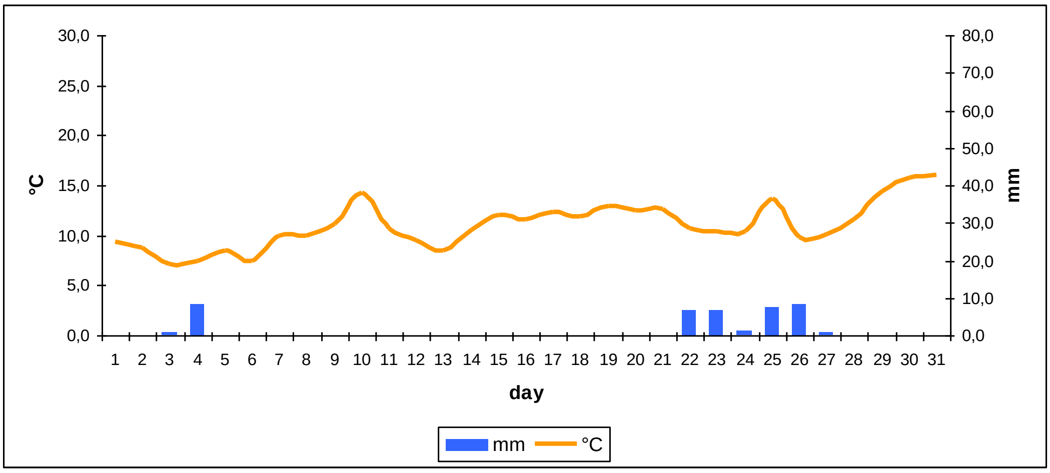
December 2016



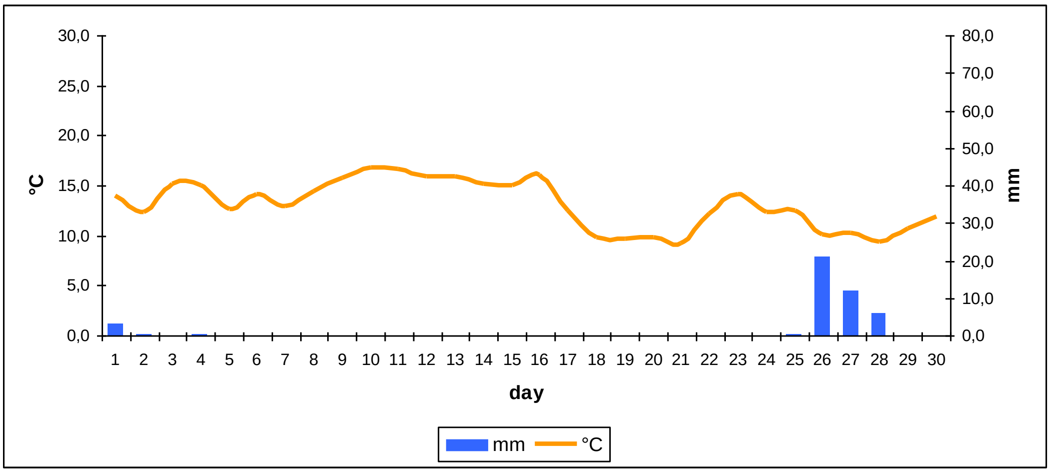
January 2017



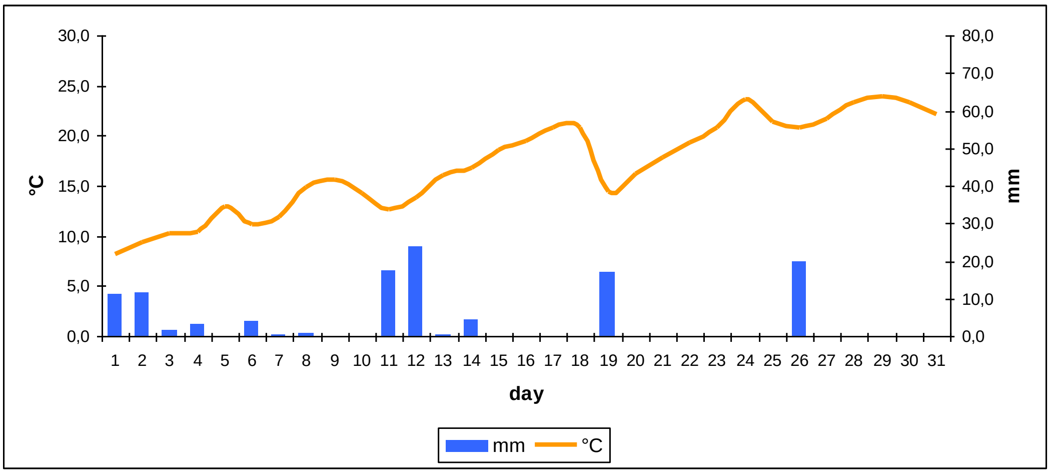
February 2017



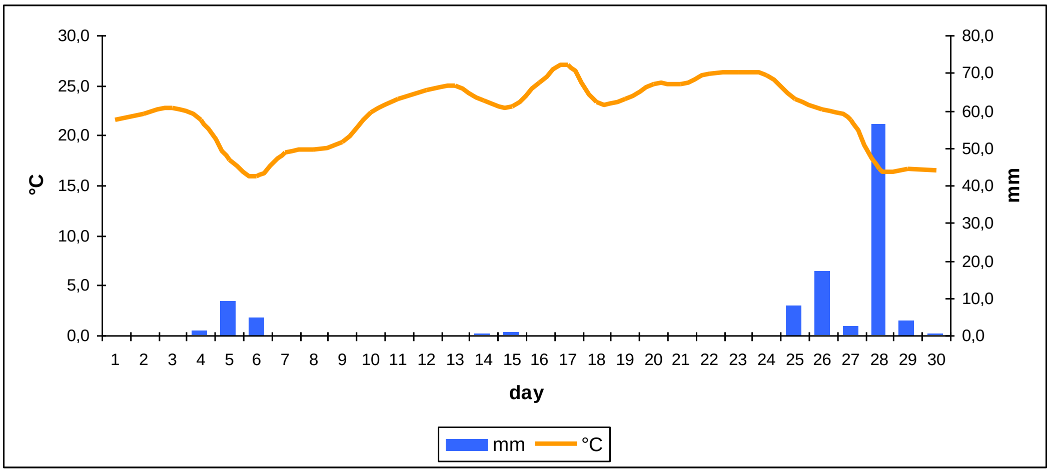
March 2017



April 2017



May 2017



June 2017

Events with high intensity precipitation have increased; some of the greater events have been observed in the following days: July 2 (maximum rain intensity = 77.4 mm/h) and July 31, 2016 (maximum rain intensity = 120.6 mm/h), August 5, 2016 (maximum rain intensity = 42.6 mm/h), September 21, 2016 (maximum rain intensity = 70.8 mm/h), October 14, 2016 (maximum rain intensity = 38.4 mm/h), and June 28, 2017 (maximum rain intensity = 55.2 mm/h).

In the below chart are reported rain and run-off cumulative curves on the Italian demonstrative Green Roof. During this 12 months period, rainfall totalled 963 mm and run-off was equal to 571 mm; the total water retention amounted to 41% of the total rain (392 mm).

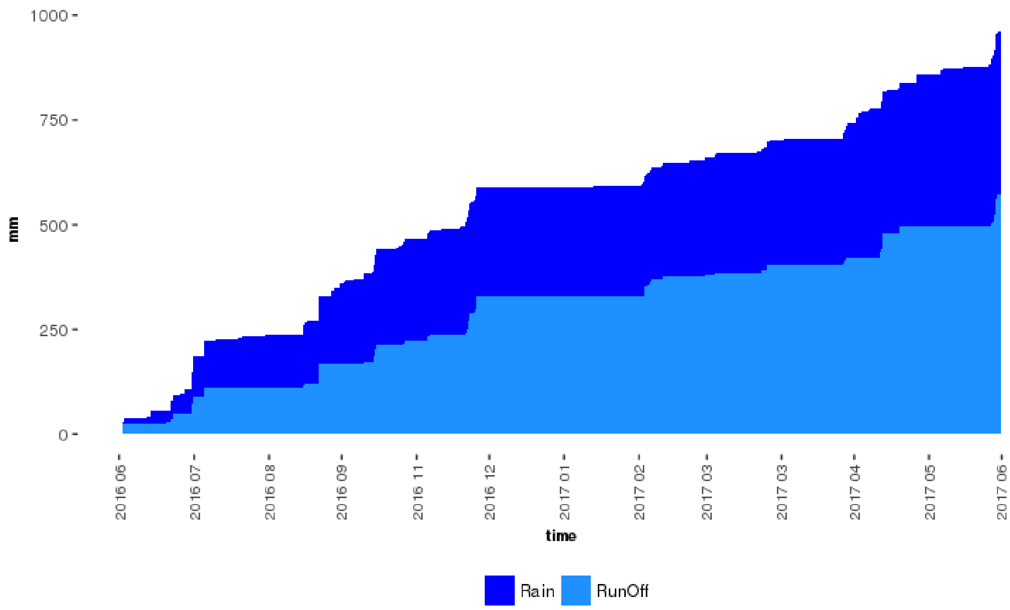


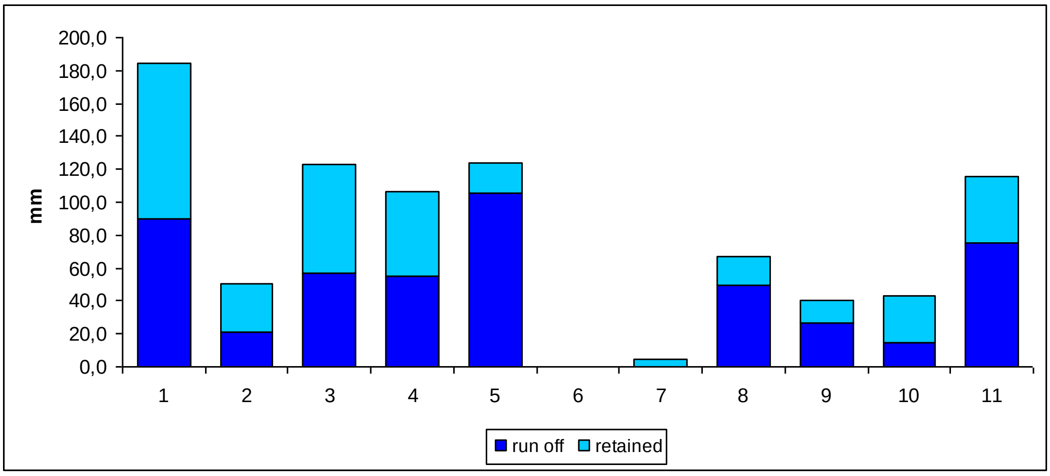
Figure 36 Cumulative rain and run-off on the green roof (July 16- June 17 – Fondazione Minoprio)

In Table 17 below rain, run-off and water retention data are reported by month and as total value. The percent of water retention varies throughout the year, ranging between 15 and 65%.

Table 17 Total precipitation, run off and % water retention for the period of study (July 2016 - June 2017)

DATE	Rain mm	run-off mm	% water retention
07/16	184.6	89.9	51
08/16	50.8	21.3	58
09/16	122,9	57,3	53
10/16	106,7	54.9	49
11/16	124,2	105,5	15
12/16	0,0	0,0	0
01/17	4,3	0,0	99
02/17	66,7	49,9	25
03/17	40,6	26,6	35
04/17	42,8	15,0	65
05/17	115,5	75,6	35
06/17	104,0	74,9	28
TOTAL/YEAR	963.1	570.9	41

The following graph illustrates monthly rain and percent of water retention; what is interesting to observe in this chart is how the amount of water retention is different month by month. This does not seem to correlate to the quantity of monthly rain. This indicates that there are other factors at play.



* Total run-off + water retained = total rain

Figure 37 Monthly rain and percent of water retention on the Italian Green Roof

The following graph shows the monthly precipitation, run-off and substrate water content (humidity) for substrate MAC7 (the one used in the monitored plot). The maximum water content at saturation point is 50% v/v (normally around 40% v/v), while at the wilting point value is between 12-15% v/v. The less moisture retained in in a substrate, the greater is its capacity to retain water (a green roof system at the saturation point loses its capacity to retain water). This reinforces studies which showed that the closer the rain events within a period of time, the less water is retained resulting in the reduction in the delay of run-off and greater values of water discharge.

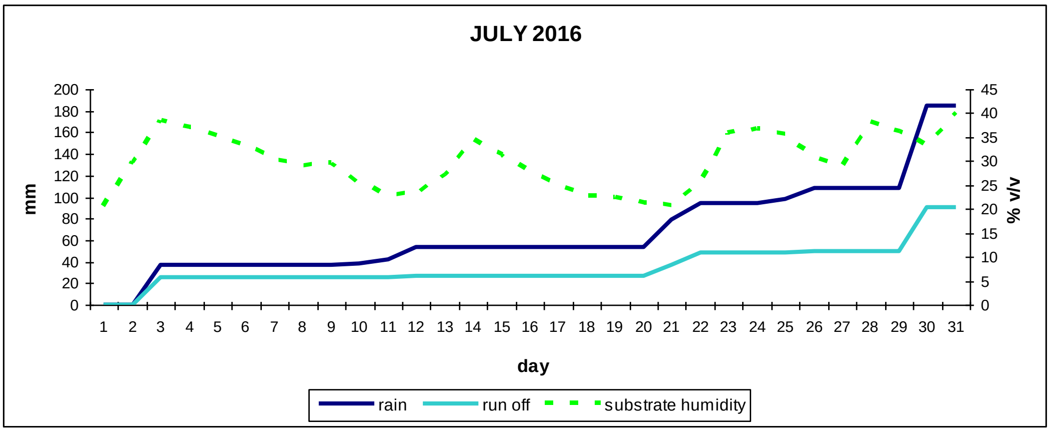


Figure 38 Precipitation, run-off and water contents values - July 2016

July 2016 was the first month with recorded rainfall. It had 8 rainy days, some with great intensity. The monthly coefficient of run-off was very good (0.49) because rainy days are well distributed during the month and the substrate was had dried out in between rainy events (as shown in the chart).

On the contrary, August 2016 had less events (5 in total). Only one significant event was recorded (August 5). During such event, the substrate humidity was between 20-25%, so the coefficient of run-off was low (0.48).

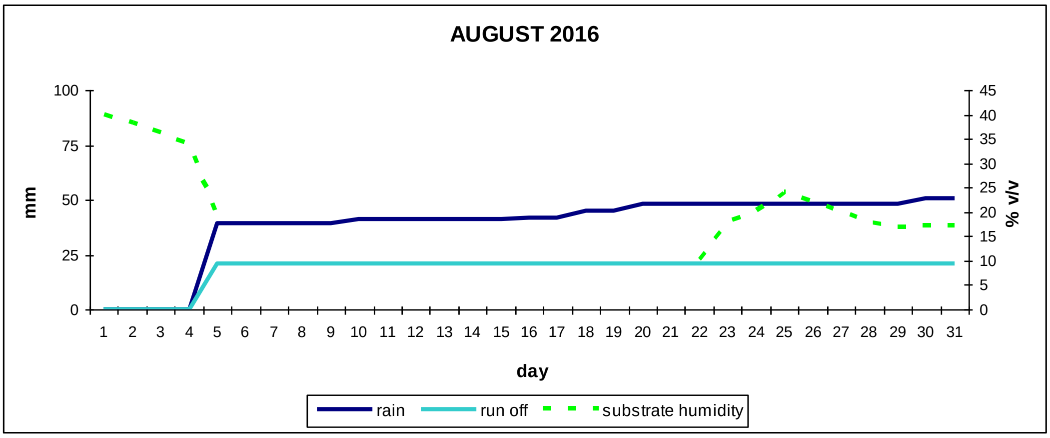


Figure 39 Precipitation, run-off and water contents values - August 2016

September 2016 is of interest because it is possible to observe two different event. The first towards the middle of the month, with more than 30 mm of rain, while the second 6 days later, with more than 60 mm of rain. It is possible to observe in the chart how during the first event there was low humidity in the substrate (less than 20% v/v) resulting in low run-off low (about 0.3), while during the second rain event, substrate moisture content was elevated (almost 40% v/v) resulting in a higher run-off coefficient (0.9), without significance delay in time.

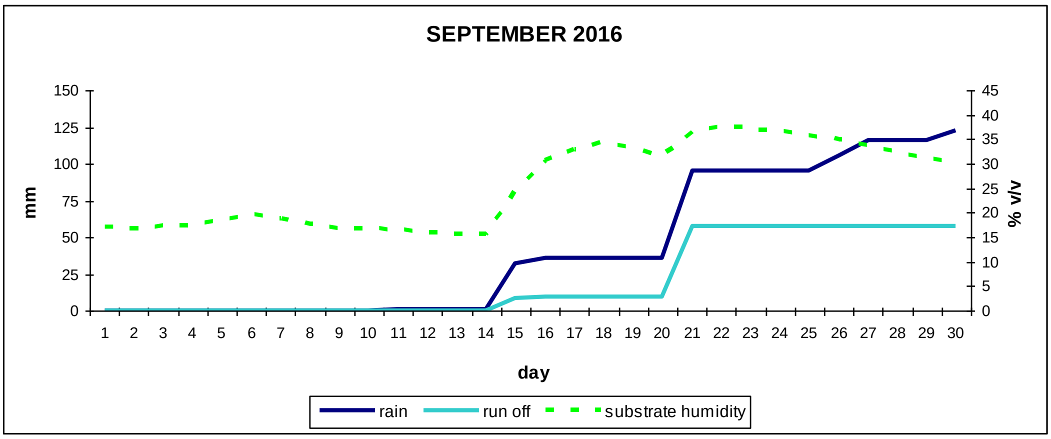


Figure 40 Precipitation, run-off and water contents values - September 2016

October 2016 had 10 rainy days, with one of these events of particular interest (October 14), with more than 37 mm registered resulting in a high run-off coefficient (near to 0.9). This was due to high substrate humidity (more than 40% v/v) prior to the rain event.

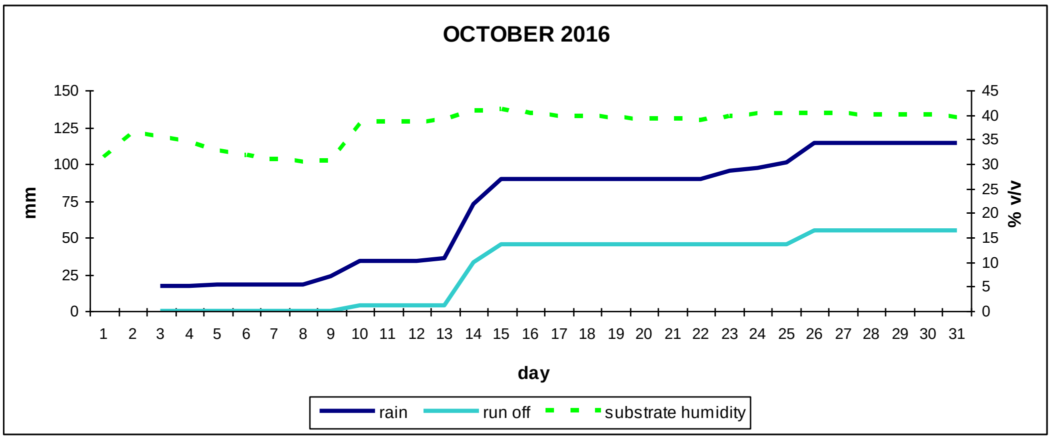


Figure 41 Precipitation, run-off and water contents values - October 2016

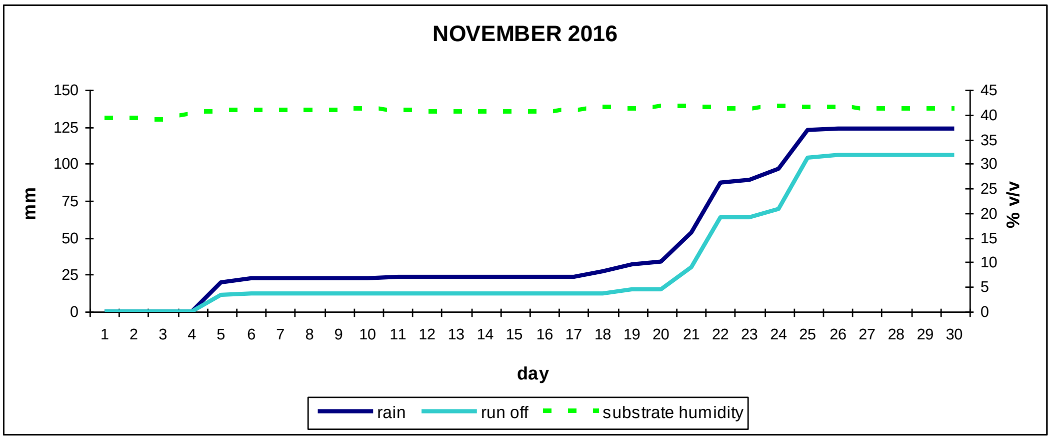


Figure 42 Precipitation, run-off and water contents values - November 2016

November 2016 recorded 124 mm of precipitation, with 11 rainy days and a very high coefficient of run-off (0.85), due to a constant high level of humidity in the green roof system.

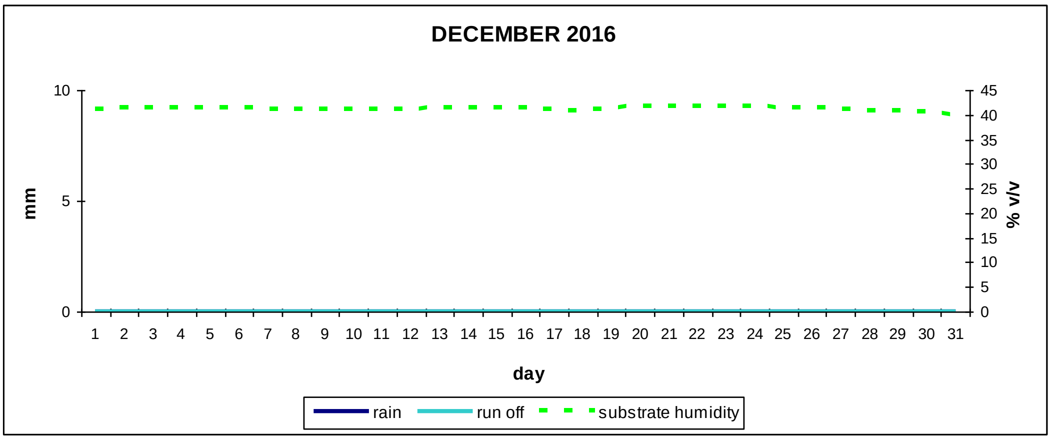


Figure 43 Precipitation, run-off and water contents values - December 2016

During December 2016 no rainfall was recorded. In January 2017, less than 5 mm or rain was recorded.

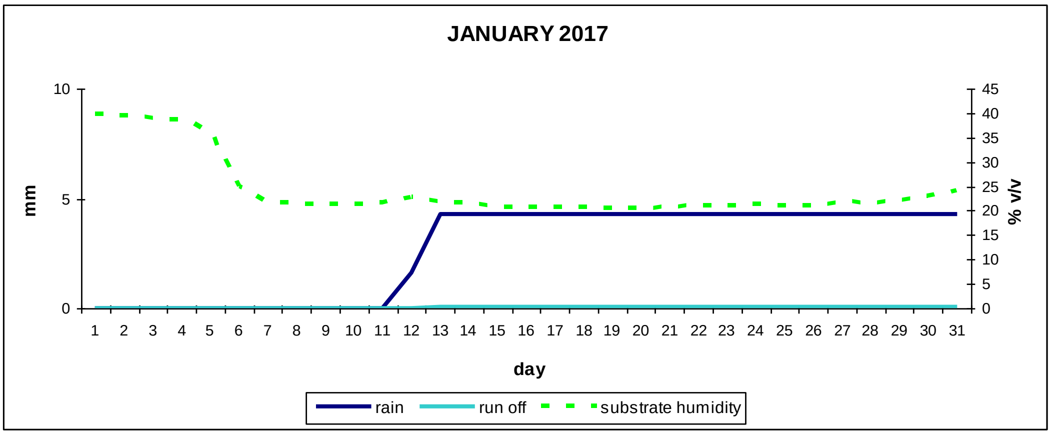


Figure 44 Precipitation, run-off and water contents values - January 2017

8 rainy days were logged during February 2017. Rain fell mainly during the first week of the month, with a run-off coefficient equal to 0.75 and a constant medium-high level of water content in the growing media.

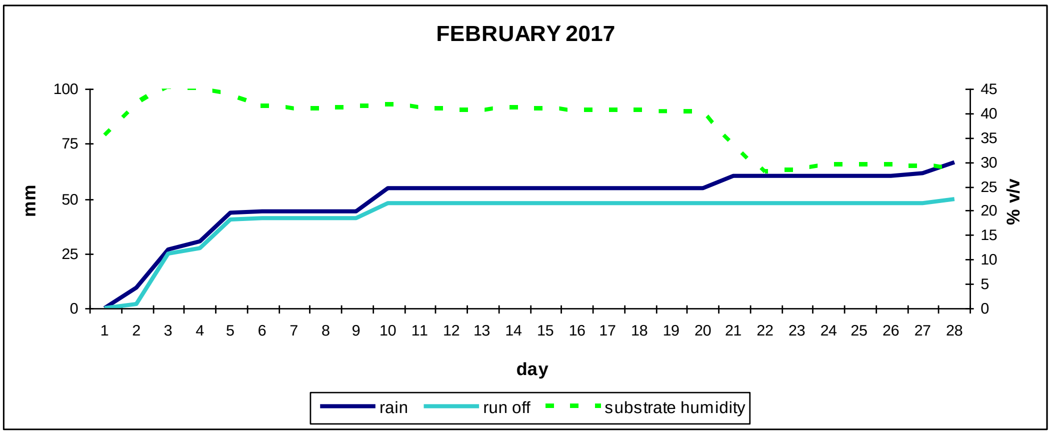


Figure 45 Precipitation, run-off and water contents values - February 2017

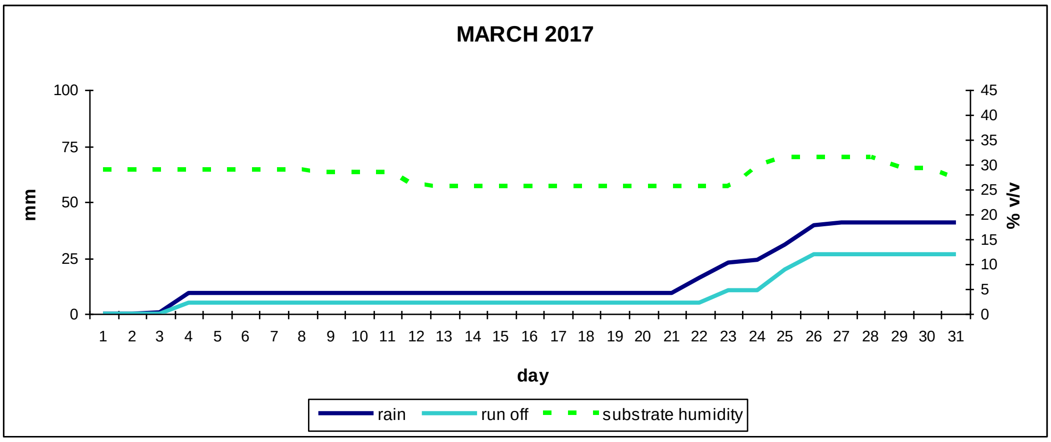


Figure 46 Precipitation, run-off and water contents values - March 2017

March and April 2017 had similar rainfall quantities, with a different run-off coefficient: 0.65 in March and 0.35 in April. Such values resulted because in April rain was mainly concentrated in the last days of the month, with a low-medium level of humidity in the substrate.

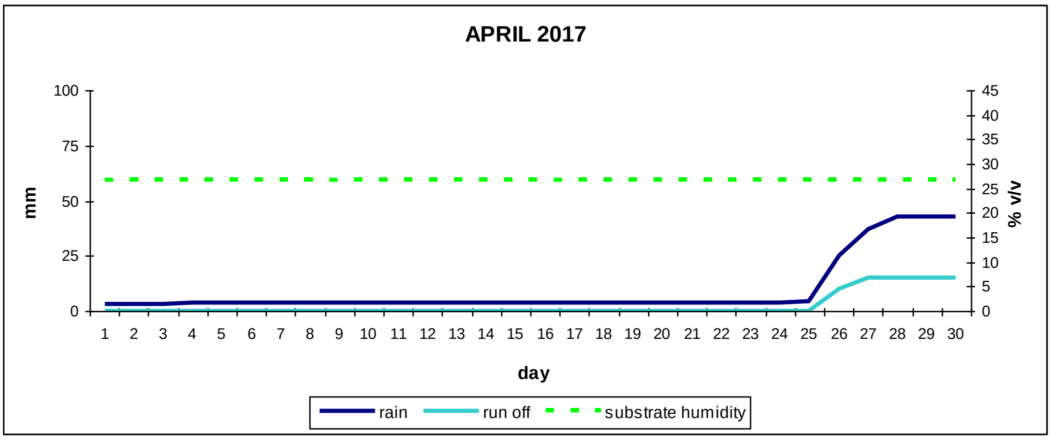


Figure 47 Precipitation, run-off and water contents values - April 2017

May was one of the major rainy month, with 12 rainy days with a total of 115 mm. The run-off coefficient is 0.65, a satisfactory value considering that most of the events have great importance in terms of quantity of rainfall (between 10 and 25 mm/event).

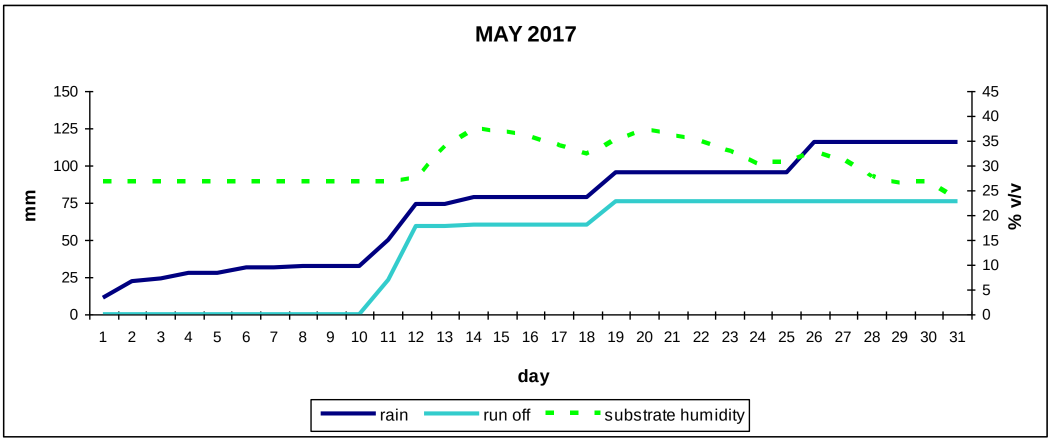


Figure 48 Precipitation, run-off and water contents values - May 2017

In June a total of 104mm of precipitation was recorded with a significant event towards the end of the month (June 28, 56 mm) resulting in a coefficient of run-off of 0.72.

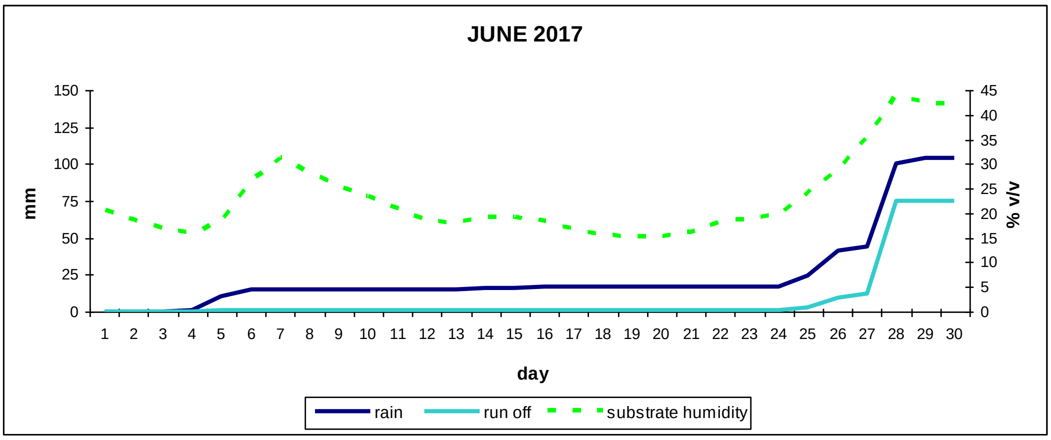


Figure 49 Precipitation, run-off and water contents values - June 2017

High coefficient of run-off relates to the length of antecedent dry weather; in this case the rain events prior to the June 28th were June 25th and 26th with 25mm of precipitation.   The coefficient of run-off is 0.33 and the water content (before the rainfall) in the substrate was around 20% v/v.

A has already reported, the events with high intensity precipitation are on the increase and the green roof system may respond differently (in terms of quantity and delay in time of run-off) in relation to its water content at the time of the rain event.

In the following chart it is possible to observe how in June 18, 2016 , a rain event with an intensity of about 15 mm in half an hour occurred, with the result that there was no delay in water discharge and reduction of run-off: the water content of the substrate before the event was already very high (50% v/v).

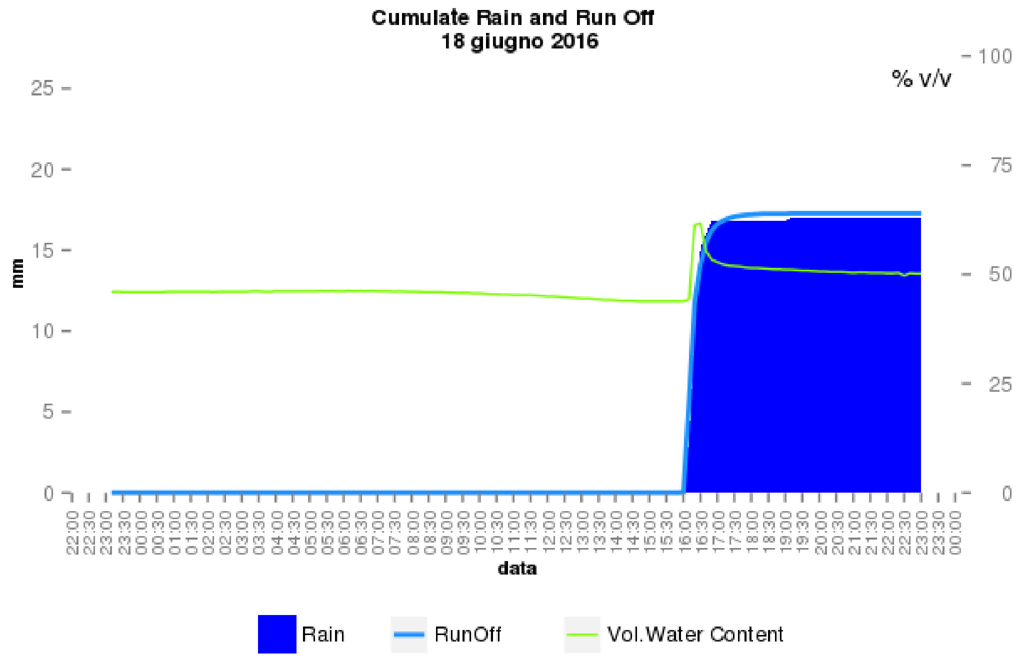


Figure 50 Rain event, run-off and volume water content on June 18th 2016

In the following chart (, May 11, 2016) a rain event of almost 30 mm was recorded between 05.00h and 09.30h. During this event the delay of run-off was more than 1 hour, with a coefficient of about 0.65, even though the humidity in the substrate was relatively high (nearly 40% v/v). This was due to the low intensity of rainfall.

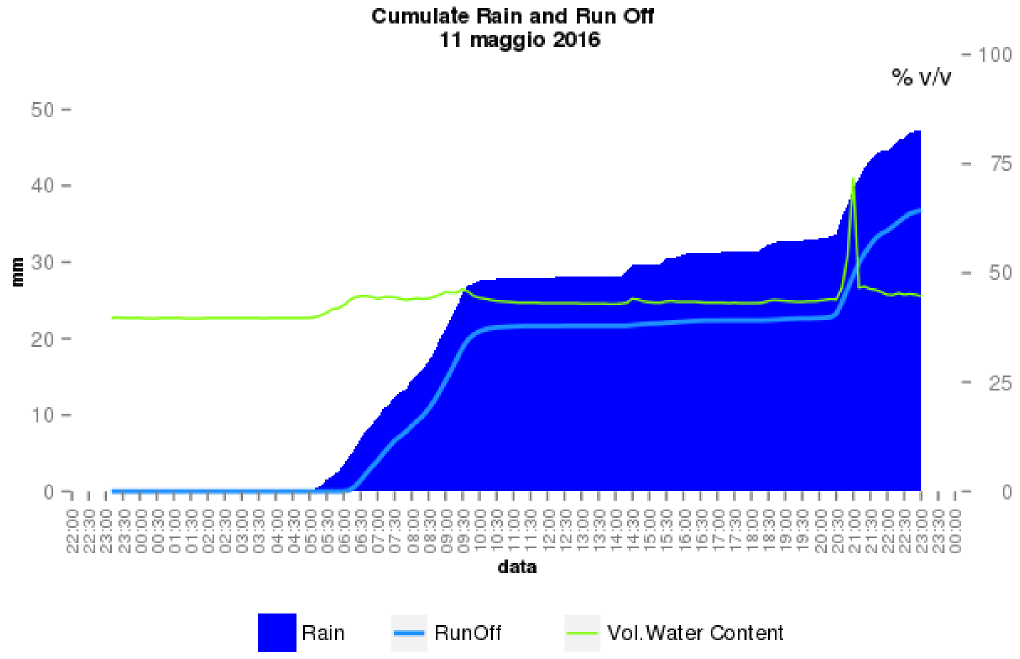


Figure 51 Rain event, run-off and volume water content on May 11th 2016

In the following table the greater values for rain intensity during the monitored period are recorded.

Table 18 High rain intensity over the monitored period (Fondazione Minoprio)

DATE	TIME	RAIN INTENSITY mm/h	DATE	TIME	RAIN INTENSITY mm/h
02/07/16	8.40	74.4	21/09/16	5.20	70,8
02/07/16	8.50	77.4	21/09/16	5.30	69,6
02/07/16	9.00	21.6	21/09/16	5.40	21,6
02/07/16	18.40	30.6	21/09/16	5.50	28,8
02/07/16	18.50	12.6	21/09/16	6.00	27,6
31/07/16	4.20	74,4	21/09/16	6.10	18
31/07/16	4.30	120,6	21/09/16	6.20	13,2
31/07/16	4.40	18,6	14/10/16	8.00	10.8
31/07/16	4.50	18	14/10/16	13.50	38.4
31/07/16	8.40	22.8	28/06/17	1.00	32.4
31/07/16	8.50	21.6	28/06/17	1.10	55.2
31/07/16	10.40	80.4	28/06/17	11.30	20,4
05/08/16	1.30	27.6	28/06/17	11.40	9
05/08/16	1.40	42.6	28/06/17	11.50	10,8
05/08/16	1.50	15.6	28/06/17	12.00	36,6
05/08/16	7.30	16,8	28/06/17	12.10	40,2
05/08/16	7.40	19,2	28/06/17	12.20	11,4
05/08/16	7.50	18	28/06/17	15.50	32.4
05/08/16	8.00	27,6			

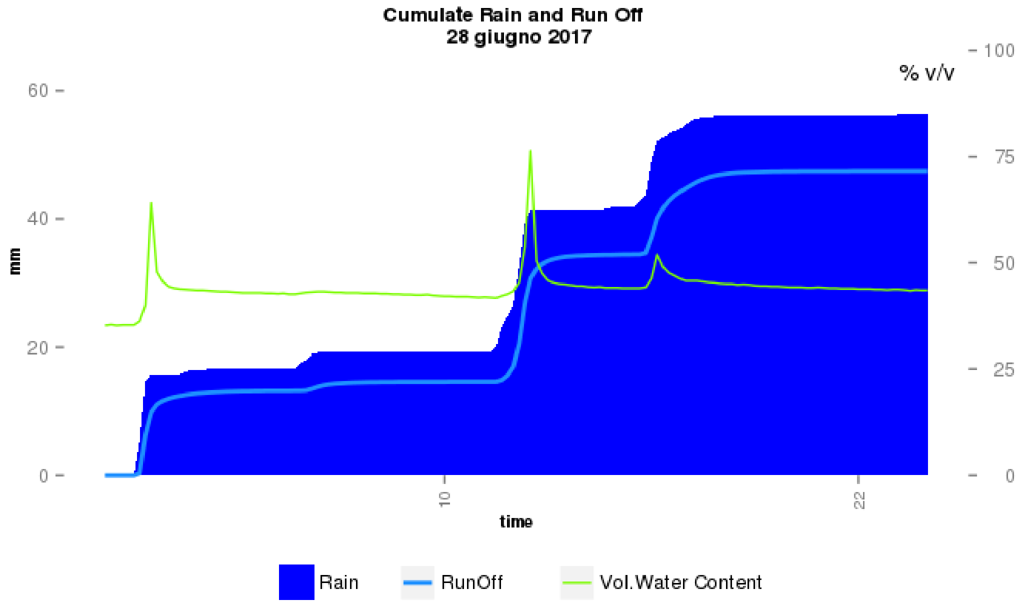


Figure 52 June 28 2017– rainfall, run-off and water content (Fondazione Minoprio)

The graph above shows how the green roof system responded to an intense rain event recorded towards the end of June 2017: prior to the high rain intensity (see arrows), we have exceptionally high water content (with peaks of oversaturation values); however, the system was able to reduce the total run-off volume and to delay the water discharge (about 1 hour in the central event at 11.30) .

The following table illustrates all daily values for rain, run-off, C (coefficient of discharge) and substrate water content for the analysed period (2016, July – 2017 June).

Table 19 Daily values for rain, run-off, Coefficient, and substrate water content (Fondazione Minoprio)

Data	rain mm	run off mm	C	substrate moisture % v/v
01/07/2016	0.0	0.0	=	20.8
02/07/2016	37.2	25.9	0.7	29.7
03/07/2016	0.1	0.03	0.3	38.4
04/07/2016	0.0	0.0	=	37.1
05/07/2016	0.0	0.0	=	35.4
06/07/2016	0.0	0.0	=	33.3
07/07/2016	0.0	0.0	=	30.3
08/07/2016	0.0	0.0	=	28.8
09/07/2016	0.0	0.0	=	29.4
10/07/2016	0.0	0.0	=	25.6
11/07/2016	1.0	0.0	0.0	22.9
12/07/2016	4.1	0.0	0.0	23.1
13/07/2016	11.6	0.6	0.1	27.3
14/07/2016	0.0	0.0	=	34.7
15/07/2016	0.0	0.0	=	31.1
16/07/2016	0.0	0.0	=	28.0
17/07/2016	0.0	0.0	=	25.0
18/07/2016	0.0	0.1	=	22.7

19/07/2016	0.0	0.0	=	22.3
20/07/2016	0.0	0.1	=	21.1
21/07/2016	0.0	0.0	=	20.6
22/07/2016	25.3	9.6	0.4	25.9
23/07/2016	15.4	12.2	0.8	35.8
24/07/2016	0.0	0.0	=	36.8
25/07/2016	0.0	0.0	=	35.6
26/07/2016	3.7	0.0	0.0	30.6
27/07/2016	9.5	0.5	0.1	29.1
28/07/2016	0.2	0.1	0.3	38.1
29/07/2016	0.0	0.0	=	36.2
30/07/2016	0.0	0.0	=	33.4
31/07/2016	76.5	40.8	0.5	40.1
01/08/2016	0.0	0.1	=	39.9
02/08/2016	0.0	0.0	=	38.2
03/08/2016	0.0	0.0	=	36.2
04/08/2016	0.1	0.0	0.0	33.7
05/08/2016	39.1	21.2	0.5	18.9
06/08/2016	0.0	0.0	=	0.0
07/08/2016	0.0	0.0	=	0.0
08/08/2016	0.0	0.0	=	0.0
09/08/2016	0.0	0.0	=	0.0
10/08/2016	2.0	0.0	0.0	0.0
11/08/2016	0.0	0.0	=	0.0
12/08/2016	0.0	0.0	=	0.0
13/08/2016	0.0	0.0	=	0.0
14/08/2016	0.0	0.0	=	0.0
15/08/2016	0.0	0.0	=	0.0
16/08/2016	0.4	0.0	0.0	0.0
17/08/2016	0.0	0.0	=	0.0
18/08/2016	3.6	0.0	0.0	0.0
19/08/2016	0.0	0.0	=	0.0
20/08/2016	3.2	0.0	0.0	0.0
21/08/2016	0.0	0.0	=	0.0
22/08/2016	0.0	0.0	=	10.3
23/08/2016	0.0	0.0	=	17.5
24/08/2016	0.0	0.0	=	20.1
25/08/2016	0.0	0.0	=	24.0
26/08/2016	0.0	0.0	=	22.0
27/08/2016	0.0	0.0	=	20.0
28/08/2016	0.0	0.0	=	17.9
29/08/2016	0.0	0.0	=	16.7
30/08/2016	2.4	0.0	0.0	17.0
31/08/2016	0.0	0.0	=	17.0

01/09/2016	0.0	0.0	=	17.0
02/09/2016	0.0	0.0	=	16.6
03/09/2016	0.0	0.0	=	17.2
04/09/2016	0.0	0.0	=	17.4
05/09/2016	0.0	0.1	=	18.5
06/09/2016	0.0	0.0	=	19.4
07/09/2016	0.0	0.0	=	18.7
08/09/2016	0.0	0.0	=	17.5
09/09/2016	0.0	0.0	=	16.7
10/09/2016	0.0	0.0	=	16.8
11/09/2016	1.2	0.0	0.0	16.5
12/09/2016	0.0	0.0	=	15.9
13/09/2016	0.0	0.0	=	15.5
14/09/2016	0.0	0.0	=	15.6
15/09/2016	30.9	8.8	0.3	24.4
16/09/2016	3.4	0.0	0.0	30.5
17/09/2016	0.0	0.0	=	32.9
18/09/2016	0.0	0.0	=	34.3
19/09/2016	0.0	0.0	=	33.2
20/09/2016	0.0	0.0	=	31.5
21/09/2016	59.6	48.3	0.8	36.5
22/09/2016	0.0	0.0	=	37.6
23/09/2016	0.0	0.0	=	37.2
24/09/2016	0.0	0.0	=	36.6
25/09/2016	0.0	0.0	=	35.8
26/09/2016	11.0	0.0	0.0	34.7
27/09/2016	9.6	0.0	0.0	33.6
28/09/2016	0.0	0.0	=	32.3
29/09/2016	0.0	0.0	=	31.0
30/09/2016	7.2	0.0	0.0	29.9
01/10/2016	0.0	0.0	=	31.3
02/10/2016	0.0	0.0	=	36.6
03/10/2016	0.0	0.0	=	35.5
04/10/2016	0.0	0.0	=	34.1
05/10/2016	0.8	0.0	0.0	32.7
06/10/2016	0.0	0.0	=	31.7
07/10/2016	0.0	0.0	=	30.9
08/10/2016	0.0	0.0	=	30.2
09/10/2016	6.2	0.1	0.0	30.5
10/10/2016	9.6	3.7	0.4	38.2
11/10/2016	0.0	0.0	=	38.4
12/10/2016	0.0	0.0	=	38.4
13/10/2016	2.6	0.0	0.0	38.8
14/10/2016	36.8	28.9	0.8	40.7

15/10/2016	16.7	12.1	0.7	41.0
16/10/2016	0.0	0.0	=	40.1
17/10/2016	0.0	0.0	=	39.7
18/10/2016	0.0	0.0	=	39.6
19/10/2016	0.2	0.0	0.0	39.3
20/10/2016	0.0	0.0	=	39.2
21/10/2016	0.0	0.0	=	39.0
22/10/2016	0.0	0.0	=	38.7
23/10/2016	5.6	0.1	0.0	39.6
24/10/2016	1.6	0.0	0.0	40.2
25/10/2016	3.6	0.1	0.0	40.3
26/10/2016	13.1	9.8	0.7	40.2
27/10/2016	0.0	0.0	=	40.2
28/10/2016	0.1	0.0	0.0	39.9
29/10/2016	0.0	0.0	=	39.9
30/10/2016	0.0	0.0	=	39.8
31/10/2016	0.0	0.0	=	39.4
01/11/2016	0.0	0.0	=	39.1
02/11/2016	0.0	0.0	=	39.1
03/11/2016	0.0	0.0	=	38.8
04/11/2016	19.4	11.6	0.6	40.3
05/11/2016	3.5	0.3	0.1	40.8
06/11/2016	0.0	0.0	=	40.9
07/11/2016	0.0	0.0	=	40.8
08/11/2016	0.0	0.0	=	40.8
09/11/2016	0.0	0.0	=	40.7
10/11/2016	0.3	0.0	0.1	40.9
11/11/2016	0.0	0.0	=	40.8
12/11/2016	0.0	0.0	=	40.5
13/11/2016	0.0	0.0	=	40.4
14/11/2016	0.0	0.0	=	40.4
15/11/2016	0.0	0.0	=	40.4
16/11/2016	0.0	0.0	=	40.4
17/11/2016	3.6	0.5	0.1	40.8
18/11/2016	5.2	2.2	0.4	41.4
19/11/2016	1.0	0.0	0.0	41.1
20/11/2016	20.1	14.6	0.7	41.5
21/11/2016	33.7	34.9	1.0	41.6
22/11/2016	1.8	0.0	0.0	41.2
23/11/2016	7.4	4.4	0.6	41.0
24/11/2016	26.3	34.9	1.3	41.6
25/11/2016	1.8	2.0	1.1	41.4
26/11/2016	0.1	0.0	0.0	41.2
27/11/2016	0.0	0.0	=	41.1

28/11/2016	0.0	0.0	=	41.2
29/11/2016	0.0	0.0	=	41.2
30/11/2016	0.0	0.0	=	41.2
01/12/2016	0.0	0.0	=	41.2
02/12/2016	0.0	0.0	=	41.2
03/12/2016	0.0	0.0	=	41.3
04/12/2016	0.0	0.0	=	41.2
05/12/2016	0.0	0.0	=	41.3
06/12/2016	0.0	0.0	=	41.2
07/12/2016	0.0	0.0	=	41.1
08/12/2016	0.0	0.0	=	41.1
09/12/2016	0.0	0.0	=	41.0
10/12/2016	0.0	0.0	=	41.1
11/12/2016	0.0	0.0	=	41.1
12/12/2016	0.0	0.0	=	41.2
13/12/2016	0.0	0.0	=	41.3
14/12/2016	0.0	0.0	=	41.3
15/12/2016	0.0	0.0	=	41.3
16/12/2016	0.0	0.0	=	41.3
17/12/2016	0.0	0.0	=	41.0
18/12/2016	0.0	0.0	=	40.8
19/12/2016	0.0	0.0	=	41.2
20/12/2016	0.0	0.0	=	41.6
21/12/2016	0.0	0.0	=	41.7
22/12/2016	0.0	0.0	=	41.7
23/12/2016	0.0	0.0	=	41.6
24/12/2016	0.0	0.0	=	41.6
25/12/2016	0.0	0.0	=	41.4
26/12/2016	0.0	0.0	=	41.2
27/12/2016	0.0	0.0	=	41.1
28/12/2016	0.0	0.0	=	40.9
29/12/2016	0.0	0.0	=	40.8
30/12/2016	0.0	0.0	=	40.5
31/12/2016	0.0	0.0	=	40.0
01/01/2017	0.0	0.0	=	39.7
02/01/2017	0.0	0.0	=	39.4
03/01/2017	0.0	0.0	=	38.8
04/01/2017	0.0	0.0	=	38.6
05/01/2017	0.0	0.0	=	36.4
06/01/2017	0.0	0.0	=	25.0
07/01/2017	0.0	0.0	=	21.9
08/01/2017	0.0	0.0	=	21.3
09/01/2017	0.0	0.0	=	21.2
10/01/2017	0.0	0.0	=	21.3

11/01/2017	1.3	0.0	0.0	21.6
12/01/2017	3.0	0.0	0.0	22.6
13/01/2017	0.0	0.0	=	21.7
14/01/2017	0.0	0.0	=	21.6
15/01/2017	0.0	0.0	=	20.8
16/01/2017	0.0	0.0	=	20.6
17/01/2017	0.0	0.0	=	20.6
18/01/2017	0.0	0.0	=	20.6
19/01/2017	0.0	0.0	=	20.5
20/01/2017	0.0	0.0	=	20.5
21/01/2017	0.0	0.0	=	20.6
22/01/2017	0.0	0.0	=	20.8
23/01/2017	0.0	0.0	=	21.0
24/01/2017	0.0	0.0	=	21.2
25/01/2017	0.0	0.0	=	21.0
26/01/2017	0.0	0.0	=	21.0
27/01/2017	0.0	0.0	=	21.7
28/01/2017	0.0	0.0	=	21.6
29/01/2017	0.0	0.0	=	22.2
30/01/2017	0.0	0.0	=	23.0
31/01/2017	0.0	0.0	=	23.9
01/02/2017	9.4	2.0	0.2	35.4
02/02/2017	17.5	23.0	1.3	42.3
03/02/2017	3.4	2.7	0.8	45.3
04/02/2017	12.2	12.0	1.0	44.9
05/02/2017	1.6	1.4	0.9	43.7
06/02/2017	0.0	0.0	=	41.2
07/02/2017	0.0	0.0	=	40.8
08/02/2017	0.0	0.0	=	40.8
09/02/2017	10.6	6.8	0.6	41.4
10/02/2017	0.0	0.1	=	41.7
11/02/2017	0.0	0.0	=	41.0
12/02/2017	0.0	0.0	=	40.6
13/02/2017	0.0	0.0	=	40.6
14/02/2017	0.0	0.0	=	41.2
15/02/2017	0.0	0.0	=	40.8
16/02/2017	0.0	0.0	=	40.6
17/02/2017	0.0	0.0	=	40.5
18/02/2017	0.0	0.0	=	40.6
19/02/2017	0.0	0.0	=	40.4
20/02/2017	5.8	0.0	0.0	40.1
21/02/2017	0.0	0.0	=	33.3
22/02/2017	0.0	0.0	=	28.0
23/02/2017	0.0	0.1	=	28.3

24/02/2017	0.0	0.0	=	29.3
25/02/2017	0.0	0.0	=	29.3
26/02/2017	0.4	0.0	0.0	29.3
27/02/2017	5.8	2.0	0.3	29.2
28/02/2017	0.0	0.0	=	28.9
01/03/2017	0.0	0.0	=	28.9
02/03/2017	0.6	0.0	0.0	28.9
03/03/2017	8.5	4.7	0.6	28.9
04/03/2017	0.1	0.0	0.0	28.9
05/03/2017	0.0	0.0	=	28.8
06/03/2017	0.0	0.0	=	28.8
07/03/2017	0.0	0.0	=	28.8
08/03/2017	0.0	0.0	=	28.8
09/03/2017	0.0	0.0	=	28.3
10/03/2017	0.0	0.0	=	28.2
11/03/2017	0.0	0.0	=	28.2
12/03/2017	0.0	0.0	=	25.8
13/03/2017	0.0	0.0	=	25.6
14/03/2017	0.0	0.0	=	25.6
15/03/2017	0.0	0.0	=	25.6
16/03/2017	0.0	0.0	=	25.6
17/03/2017	0.0	0.0	=	25.6
18/03/2017	0.0	0.0	=	25.6
19/03/2017	0.0	0.0	=	25.6
20/03/2017	0.0	0.0	=	25.6
21/03/2017	6.7	0.3	0.0	25.6
22/03/2017	6.8	5.4	0.8	25.6
23/03/2017	1.1	0.0	0.0	25.6
24/03/2017	7.1	7.4	1.0	29.7
25/03/2017	8.8	8.7	1.0	31.4
26/03/2017	0.0	0.0	=	0.0
27/03/2017	0.9	0.0	0.0	31.4
28/03/2017	0.0	0.0	=	31.3
29/03/2017	0.0	0.0	=	29.6
30/03/2017	0.0	0.0	=	29.3
31/03/2017	0.0	0.0	=	27.1
01/04/2017	3.1	0.0	0.0	26.6
02/04/2017	0.3	0.0	0.0	26.6
03/04/2017	0.0	0.0	=	26.6
04/04/2017	0.5	0.0	0.0	26.6
05/04/2017	0.0	0.0	=	26.6
06/04/2017	0.0	0.0	=	26.6
07/04/2017	0.0	0.0	=	26.6
08/04/2017	0.0	0.0	=	26.6

09/04/2017	0.0	0.0	=	26.6
10/04/2017	0.0	0.0	=	26.6
11/04/2017	0.0	0.0	=	26.6
12/04/2017	0.0	0.0	=	26.6
13/04/2017	0.0	0.0	=	26.6
14/04/2017	0.0	0.0	=	26.6
15/04/2017	0.0	0.0	=	26.6
16/04/2017	0.0	0.0	=	26.6
17/04/2017	0.0	0.0	=	26.6
18/04/2017	0.1	0.0	0.0	26.6
19/04/2017	0.0	0.0	=	26.6
20/04/2017	0.0	0.0	=	26.6
21/04/2017	0.0	0.0	=	26.6
22/04/2017	0.0	0.0	=	26.6
23/04/2017	0.0	0.0	=	26.6
24/04/2017	0.0	0.0	=	26.6
25/04/2017	0.3	0.0	0.0	26.6
26/04/2017	20.8	10.3	0.5	26.6
27/04/2017	11.7	4.7	0.4	26.6
28/04/2017	6.0	0.0	0.0	26.6
29/04/2017	0.0	0.0	=	26.6
30/04/2017	0.0	0.0	=	26.6
01/05/2017	11.2	0.0	0.0	26.6
02/05/2017	11.4	0.0	0.0	26.6
03/05/2017	1.4	0.0	0.0	26.6
04/05/2017	3.6	0.0	0.0	26.6
05/05/2017	0.0	0.0	=	26.6
06/05/2017	4.0	0.0	0.0	26.6
07/05/2017	0.2	0.0	0.0	26.6
08/05/2017	0.7	0.0	0.0	26.6
09/05/2017	0.1	0.1	0.7	26.6
10/05/2017	0.0	0.0	=	26.6
11/05/2017	17.5	23.0	1.3	26.6
12/05/2017	23.9	35.8	1.5	27.4
13/05/2017	0.2	0.2	0.8	34.0
14/05/2017	4.3	1.3	0.3	37.2
15/05/2017	0.1	0.0	0.0	37.1
16/05/2017	0.0	0.0	=	35.5
17/05/2017	0.0	0.0	=	34.0
18/05/2017	0.0	0.0	=	32.2
19/05/2017	17.1	15.1	0.9	34.9
20/05/2017	0.1	0.0	0.3	37.2
21/05/2017	0.0	0.0	=	36.0
22/05/2017	0.0	0.0	=	34.7

23/05/2017	0.0	0.0	=	32.7
24/05/2017	0.0	0.0	=	30.2
25/05/2017	0.0	0.0	=	30.6
26/05/2017	19.7	0.0	0.0	32.5
27/05/2017	0.0	0.0	=	31.1
28/05/2017	0.0	0.0	=	27.8
29/05/2017	0.0	0.0	=	26.3
30/05/2017	0.0	0.0	=	26.7
31/05/2017	0.0	0.0	=	23.0
01/06/2017	0.0	0.0	=	20.5
02/06/2017	0.0	0.0	=	18.6
03/06/2017	0.0	0.0	=	16.9
04/06/2017	1.3	0.0	0.0	15.9
05/06/2017	9.2	0.5	0.1	18.3
06/06/2017	4.7	0.2	0.0	26.5
07/06/2017	0.1	0.0	0.0	31.3
08/06/2017	0.0	0.0	=	28.1
09/06/2017	0.0	0.0	=	25.4
10/06/2017	0.0	0.0	=	23.2
11/06/2017	0.0	0.0	=	20.8
12/06/2017	0.0	0.0	=	18.4
13/06/2017	0.0	0.1	=	17.9
14/06/2017	0.3	0.0	0.0	19.2
15/06/2017	0.8	0.0	0.0	19.2
16/06/2017	0.1	0.0	0.0	18.3
17/06/2017	0.0	0.0	=	16.7
18/06/2017	0.0	0.0	=	15.3
19/06/2017	0.0	0.0	=	15.2
20/06/2017	0.0	0.0	=	15.1
21/06/2017	0.0	0.0	=	16.0
22/06/2017	0.0	0.0	=	18.1
23/06/2017	0.0	0.1	=	18.9
24/06/2017	0.0	0.0	=	19.7
25/06/2017	8.1	1.5	0.2	24.3
26/06/2017	17.0	7.0	0.4	28.9
27/06/2017	2.3	2.9	1.2	35.5
28/06/2017	56.3	62.4	1.1	43.9
29/06/2017	3.8	0.2	0.1	42.5
30/06/2017	0.3	0.0	0.1	41.8

The monitoring of green roof on site was useful to obtain monthly and annual data of run-off and the water retention capacity. To better understand the topic about delay in run-off, a number of tests have been undertaken in a laboratory rain simulator (rain chamber). Tests conducted referred to that described by the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) guidelines (FLL, 2008). The guideline description permits the determination of the coefficient of discharge (C), based on the ratio of cumulative run-off to cumulative rainfall at the end of a 15-minute constant intensity rainfall of 27 mm (108 mm/h).

The laboratory rain simulator (dimension 1m x 5m) is has a drainage gradient of 2%. During the testing period, the various components of a green roof are installed within the simulator. Only the vegetation is excluded. The system is then fully saturated and left for 24 hours to drain access water. Following this 24 hour period, a block rain of consistent intensity equivalent to 27 l/m^2 in 15 minute is applied (intensity of 1.8 mm/min = 108 mm/h). The outlet water flow during the rain simulation period related to time is monitored. The test is repeated for three times after 24 hours. The coefficient of discharge (C=0-1) is so determined.

Figure 53 Rain Chamber at Fondazione Minoprio

Figure 54 Rain test in progress within the rain chamber

Figure 55 High intensity rain test in progress within the rain chamber

Figure 56 KIPP 1000 used to quantify run-off

Each Italian and Maltese green roof demonstration system has been tested considering two different depth of substrates: 10cm and 15cm.

Increasing growing media depth would reduce run-off significantly, while the run-off delay time increases. With only 10 cm of growing media, run-off coefficient is satisfactory (around 0.5 – a little better than UNI references).

Table 20 shows results obtained from each single test (3 replications/test).

Table 20 Data from the rainfall simulator

CODE	rain mm/h	run-off coeff	tot. rain water liters	tot. drained water liters	water retention liters	water retention %
MAC7 h 10 cm	107	0,40	134	84	50	37,31
MAC7 h 10 cm	106	0,47	133	94	39	29,32
MAC7 h 10 cm	110	0,44	138	91	47	34,06
MAC7 h 15 cm	106	0,21	133	68	65	48,87
MAC7 h 15 cm	110	0,23	137	75	62	45,26
MAC7 h 15 cm	119	0,27	149	83	66	44,30
MAC7/FC h 10 cm	106	0,43	133	91	42	31,58
MAC7/FC h 10 cm	110	0,33	138	88	50	36,23
MAC7/FC h 10 cm	126	0,37	158	103	55	34,81
MAC7/FC h 15 cm	132	0,18	165	89	76	46,06
MAC7/FC h 15 cm	130	0,20	162	93	69	42,59
MAC7/FC h 15 cm	122	0,22	153	96	57	37,25
MAC7/T h 10 cm	128	0,43	160	113	47	29,38
MAC7/T h 10 cm	126	0,49	158	121	37	23,42
MAC7/T h 10 cm	124	0,49	155	118	37	23,87
MAC7/T h 15 cm	130	0,35	163	112	51	31,29
MAC7/T h 15 cm	124	0,35	155	107	48	30,97
MAC7/T h 15 cm	122	0,36	152	108	44	28,95
TA h 10 cm	122	0,51	152	110	42	27,63
TA h 10 cm	130	0,51	162	114	48	29,63
TA h 10 cm	125	0,51	156	110	46	29,49
TA h 15 cm	126	0,40	158	104	54	34,18
TA h 15 cm	112	0,42	140	98	42	30,00
TA h 15 cm	116	0,36	145	99	46	31,72
MALTA1 h 10 cm	118	0,38	147	85	62	42,18
MALTA1 h 10 cm	109	0,43	136	88	48	35,29
MALTA1 h 10 cm	120	0,43	150	94	56	37,33
MALTA1 h 15 cm	120	0,29	150	84	66	44,00
MALTA1 h 15 cm	122	0,25	152	78	74	48,68
MALTA1 h 15 cm	125	0,28	156	85	71	45,51
MALTA2 h 10 cm	114	0,31	143	78	65	45,45
MALTA2 h 10 cm	117	0,36	156	92	64	41,03
MALTA2 h 10 cm	114	0,38	142	88	54	38,03
MALTA2 h 15 cm	116	0,26	145	76	69	47,59
MALTA2 h 15 cm	114	0,26	142	75	67	47,18
MALTA2 h 15 cm	126	0,31	158	85	73	46,20

In the following charts, average run-off coefficient and water retention are reported.

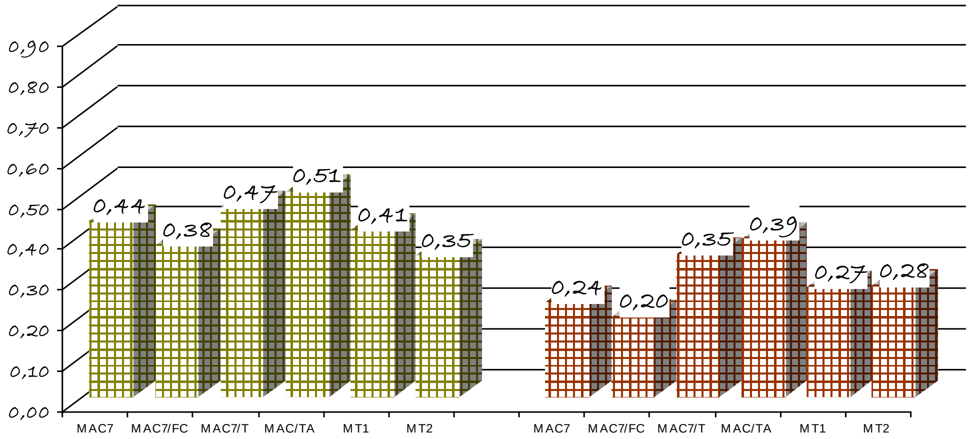


Figure 57 Average run-off coefficient for different depths of substrate

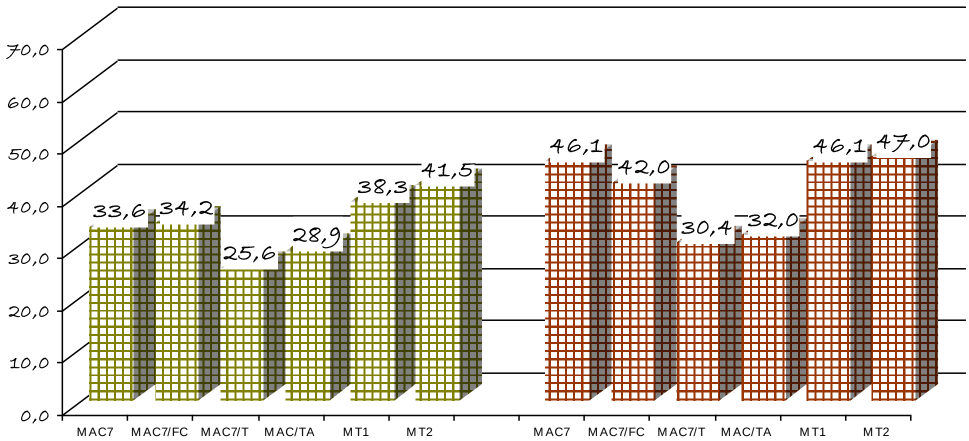
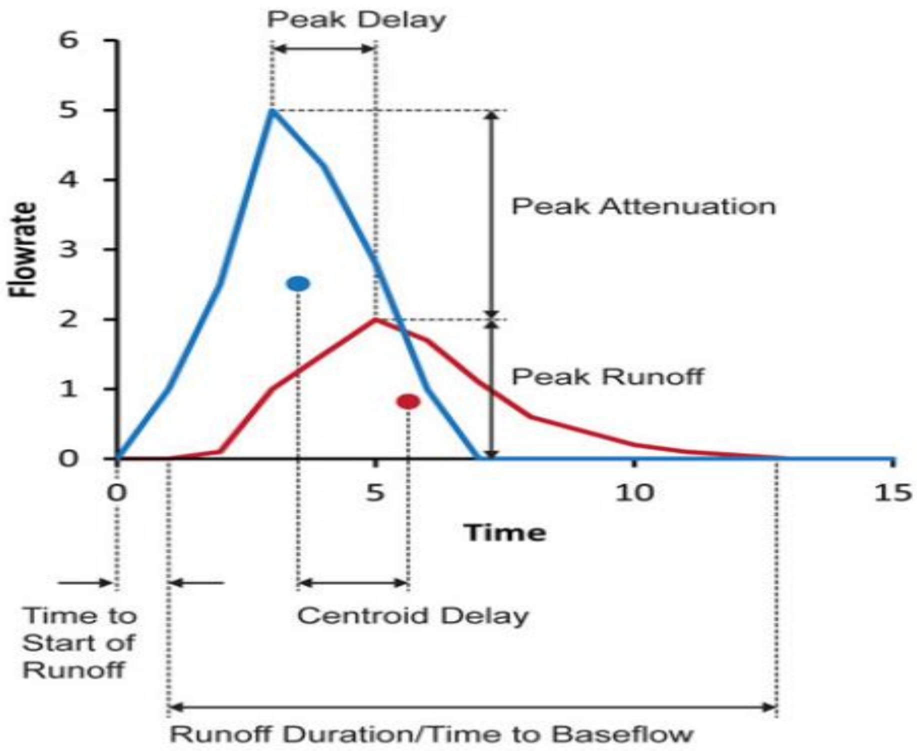
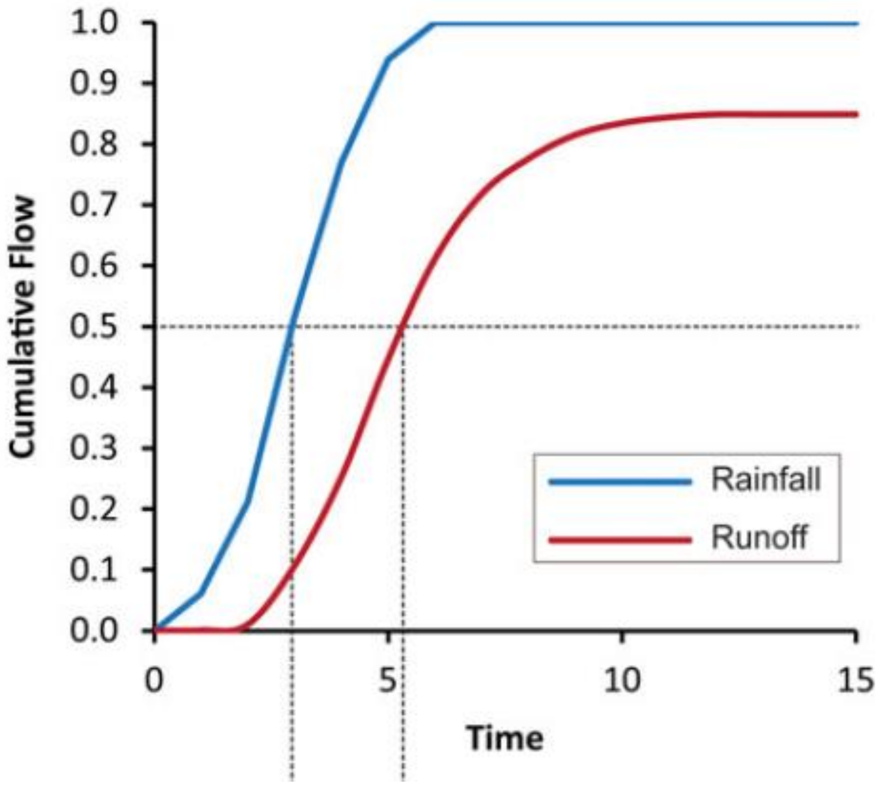


Figure 58 Average water retention of the system for different depths of substrate

Refer to Annex 3 to view graphs of all the tests performed.

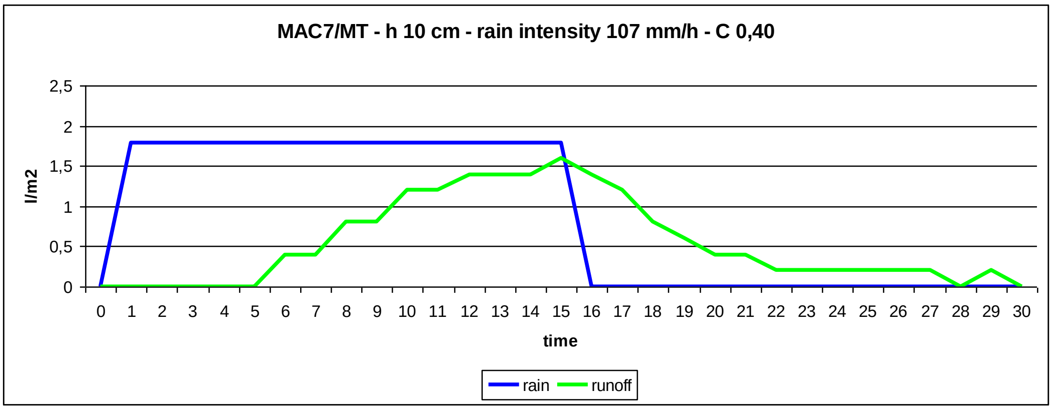
Typical run-off charts are illustrated here under. The graph to the left illustrates the different measures of the detention capacity of a green roof system (peak delay, peak attenuation, delay of starting time and of the peak of run-off) while the graph to the right describes the retention ability of the system (the proportion of rainfall that is retained by the system).

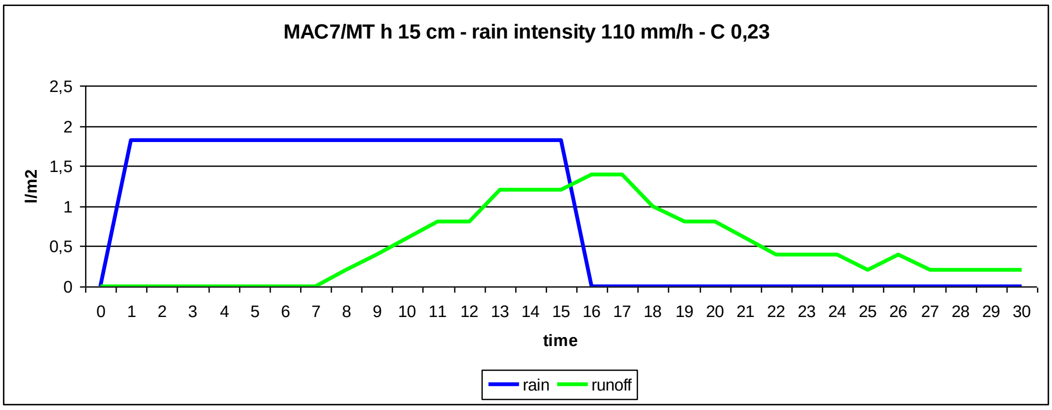


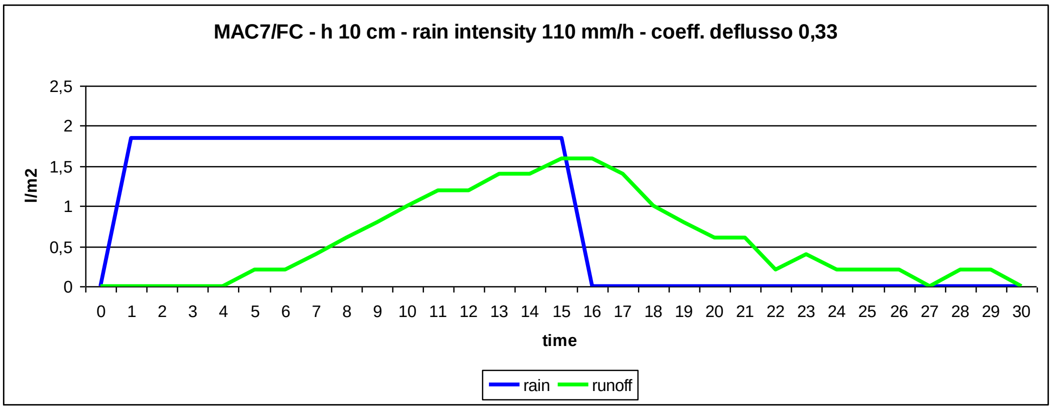


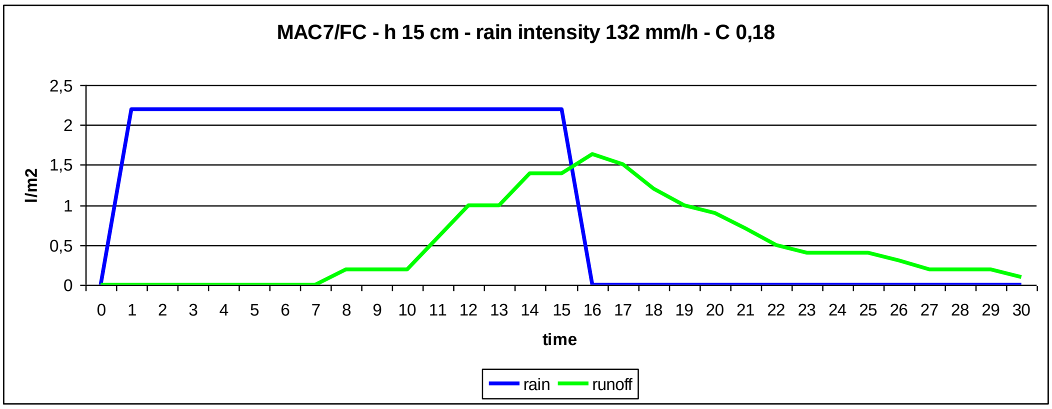
Reference: Stovin et Al., Urban Water Journal, 2017 – Vol 14 No 6

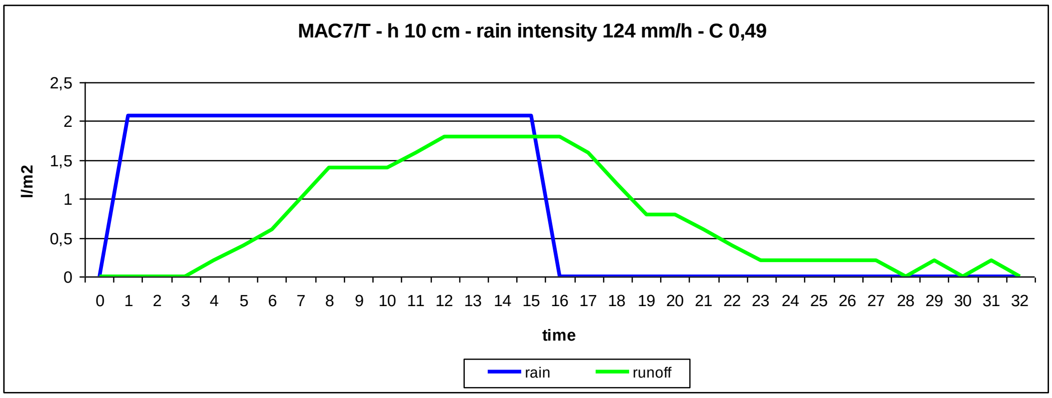
Below are graphs extrapolated from tests conducted in the rain simulator with two different depths for every type of substrate mix (C = run-off coefficient). From such graphs, it is possible to verify the detention performance of the green roof system and how the substrate depth increase improves the detention performance of the system, especially in terms of peak delay.

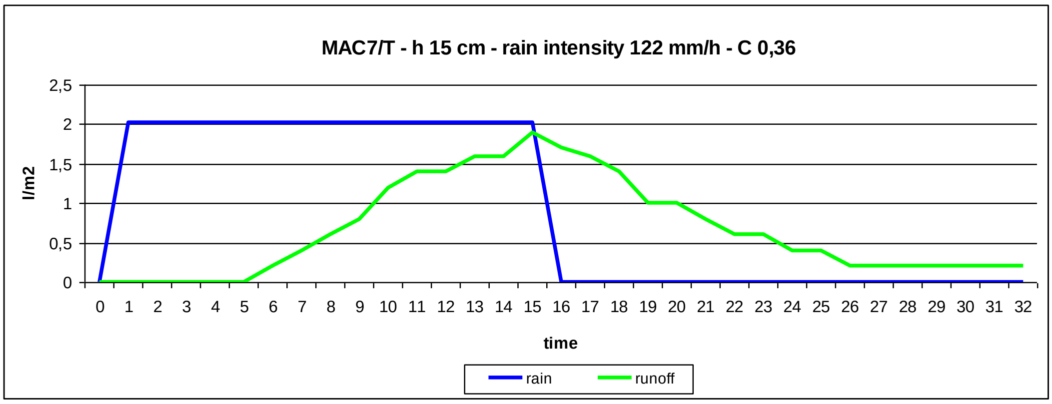


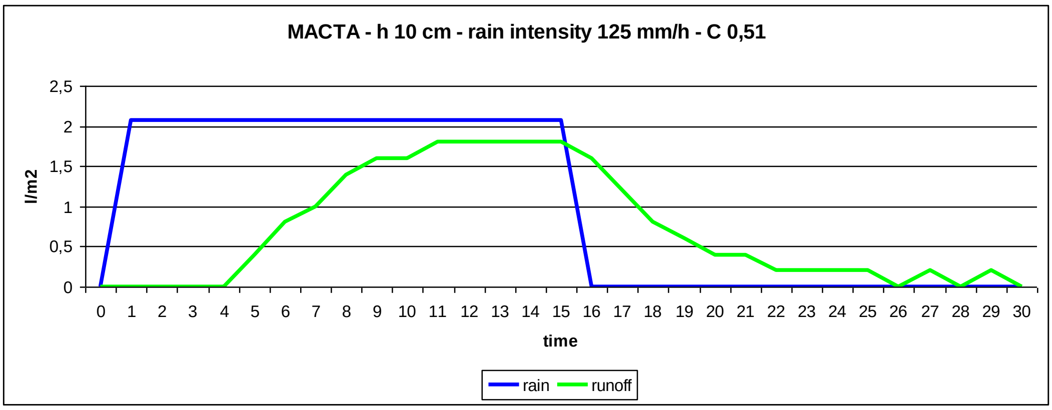


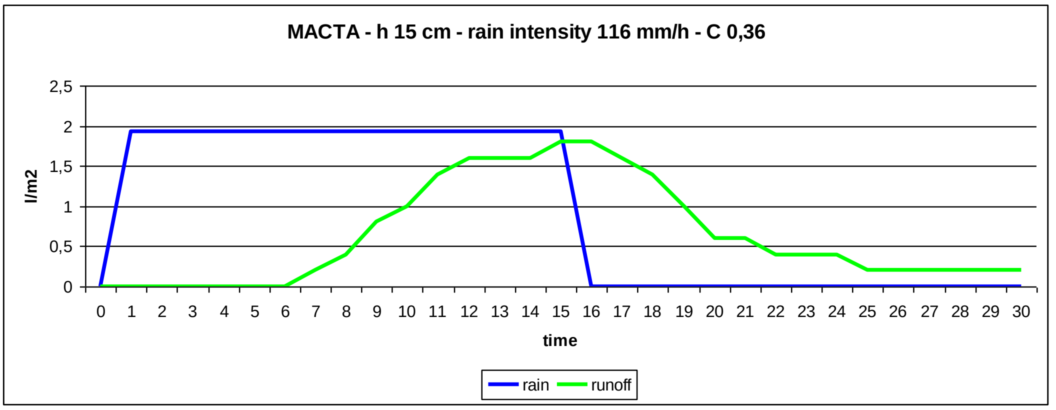


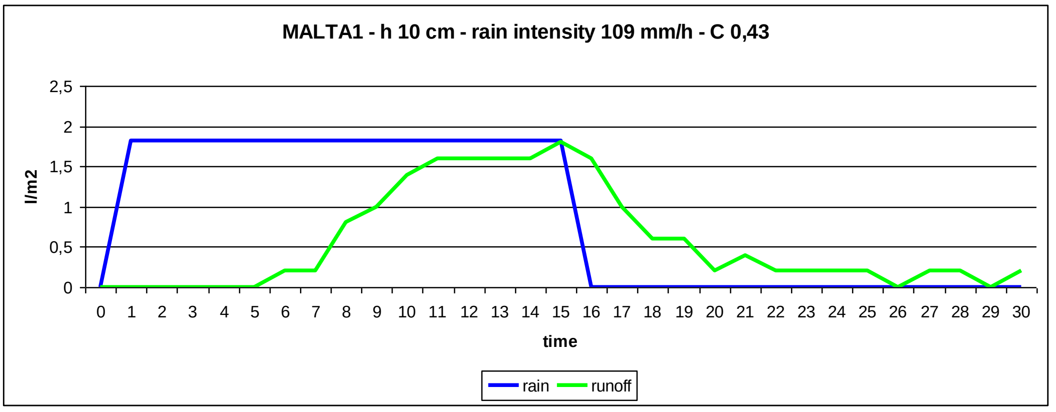

MAC7/FC - h 15 cm - rain intensity 132 mm/h - C 0,18
l/m2
2,5
2
1,5
1
0,5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
time
rain
runoff

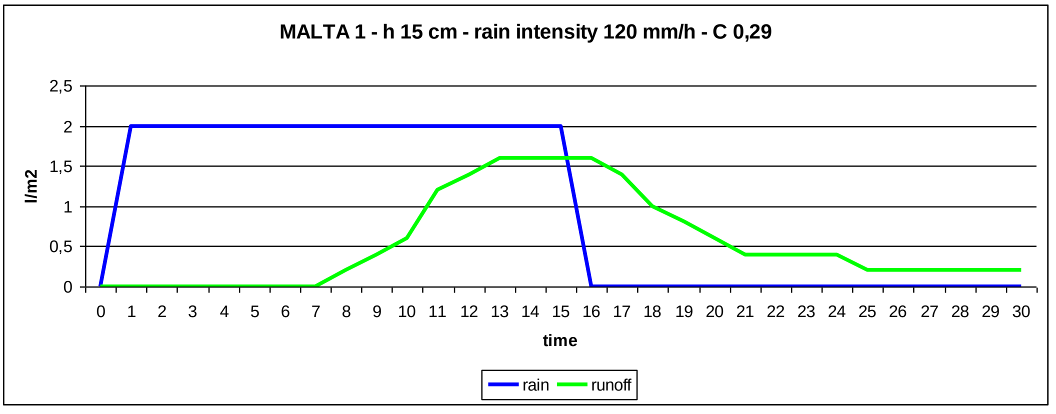

MAC7/T - h 10 cm - rain intensity 124 mm/h - C 0,49
l/m2
2,5
2
1,5
1
0,5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
time
rain
runoff

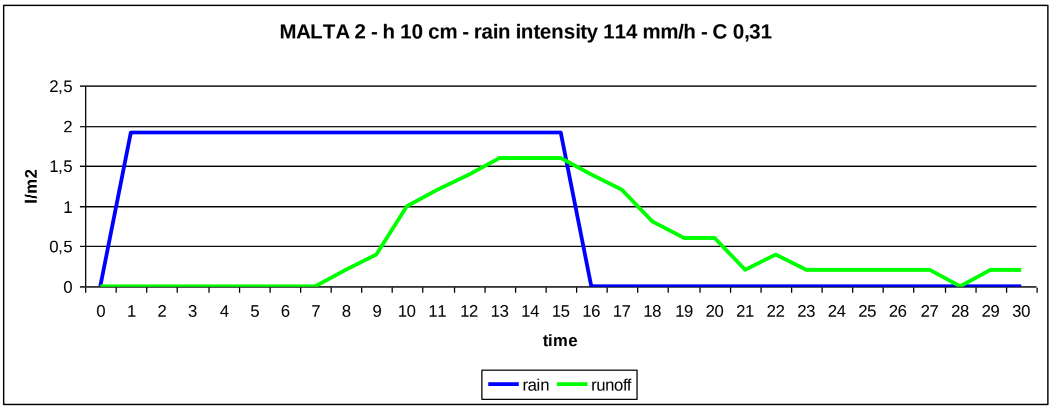

MAC7/T - h 15 cm - rain intensity 122 mm/h - C 0,36
l/m2
2,5
2
1,5
1
0,5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
time
rain
runoff

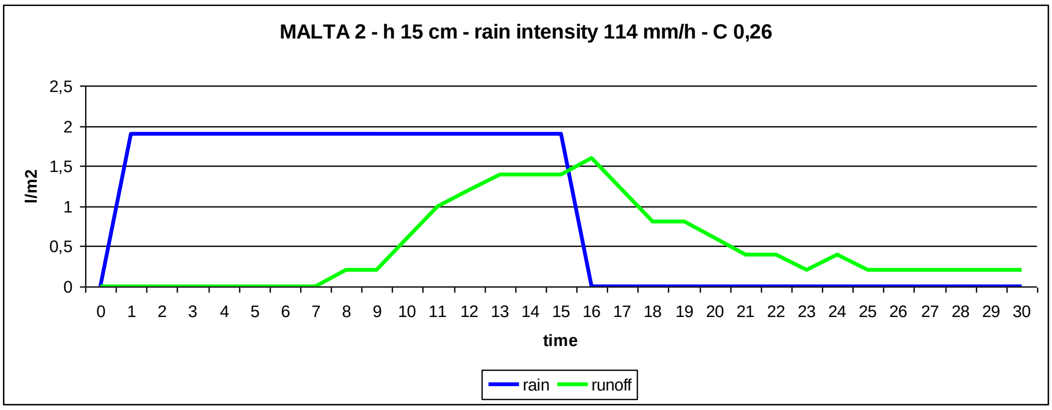

MACTA - h 10 cm - rain intensity 125 mm/h - C 0,51
l/m2
2,5
2
1,5
1
0,5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
time
rain
runoff


MACTA - h 15 cm - rain intensity 116 mm/h - C 0,36
l/m2
time
rain
runoff


MALTA1 - h 10 cm - rain intensity 109 mm/h - C 0,43
l/m2
time
rain
runoff


MALTA 1 - h 15 cm - rain intensity 120 mm/h - C 0,29
l/m2
time
rain
runoff


MALTA 2 - h 10 cm - rain intensity 114 mm/h - C 0,31
l/m2
time
rain
runoff



A test in the rain simulator has been conducted also for the gravel used on the referent plot on the Italian roof (depth 4 cm). The run-off coefficient measured during the standard test (15 minutes with rain intensity of 108 mm/h) was 0.7.

Of interest was the behaviour of run-off between gravel and green roof substrate. In the following chart, gravel and substrate run-off are compared (108 mm/h rain intensity for 15 minutes). With gravel (4 cm depth) run-off was observed after less than 2 minutes, while with the substrate (10 cm depth) run-off started after 5 minutes, when the intensity of run-off on gravel was still high. Run-off delay after the end of the rainfall differ in both situations: on gravel run-off stops 7 minutes after the end of the rain event, while on substrate, run-off continues for a longer period.

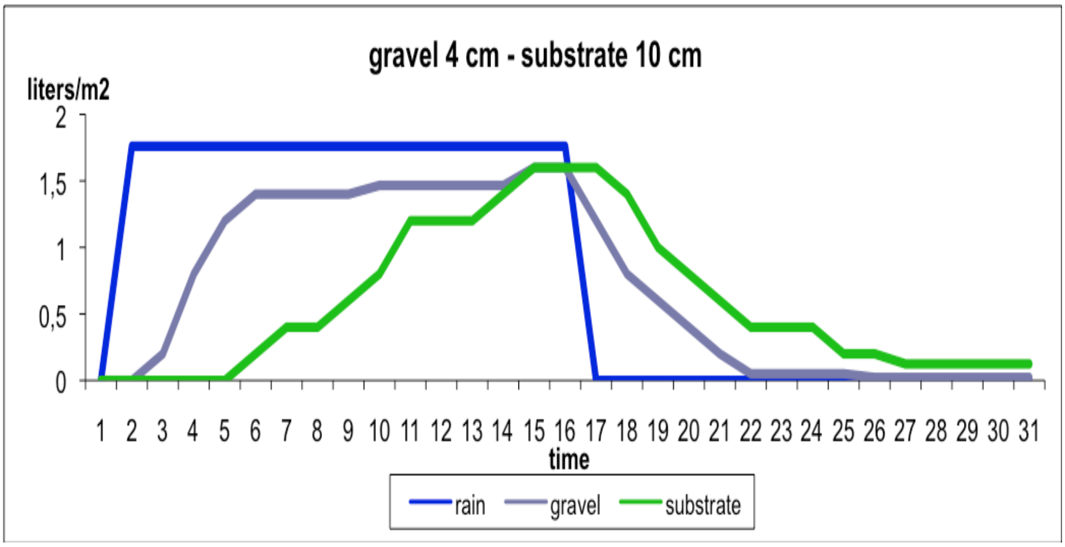
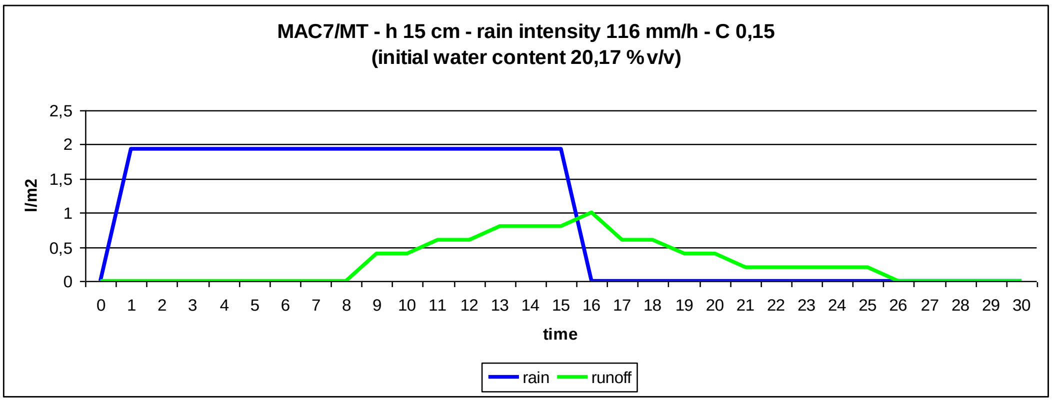


Figure 59 Comparison between gravel and substrate run-off

Other tests

Other tests have been carried out in the rain simulator.

A test has been conducted to quantify the responses of the green roof systems at different conditions of substrate humidity. In the following charts it is possible to observe the run-off trend when rainfall was applied in dry (20% of substrate humidity) or in saturated conditions (rainfall applied 24 hours after a previous event). In dry conditions there was a slight delay in the beginning of the outflow and in the run-off peak. The peak attenuation and the duration of run-off are significant results.



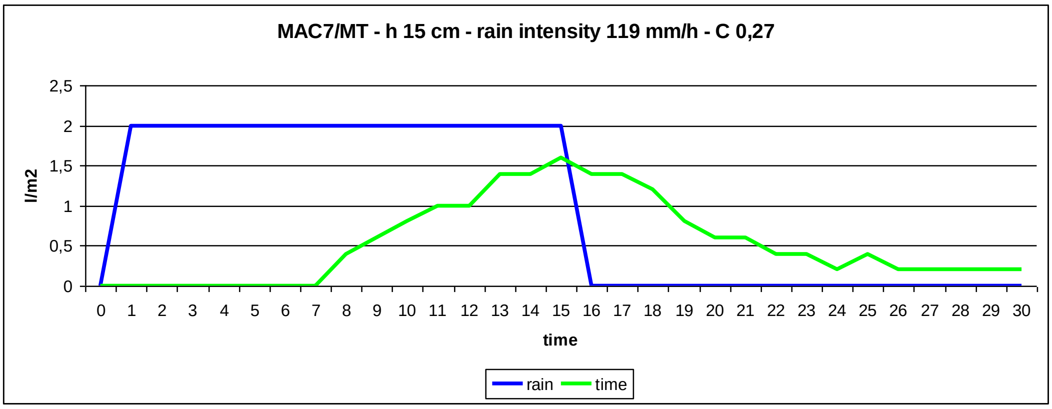
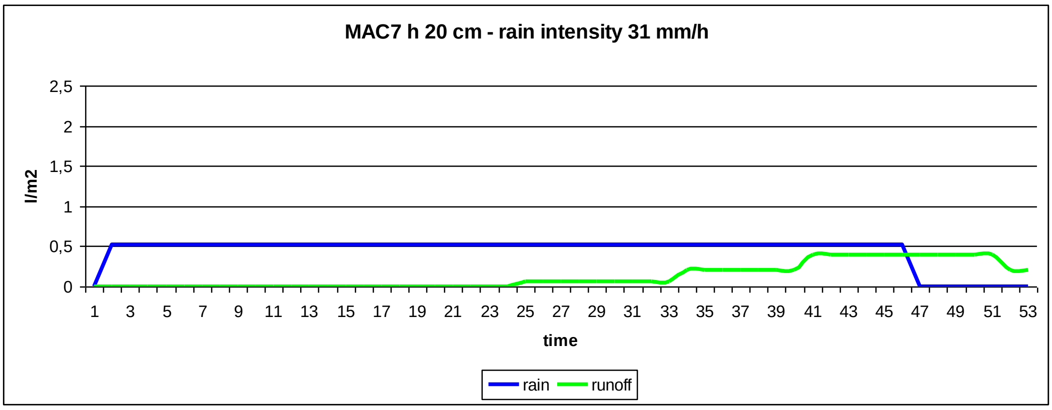
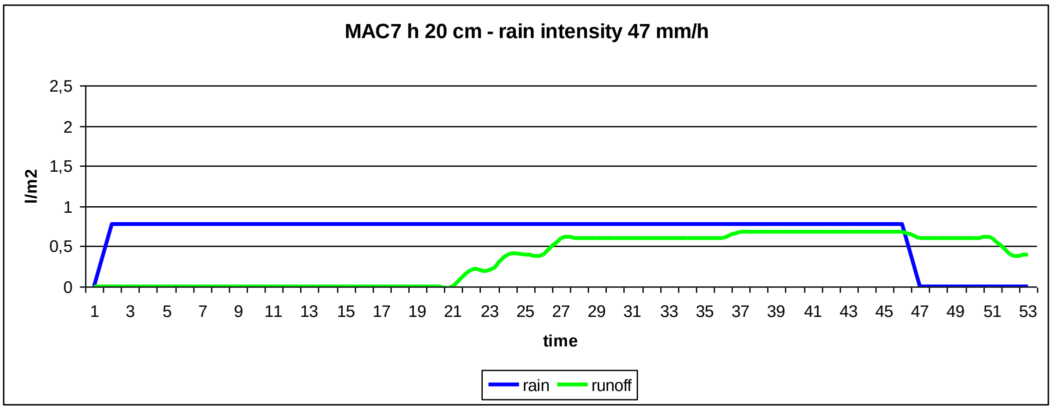


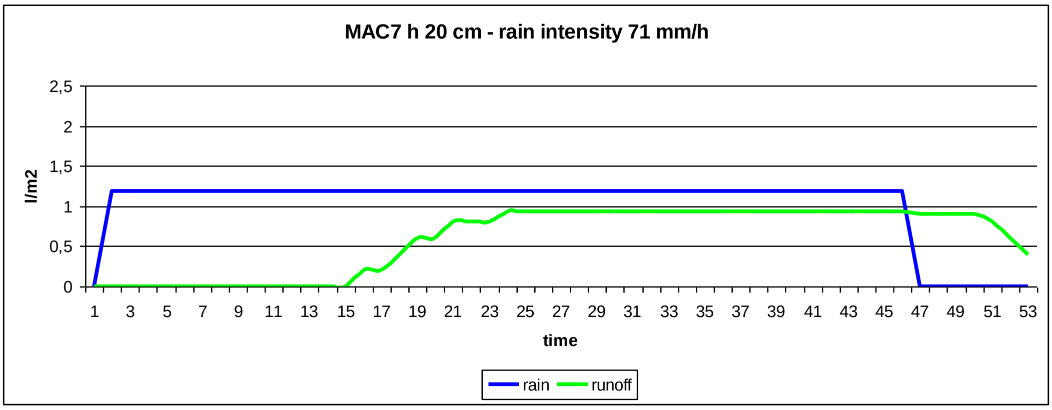
Figure 60 Comparison between dry and saturation conditions

Tests have been conducted also to simulate longer rain events (45 minutes) at different intensity and different substrate depths. These tests have been conducted in saturated conditions (24 hour after a previous rainfall).

In the following charts the performance of MAC7 with depth 20 cm and 4 different rain intensities were conducted (from 30 to 106 mm/h for 45 minutes). Detention properties vary considerably depending on the intensity of the rain. Run-off starts between 10 and 25 minutes after the rain event, while run-off peak delays between 30 and 40 minutes.







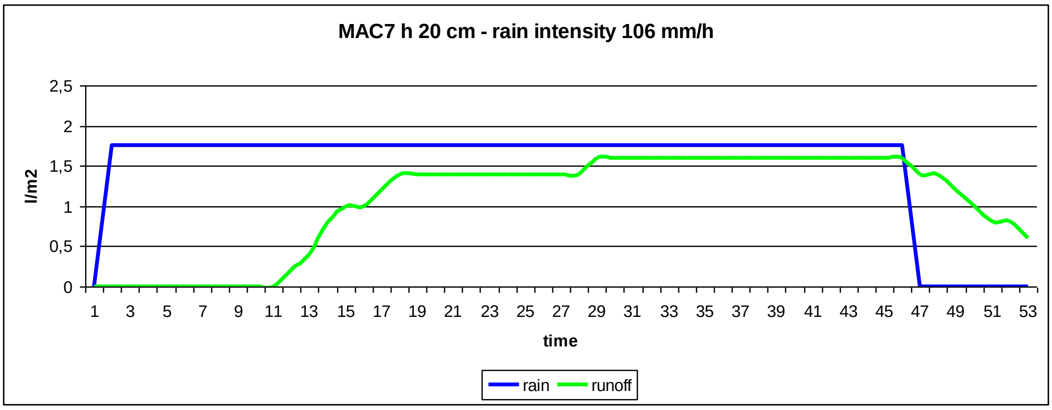
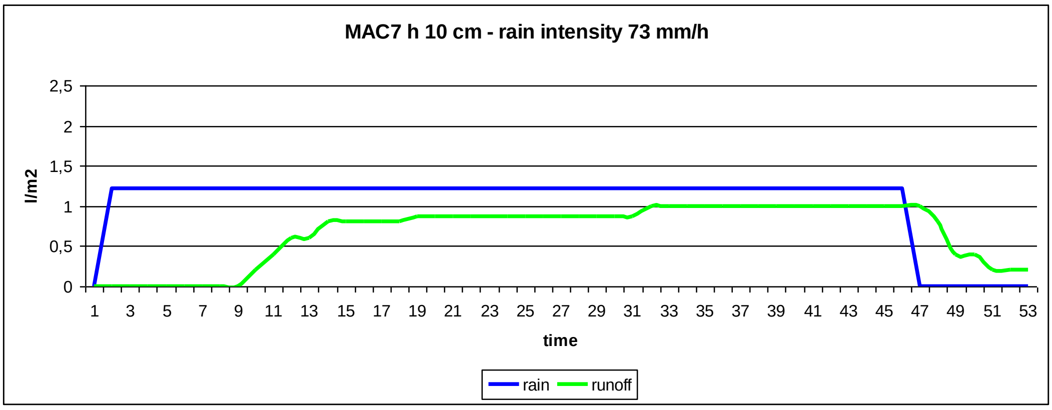
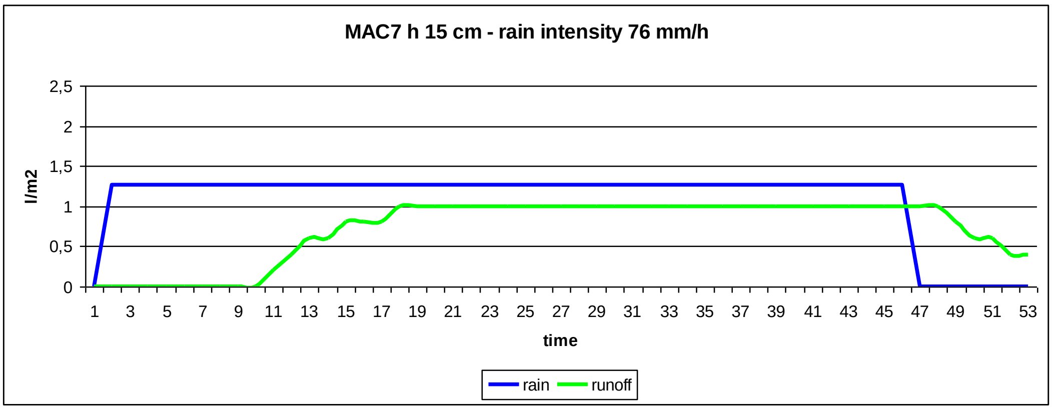


Figure 61 Comparison between different rain intensity

The charts below show performance of MAC7 with different substrate depth (from 10 to 20 cm) under the same rain intensity (about 70 mm/h for 45 minutes).

Also in this case some of the detention properties are different as these are related to substrate depth: delays are observed for run-off peak and for the commencement time of run-off..





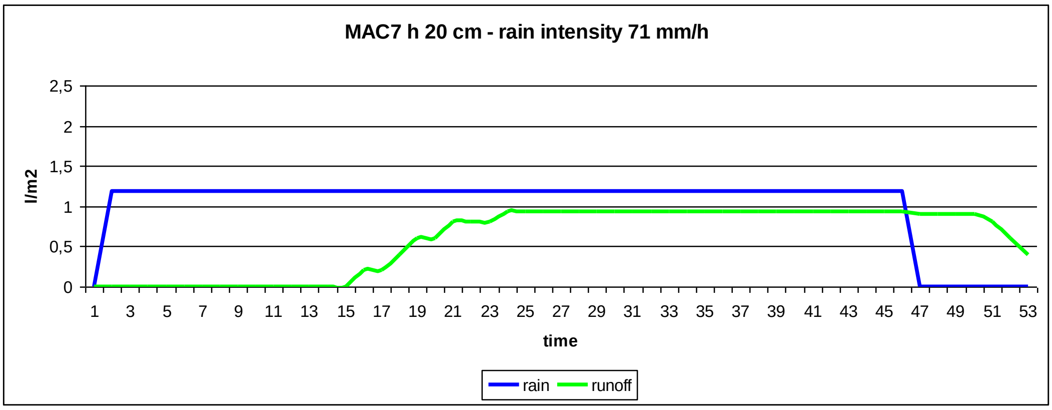


Figure 62 Comparison between different substrate depths

The tests carried out with different substrate depths and different rainfall intensity allowed for obtaining the equation of regression line and its correlation coefficient (R^2) in order to predict the responses of a green system in different conditions; the correlation coefficient indicates how significant the equation is: the closer R^2 is to 1, the more precise is the equation. Generally a positive coefficient must be at least > 0.70.

In the first figure, 3 different equations are given for single substrate depth, with a very positive value of the correlation coefficient (R^2 always > 0.7). The equations may be used to predict the run-off coefficient with different rain intensity, for a defined substrate depth.

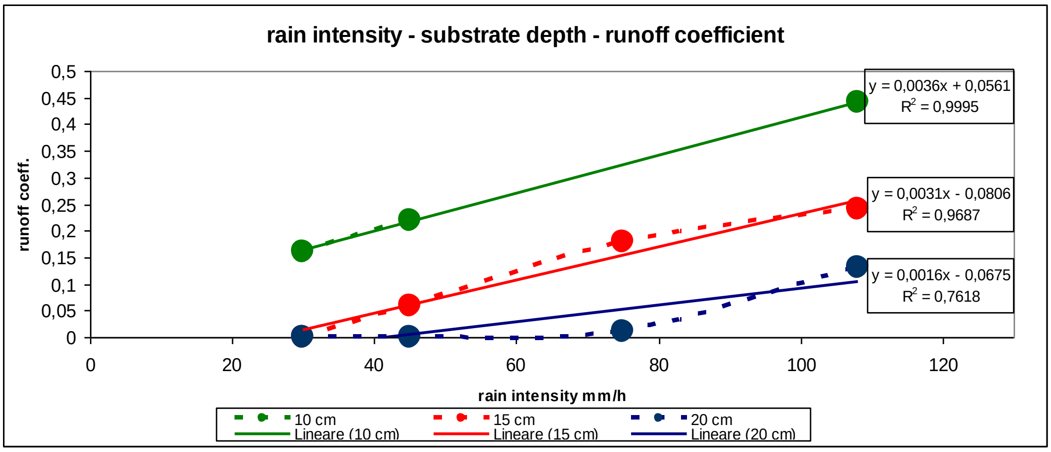


Figure 63 Regression lines to predict run-off coefficient for different rain intensity

For example: for a substrate depth of 15 cm (red line), with a rain intensity of 50 mm/h, using the line equation for such situation, the run-off coefficient will be 0.07, as calculated below:

[C = rain intensity mm/h*0.0031]-0.0806 = [C = 50*0.0031]-0.0806 = 0.07

In the figure 46 below, 4 different equations are given for different rain intensity values, with a very positive value of the correlation coefficient (R^2 always > 0.7). The equations may be use to predict, for a defined rain intensity, the run-off coefficient for different substrate depth.

For example, for a rain intensity of 30 mm/h (light blue line), with a substrate depth of 8 cm, using the line equation for such situation, the run-off coefficient will be 0.17, as calculated below:

[C = cm*0.0159]+0.2925 = 0.17 [C = 8*0.0159]+0.2925 = 0.17

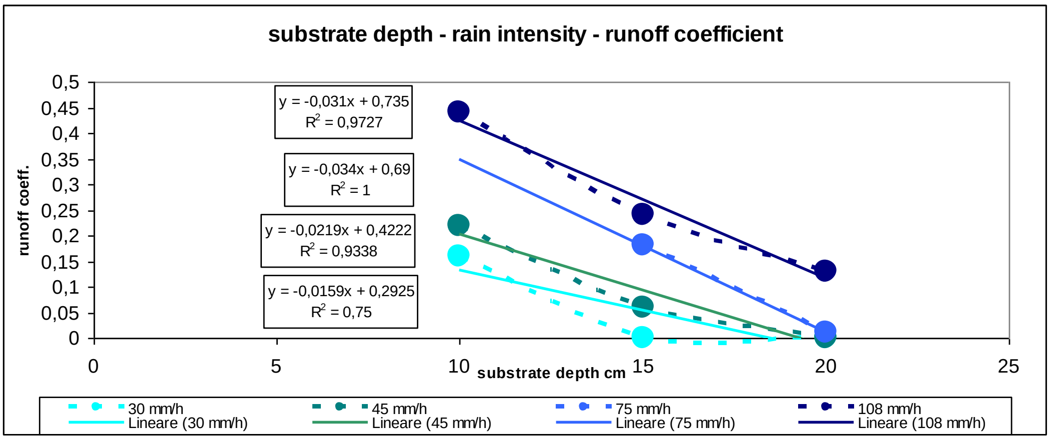


Figure 64 Regression lines to predict run-off coefficient for different substrate depth

Run-off Water Quality- Malta

Tests were carried out on the run-off water from two green roof 1m x 1m recycled plastic test trays. Each test tray was filled with 17cm deep substrate, one tray filled with Malta 1 type substrate and the second with Malta 2 type substrate. No plants were cultivated in these trays. Water was collected by means of a Kipp100 tipping counter. The tipping counter measures water flows of up to 5 litres per minute with a resolution of 100 ml. An additional tipping cup with resolution 10 ml per count was used to collect water samples.

Samples were collected on the following dates: 1/12/2016, 19/12/2016 and 9/2/2017. Each sample collected contained water accumulated within the sample bottle from the previous collection date. The sample collected first contained all the precipitation resulting from the beginning of the rainy season.

Figure 65 Kipp100 located below the test tray

Figure 66 1m x 1m test trays made from recycled plastic

In February 2017, rain water was collected separately in a bucket to be used as a control. The results follow:

Figure 67 Water quality analysis report for Maltese green roof run-off

CODE	MONITORING MALTA WATER RUN-OFF QUALITY – 2016/2017								
	pH	Salinity	N-NO_3	N-NH_4	P	K	Ca	Mg	Na
	(unit)	(mS/Cm)	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
MT1 – 01-12-16	**8.9**	**1.71**	**83.55**	**1.57**	**1.49**	**108.66**	**103.78**	**44.35**	**95.55**
MT1 - 19-12-16	**7.5**	**0.68**	**11.52**	**1.19**	**5.90**	**64.26**	**48.72**	**19.92**	**65.32**
MT1 – 09-02-17	**10**	**1.63**	**1.35**	**1.90**	**0.86**	**111.37**	**54.98**	**18.77**	**144.37**
MT2 – 01-12-16	**10.1**	**3.13**	**1.58**	**1.57**	**0.18**	**160.26**	**121.84**	**40.95**	**149.06**
MT2 – 19-12-16	**9**	**3.32**	**3.84**	**1.94**	**1.04**	**165.91**	**125.62**	**45.53**	**203.48**
MT2 – 09-02-17	**9.6**	**0.41**	**1.13**	**1.47**	**2.56**	**43.82**	**25.88**	**9.94**	**40.38**
RAIN – 09-02-17	**7.2**	**0.03**	**<1.13**	**1.47**	**0.06**	**1.01**	**4.70**	**0.44**	**2.82**

CODE	MONITORING MALTA WATER RUN-OFF QUALITY – 2016/2017								
	Fe	**Mn**	**Cu**	**Zn**	**Pb**	**Cd**	**TSS***	**TDS***	**TS***
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
MT1 – 01-12-16	**0.78**	**0.02**	**0.04**	**0.02**	**0.08**	**<0.01**	**0**	**1630**	**1630**
MT1 - 19-12-16	**7.95**	**0.19**	**0.07**	**0.09**	**0.02**	**<0.01**	**298**	**960**	**1258**
MT1 – 09-02-17	**0.14**	**<0.01**	**0.03**	**0.01**	**<0.01**	**<0.01**	**12**	**935**	**947**
MT2 – 01-12-16	**0.04**	**<0.01**	**0.04**	**<0.01**	**0.08**	**<0.01**	**2035**	**184**	**2219**
MT2 – 19-12-16	**0.17**	**0.01**	**0.06**	**0.01**	**<0.01**	**<0.01**	**4**	**2175**	**2179**
MT2 – 09-02-17	**4.34**	**0.07**	**0.02**	**0.03**	**<0.01**	**<0.01**	**68**	**425**	**493**
RAIN – 09-02-17	**<0.01**	**<0.01**	**<0.01**	**0.01**	**<0.01**	**<0.01**	**<1**	**<1**	**<1**

*TSS - Total suspended solids
*TDS - Total dissolved solids
*TS - Total solids

Nutrients in water run-off from green roofs is higher than those in precipitation. This confirms results from previous studies where it was found that green roofs act as a source of nutrient contamination as opposed to a sink (Kuoppamaki, et al., 2016). The high nutrient levels can be related to the substrate components considering that no plants were grown in the substrate and no fertilizers were used. However, the level of nutrients leached generally decreases over time unless fertilizers and other agrichemicals are used. This phenomenon has been documented in past studies. (Kuoppamaki, et al., 2016)

Initial results have shown that the pH was on average higher in the substrate containing biochar (MT2). This was expected considering that biochar is alkaline in nature and is used to increase pH in acidic soils. Nitrate levels vary between 1.58 mg/l and 83.55mg/lt. Nitrate levels in the MT2 substrate were much lower confirming the ability of biochar to reduce nitrate leaching. The numerous micro- to macro-pores in biochar help in the adsorption of nutrients thus decreasing the leaching of such elements through water run-off. These elements would then be made available for uptake by plants thanks to bacteria and other micro-fauna in the substrate. Of particular note is that levels of heavy metals were often below the analytical detection limit and within allowable levels. Salinity level was high in the beginning, but then they decreased over time, especially in MT2 substrate; these values are correlated with the presence of soluble anions and cations.

Initial results for total solids parameter (suspended solids + dissolved solids) are high due to the presence of organic matter and organic carbon in the substrates; over time these values decrease, especially for MT2 substrate. However, it should be also noted that since the sample bottle was exposed to sun light (indirectly), algae formed in the sample bottle contributing to suspended solids

Although in the short study conducted nutrient levels did show a level of decline it would be fair to say that further studies should be carried out to establish the quantity and concentration of nutrients leached over time. Due to the low rainfall, run-off is limited and may be the cause of higher concentrations of elements within the run-off. Biochar properties vary depending on the production process and feedstock. Establishing the characteristics of biochar before use on green roofs would help in avoiding inadvertent effects.

Run-off Water Quality - Italy

In the North of Italy precipitation is generally abundant and in the last years high intensity events were more frequent, causing significant run-off and, therefore, a strong leaching from substrates.

Tests were carried out on the run-off water from the monitored plot of the Italian green roof, with the presence of vegetation. During the year few and light fertilizer distributions have been carried out.

Water flow was collected by means of a Kipp100 tipping counter, in four different period: April, May, July and October 2016. During the last sampling, a sample from the reference plot (gravel) was collected.

Analysis have been done for the main soluble elements, heavy metal and total solids.

Results, reported in the following tables show a constant pH value and low salinity for both green roof and gravel run-off. Soluble salts, nitrate and ammonium decrease over time, with values from both plots not differing significantly. Basic ions (K, Ca, Mg, Na) and phosphorous show variable trend, but always at low levels. Also heavy metal levels are low and within standard levels.

The COD (Chemical Oxygen Demand) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. The COD test is used to quantify the amount of organics in water. In Italy water discharges (urban waste water or industrial waste water) are regulated; however there are no clear normative reference for roof water discharge. Values limits of emissions in surface waters and sewerage are fixed for COD and should vary between 160 and 500 mg/L, while for urban waste water the top limit is 125 mg/L.

When urban and industrial waste water is discharged into soil, COD limit value are 100 mg/L. Other limits are set, i.e. for total Nitrogen (< 15 mg/L), and total Phosphorous (< 2 mg/L), Total suspended solid (< 25 mg/L), Lead and Copper (< 0.1 mg/L), and Iron (< 2 mg/L).

COD values in green roof water run-off was suitable and below the maximum allowable limits. Total Suspended Solids values were positive and in accordance with Italian Standard. There was no substantial difference between run-off from gravel water and green roof substrates.

Table 21 Water quality analysis report for the Italian green roof run-off

CODE	MONITORING ITALY WATER RUN OFF QUALITY – 2016/2017								
	pH (unit)	Salinity (mS/cm)	$N\text{-}NO_3$ mg/l	$N\text{-}NH_4$ mg/l	P mg/l	K mg/l	Ca mg/l	Mg mg/l	Na mg/l
MAC7 – 07-04-16	7.1	0.12	7.23	6.94	0.91	4.99	10.39	1.53	2.78
MAC7 - 02-05-16	7.7	0.12	1.35	3.75	0.86	4.16	14.85	1.96	3.86
MAC7 – 22-07-16	7.6	0.09	2.03	0.90	1.23	7.51	27.26	2.11	5.87
MAC7 – 14-10-16	7.8	0.19	<1.13	2.86	0.94	0.61	30.08	6.57	7.03
GRAVEL – 14-10-16	7.6	0.09	<1.13	1.94	0.40	2.76	13.35	1.85	0.97

CODE	MONITORING ITALY WATER RUN OFF QUALITY – 2016/2017							
	Cu mg/l	Zn mg/l	Pb mg/l	Cd mg/l	COD* mg/l	TSS* mg/l	TDS* mg/l	TS* mg/l
MAC7 – 07-04-16	0.01	0.21	<0.01	<0.01	59			
MAC7 - 02-05-16	0.02	0.33	0.19	<0.01	61			
MAC7 – 22-07-16	0.02	0.24	0.04	<0.01	90	0	145	145
MAC7 – 14-10-16	0.04	0.12	<0.01	<0.01	72	10	175	185
GRAVEL – 14-10-16	0.02	0.11	<0.01	<0.01	35	16	95	111

*COD – Chemical Oxygen Demand
*TSS - Total suspended solids
*TDS - Total dissolved solids
*TS - Total solids

6. Conclusion

Over the years the urban footprint in Malta has increased dramatically. Water harvesting methods have often been neglected and gardens have been destroyed giving rise to localised flooding. Such flooding has resulted in the spending of taxpayers' money to mitigate the damage which results.

In Italy the situation is not too different, in fact a law on land use is being discussed with the goal to minimize soil consumption. Flooding events are a real and increasing problem.

Although green roofs are popular in many westernised countries especially within Europe, in Malta such technology has not gained ground due to misconceptions by property owners and the design professions. Green roofs have been reported to reduce flooding in a number of studies (Fioretti, et al., 2010), (Mentens, et al., 2006). In Italy green roof technology is better understood especially in the northern regions possibly due to influences from Germany. However, the complicated economic situation of recent years has slowed down the development of this sector. In 2007, Italy published its first green roofs standard for the construction and maintenance of green roofs.

This report had looked at how green roofs within the context of Malta and Italy can help mitigate and reduce flooding in urban areas. Results from the experiment conducted at the Faculty for the Built Environment and at Fondazione Minoprio as part of the LifeMedGreenRoof project have been reported.

The data acquired provides useful initial baseline information on the potential performance of green roofs in the Maltese environment to combat flooding within the urban context. Studies (Fioretti, et al., 2010) (Mentens, et al., 2006) within the Mediterranean on the performance of green roofs have been previously carried out with results similar to what has been achieved in this project. Dry periods between rain events allow the substrate to dry up permitting high storage of water during the following rain event. The results show that green roofs in Malta are able to withhold within the system much of the precipitation resulting on a green roof. Green roofs can be used with confidence to support sustainable urban design and mitigate flooding.

Similar information has also been confirmed by the results acquired on the Italian green roof. In the monitored months dry and very wet periods have been observed. Despite the low depth of the substrate (10 cm), the green roof system has generally given excellent results in terms of water retention, run-off reduction, delays in starting time of run-off, and run-off peak reduction.

The storm water retention of the green roof can be further enhanced by the type of vegetation used as well as the drainage module installed. On the Maltese and Italian green roofs, the drainage module utilised does not retain any water within it. This means that using drainage modules with an integrated reservoir increased the stormwater management performance of the green roofs.

Although, this study has shown that green roofs can drastically reduce storm water run-off in Malta and in Italy, it has to be kept in mind that the year in which the study was conducted happened to be one of the driest winters for Malta. Therefore, it would be of benefit to conduct further studies over the coming years to refine and understand better the results achieved and how climate influences the performance of the green roofs locally. In addition to a dry winter, heavy downpours were not experienced either.

The long periods of antecedent dry weather before rain events have had significant impact on the water regime of the green roof, this has been clearly illustrated. Such long periods of dry weather encourage the evaporation (evapotranspiration) of any moisture trapped within the growing medium. Wind also helps in the rate of evaporation of moisture from within the green roof. How such roofs perform in heavy precipitation or wetter winters has been demonstrated with the Italian demonstration green roof and, moreover during such tests different rainfall event have been tested. Results have confirmed that green roof systems may be a real solution in terms of flooding reduction.

The selected growing media have also performed well in terms of vegetation support. Unfortunately local materials from Malta have not been adequate for use on green roofs. Some like vermicompost, may be adequate, but the current production capacity is still very low and should be observed for the future. Very good responses have been obtained by the use of biochar. The positive influence of biochar was evident in terms of water retention capacity, vegetation development and water run-off quality.

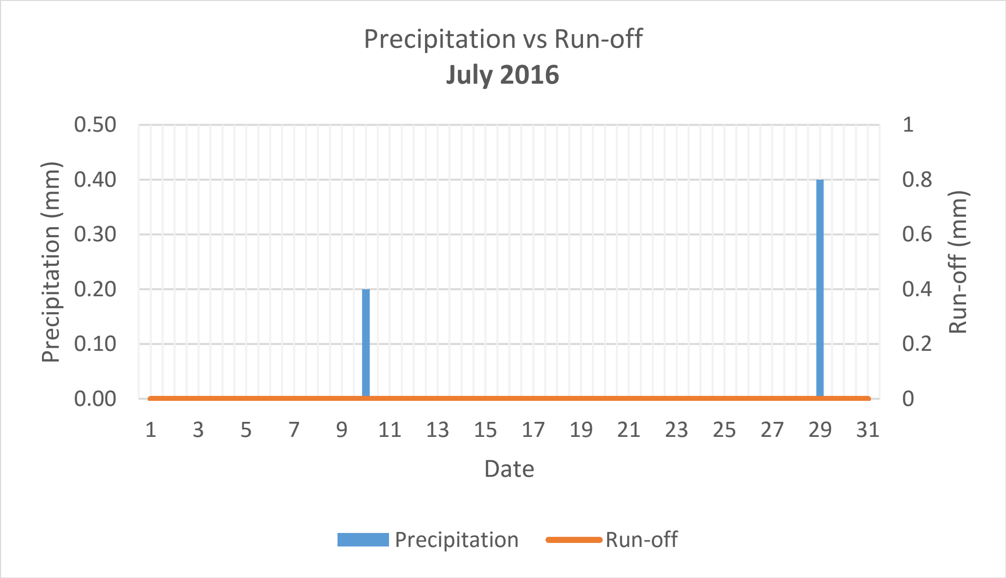
Water quality from run-off in both countries is expected to improve over time. Differences have been observed between Malta and Italy. The low run-off intensity in Malta's green roof due to the low precipitation levels, led to water run-off with higher concentrations of soluble ions and organic compounds. However, a decrease was still observed over time. In the Italian experience, the run-off water quality showed good values (within national limits) after a few months. In both green roof no heavy metals have been found.

The target expected to be achieved at project inception vis-à-vis water retention in Malta for an extensive green roof with growing medium depth >15cm – 20cm was 60-67% was comfortably achieved. In Italy the expected target has been achieved (average annual water retention of 50-55% for extensive green roofs with 10 cm depth of substrate).

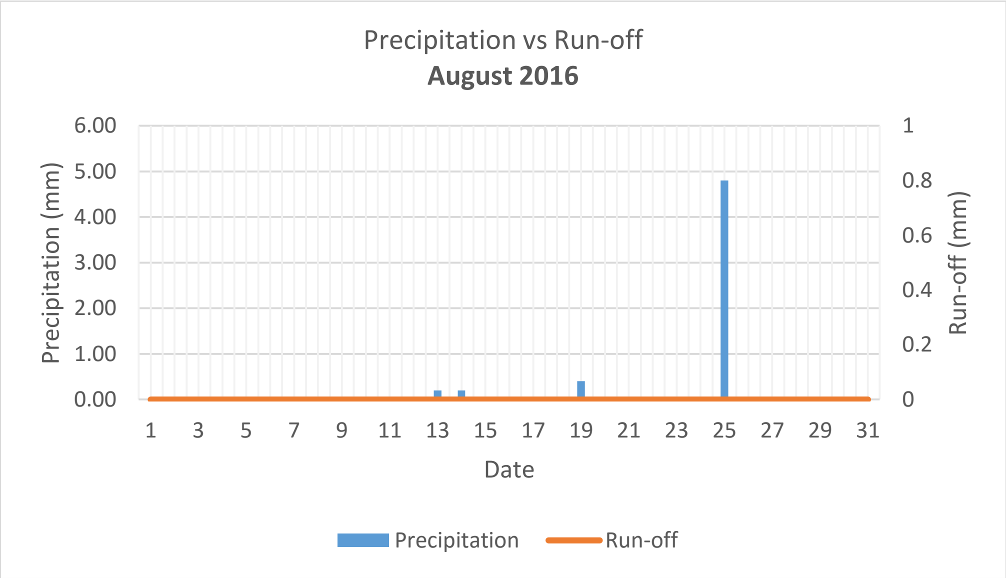
However, it is important to emphasize that <u>one</u> green roof will not be the solution to water management problems within the urban areas (Giacomello, 2012) and that green roofs are not the only available solution to the environmental problems within towns and cities. It is with the proliferation of green roofs over a territory together with other green infrastructure systems that would have a significant influence on such problems. In addition, the uptake and encouragement of green roofs should not be seen as a licence to increase urban sprawl and intensify urbanisation.

Annex 1

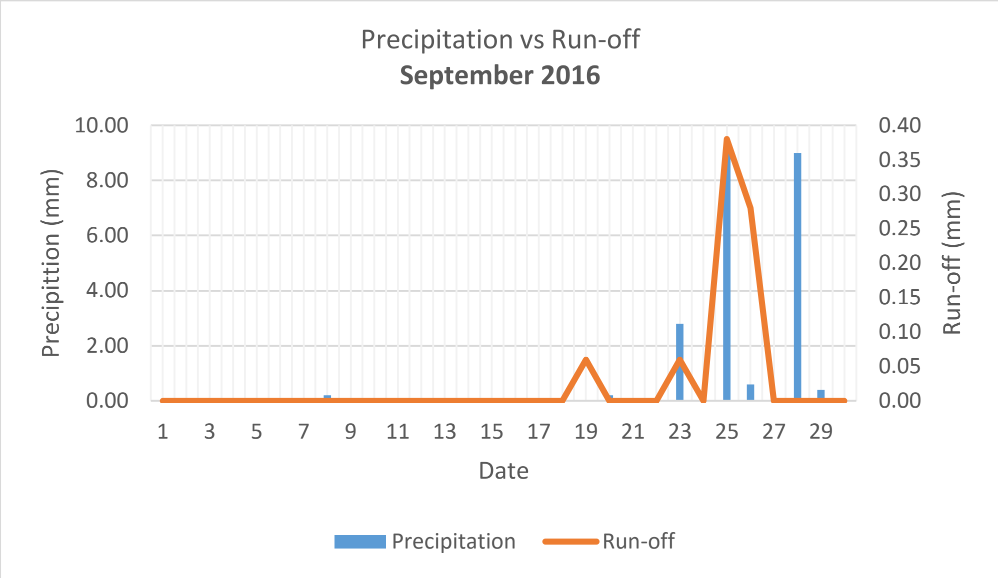
Monthly precipitation and water run-off, Maltese green roof



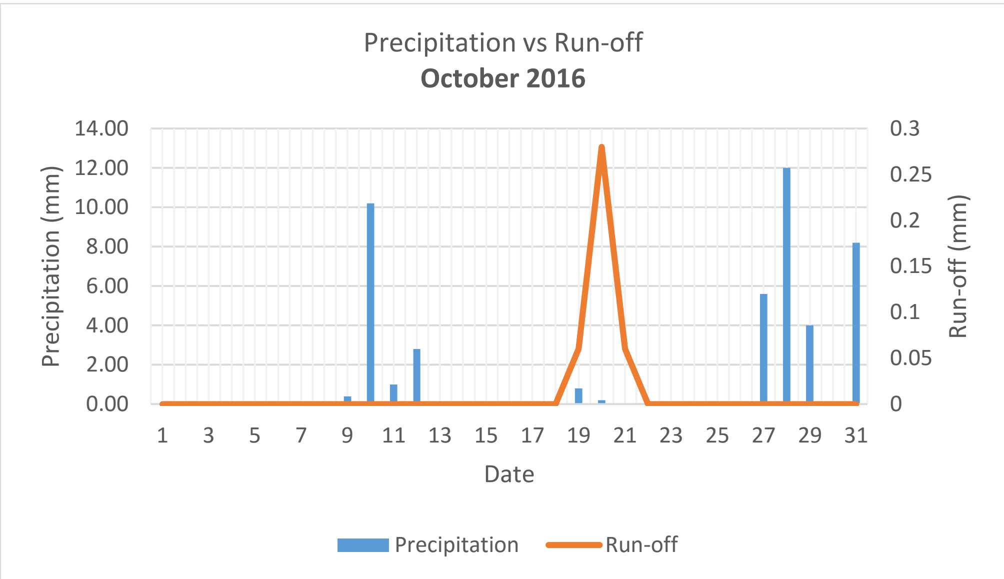
	No. of events	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events	2	0.40	0	0.60
Run-off	0	0	0	0



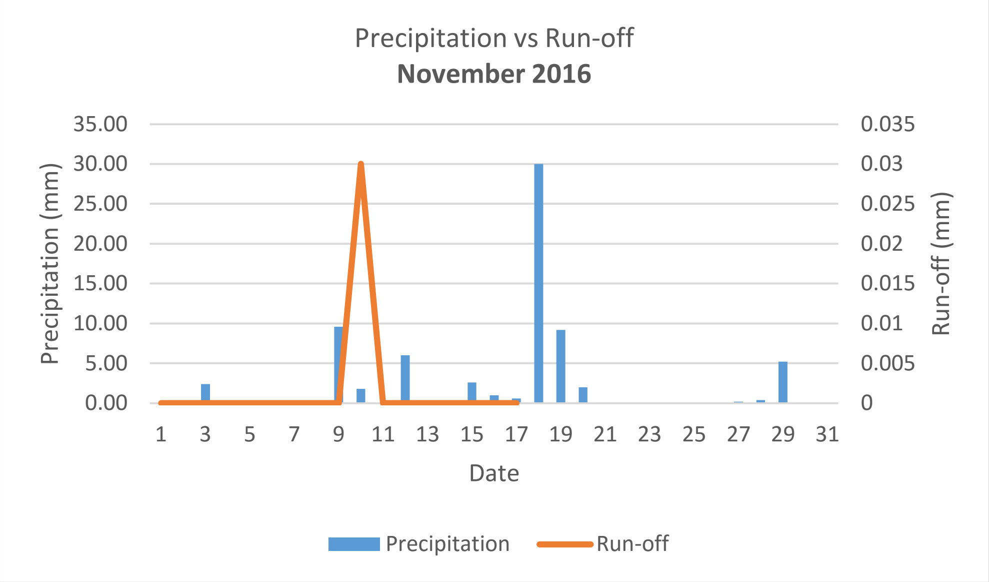
	No. of events	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events	4	4.80	0	5.60
Run-off	0	0	0	0



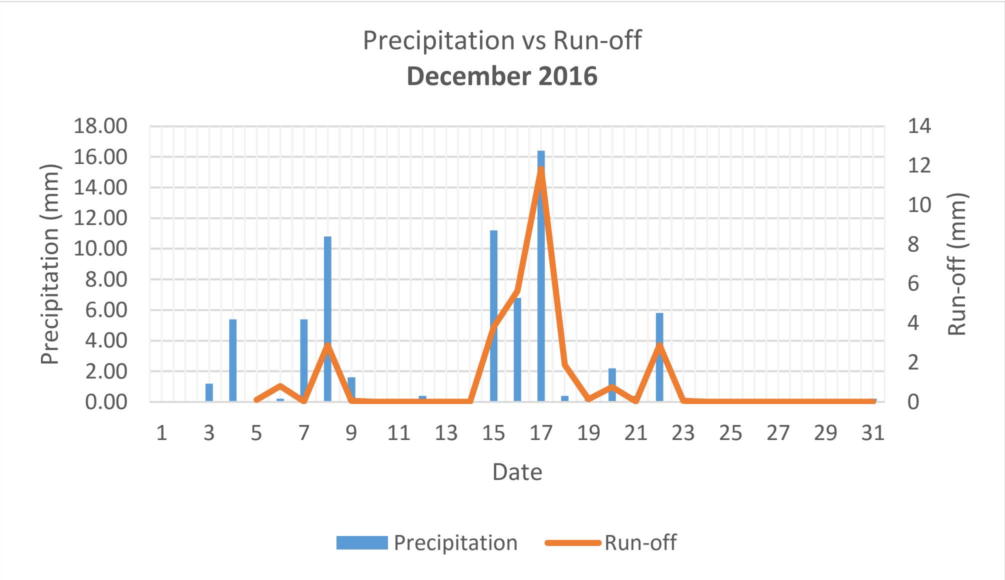
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events	7	9.00	0	22.20
Run-off	4	0.38	0	0.78



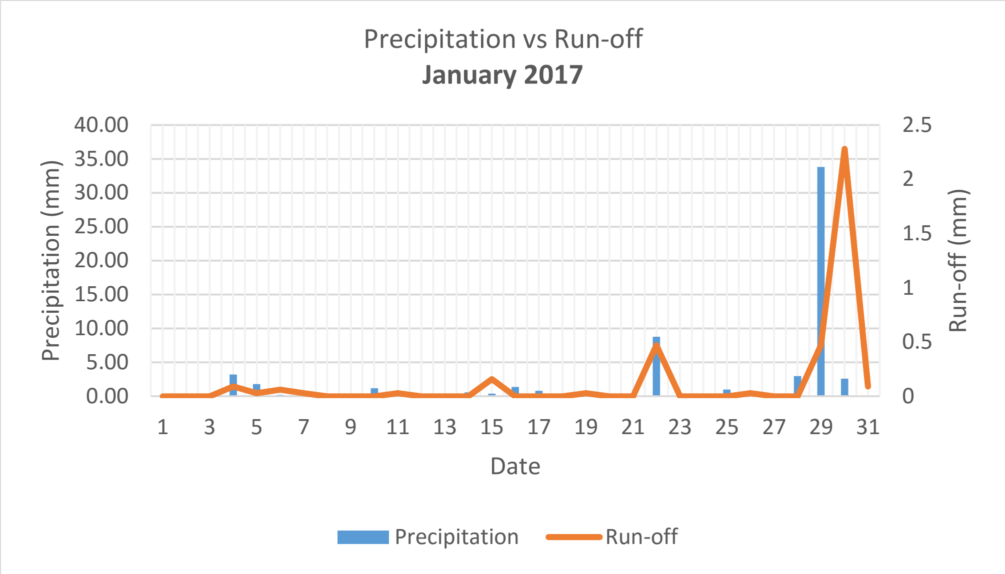
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events	10	12.00	0	45.20
Run-off	4	0.28	0	0.40



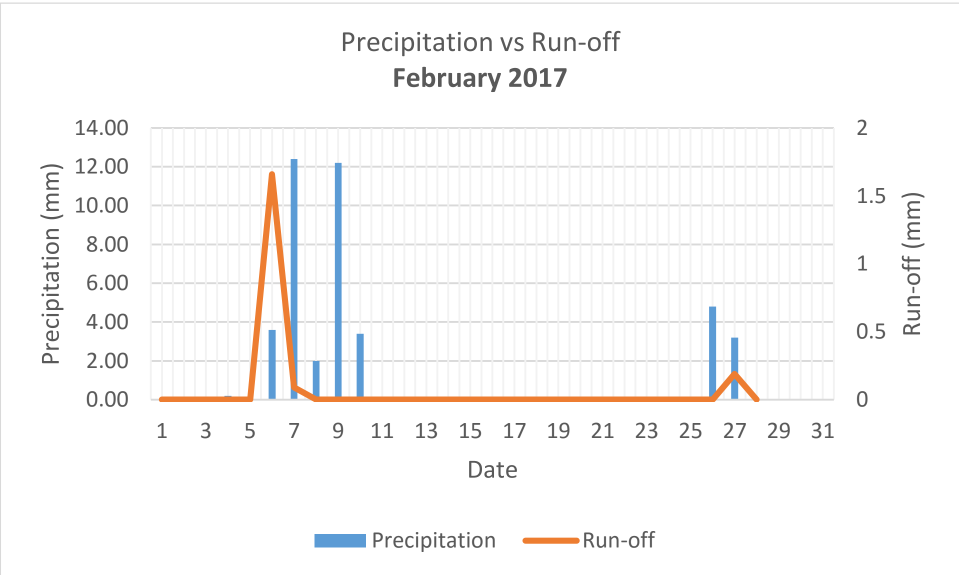
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	7	9.60	0	24.00
Run-off*	1	0.03	0	0.03
*Taken from 1st -17th November				



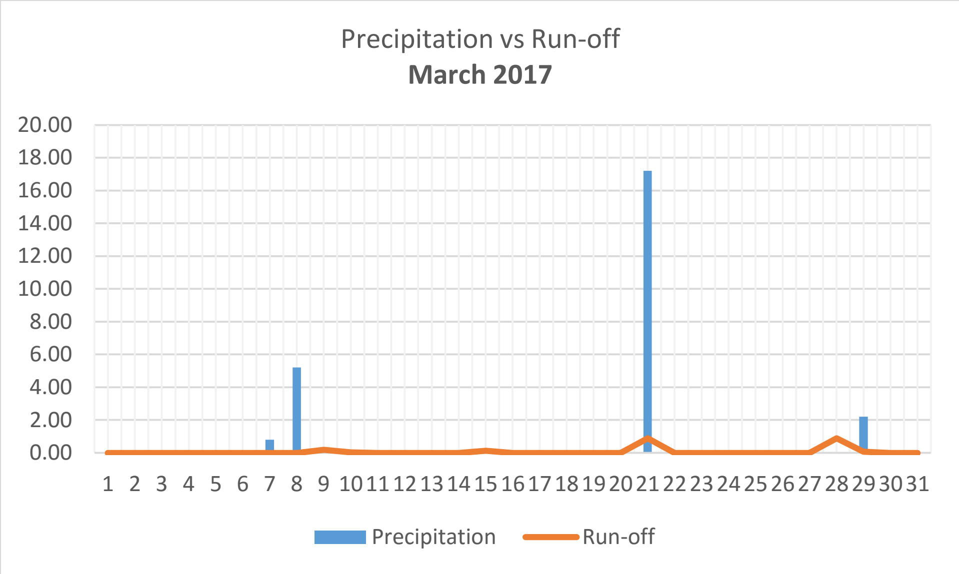
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	10	16.40	0	44.20
Run-off*	9	11.48	0	27.01
*Taken from 10th -31st December				



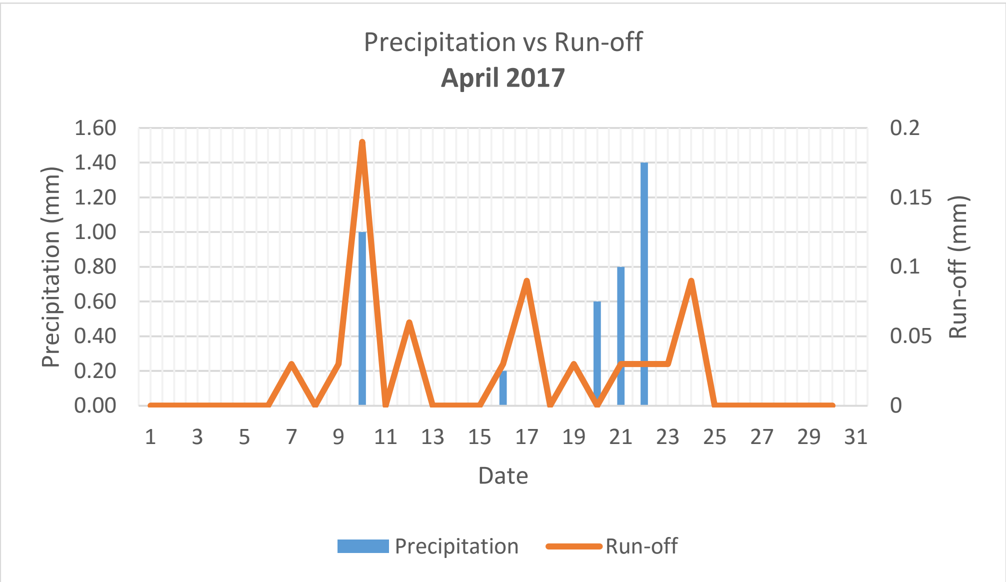
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	19	33.80	0	60.20
Run-off*	12	2.28	0	3.77



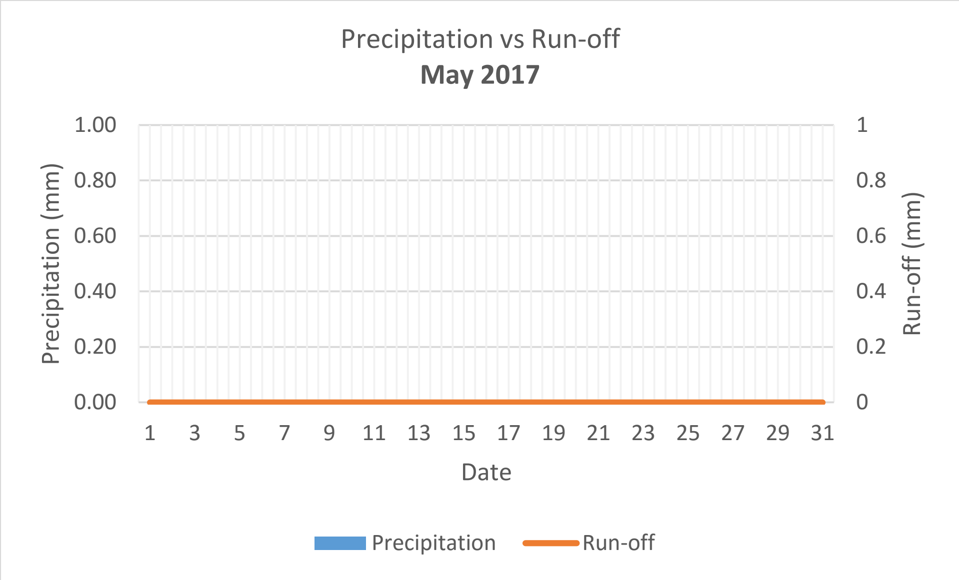
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	8	12.40	0	41.80
Run-off*	3	1.66	0	1.94



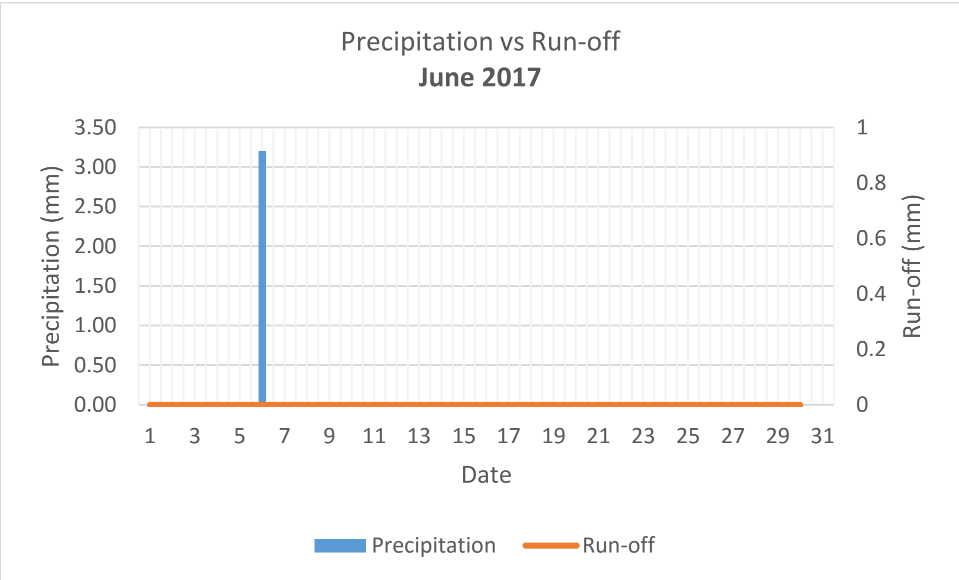
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	4	17.20	0	25.40
Run-off*	6	0.88	0	2.17



	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	5	1.40	0	4.00
Run-off*	11	0.19	0	0.64



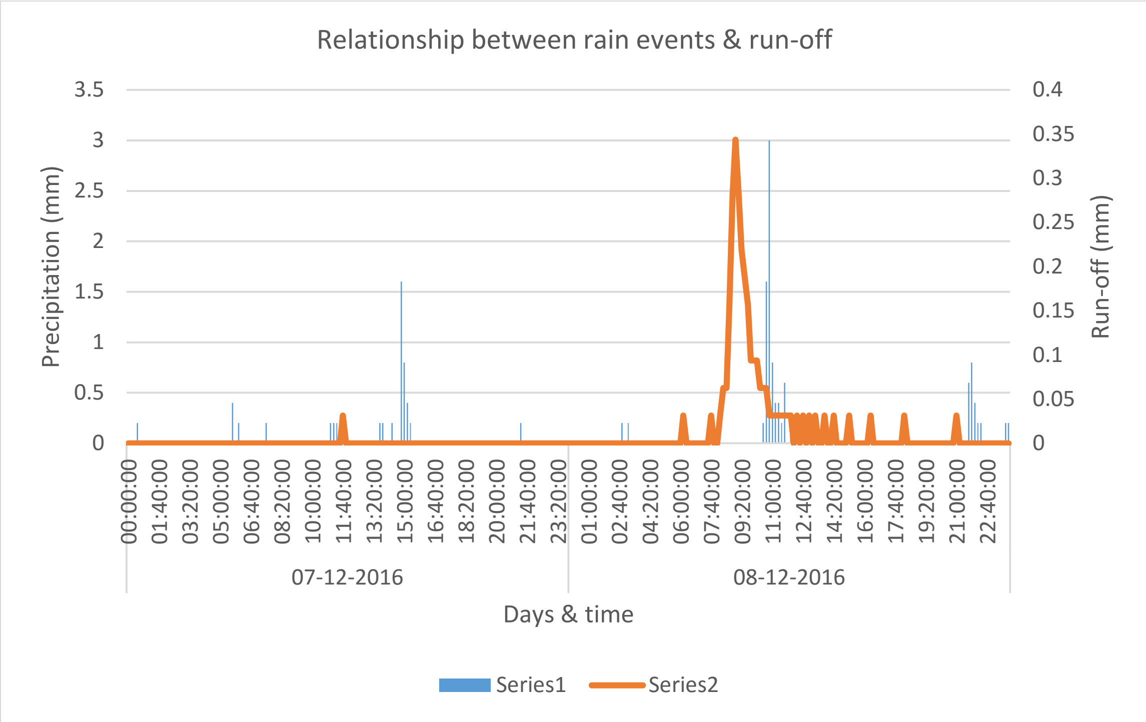
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	0	0	0	0
Run-off*	0	0	0	0

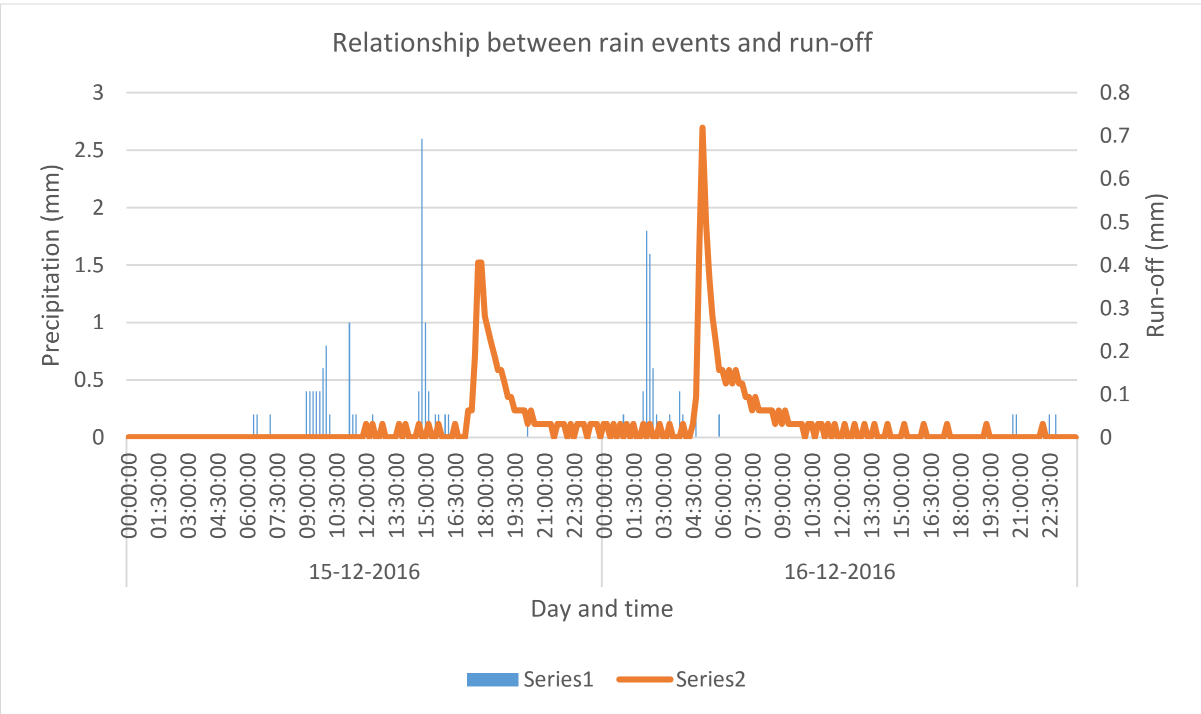


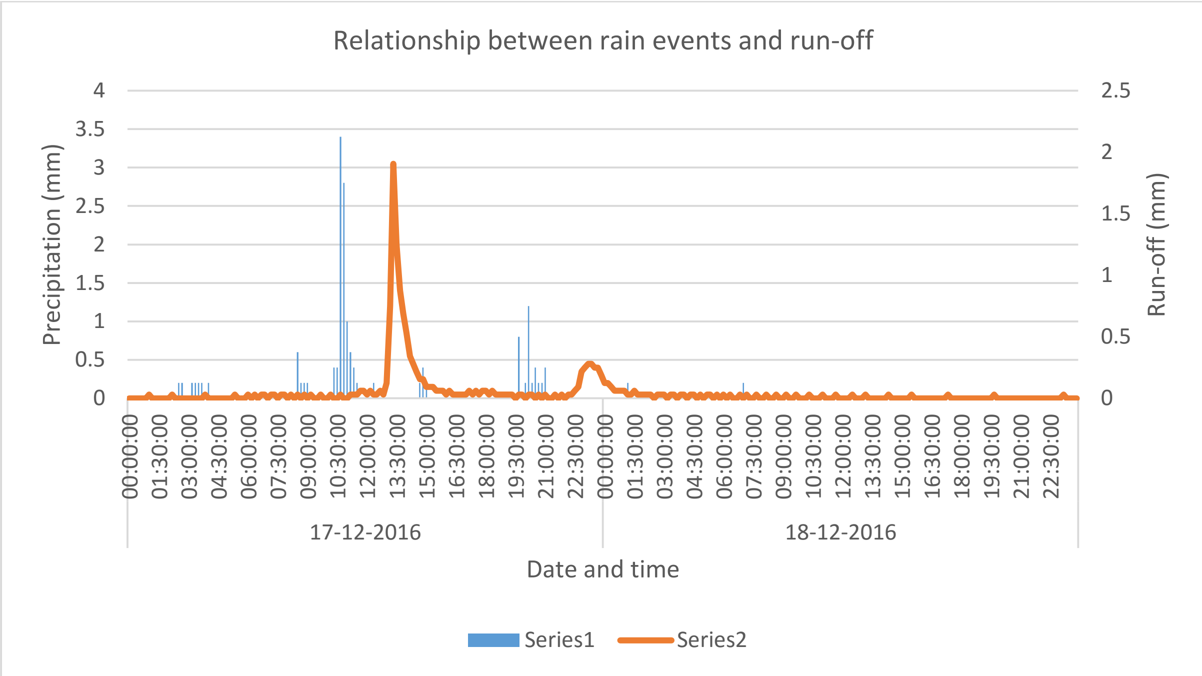
	No. of days	Maximum (mm)	Minimum (mm)	Total (mm)
Rain events*	1	3.20	0	3.20
Run-off*	0	0	0	0

Annex 2

Precipitation and run-off association, Maltese green roof





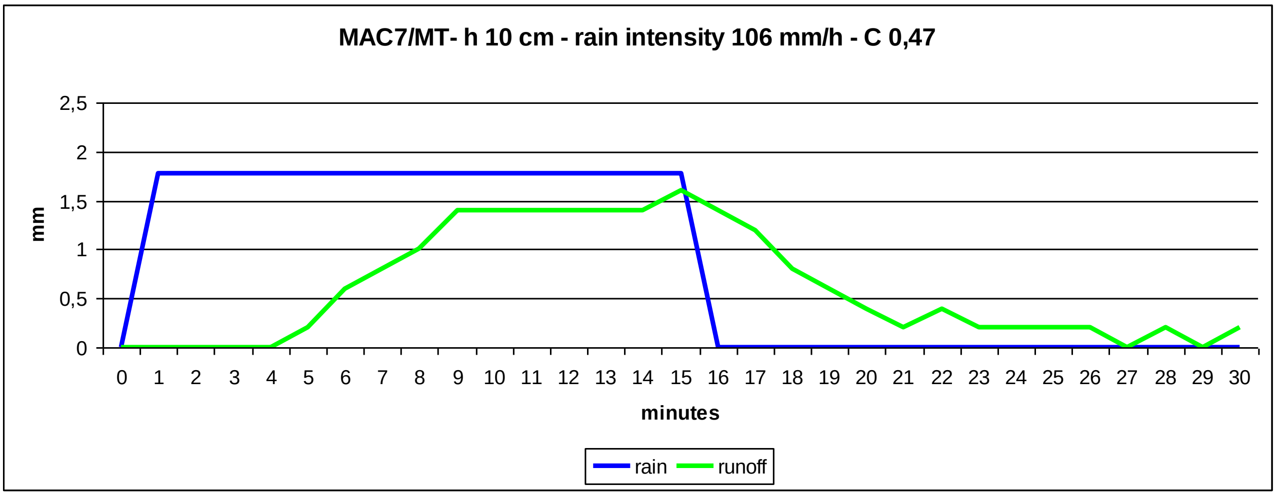

Relationship between rain events and run-off
Precipitation (mm)
Run-off (mm)
4
3.5
3
2.5
2
1.5
1
0.5
0
2.5
2
1.5
1
0.5
0
00:00:00
01:30:00
03:00:00
04:30:00
06:00:00
07:30:00
09:00:00
10:30:00
12:00:00
13:30:00
15:00:00
16:30:00
18:00:00
19:30:00
21:00:00
22:30:00
17-12-2016
18-12-2016
Date and time
Series1
Series2

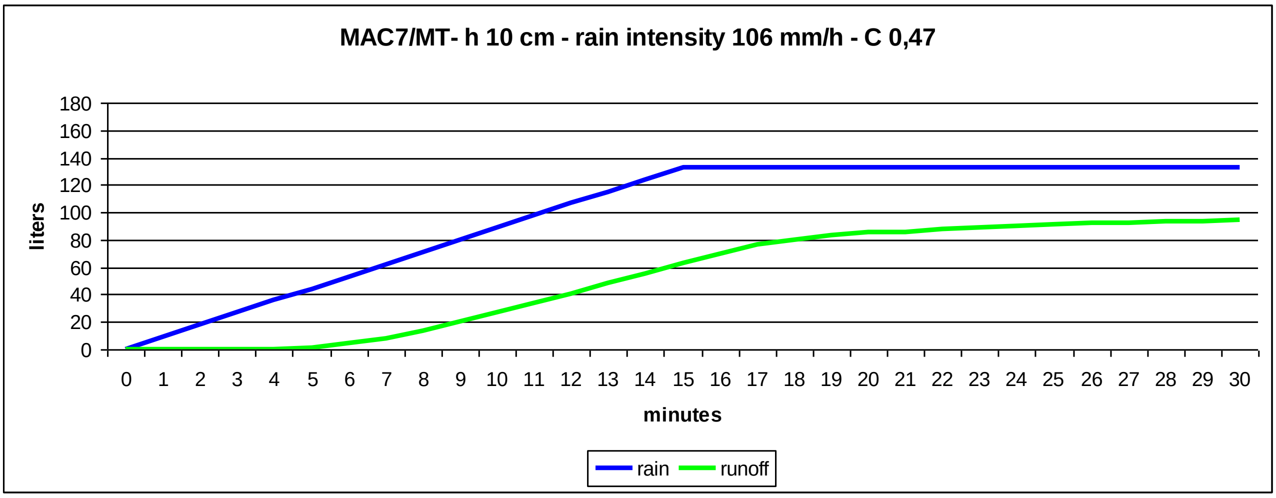
Annex 3

Data from rainfall simulator tests

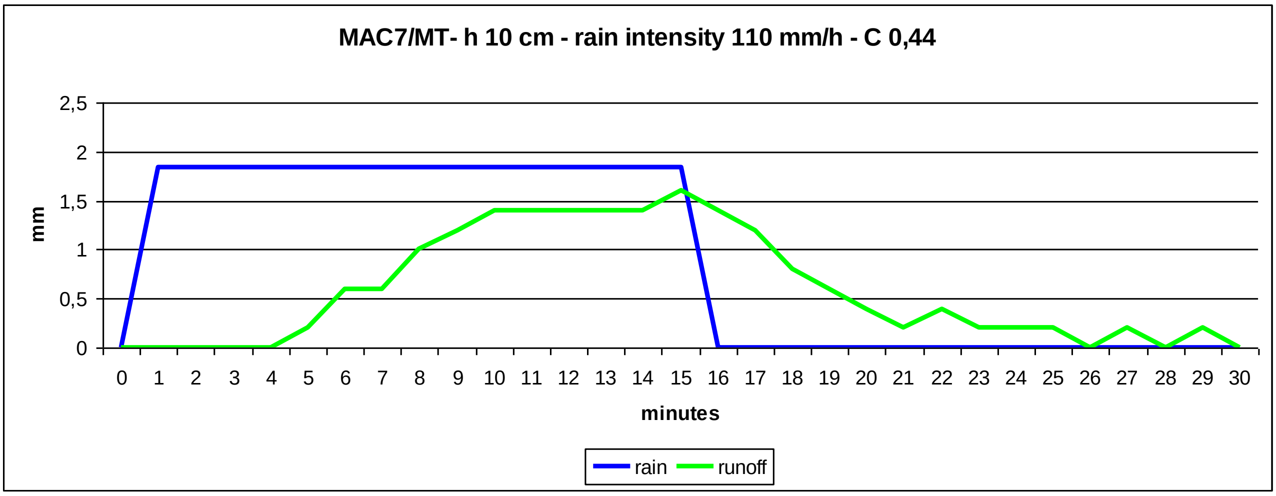
LEGENDA
C = RUNOFF COEFFICIENT
h = SUBSTRATE DEPTH

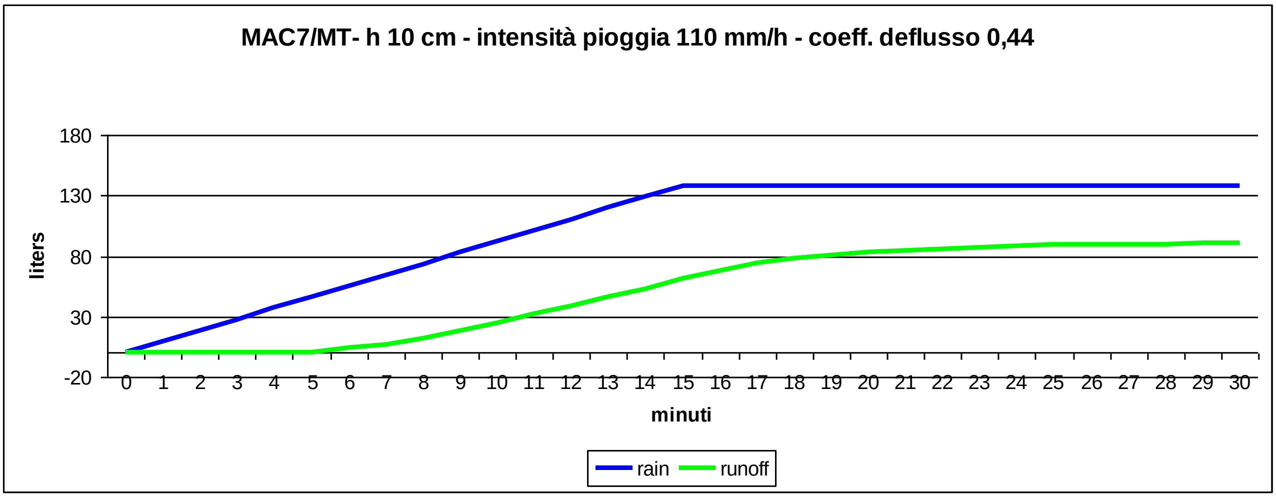
For each test there are 2 charts: the first one gives data minute by minute, the second one is a cumulative chart.



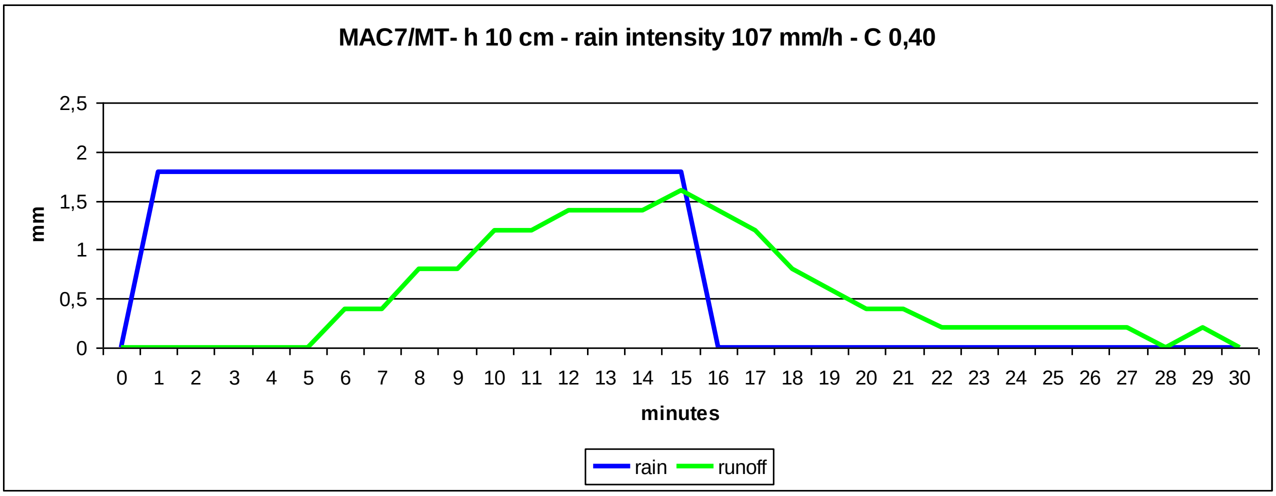


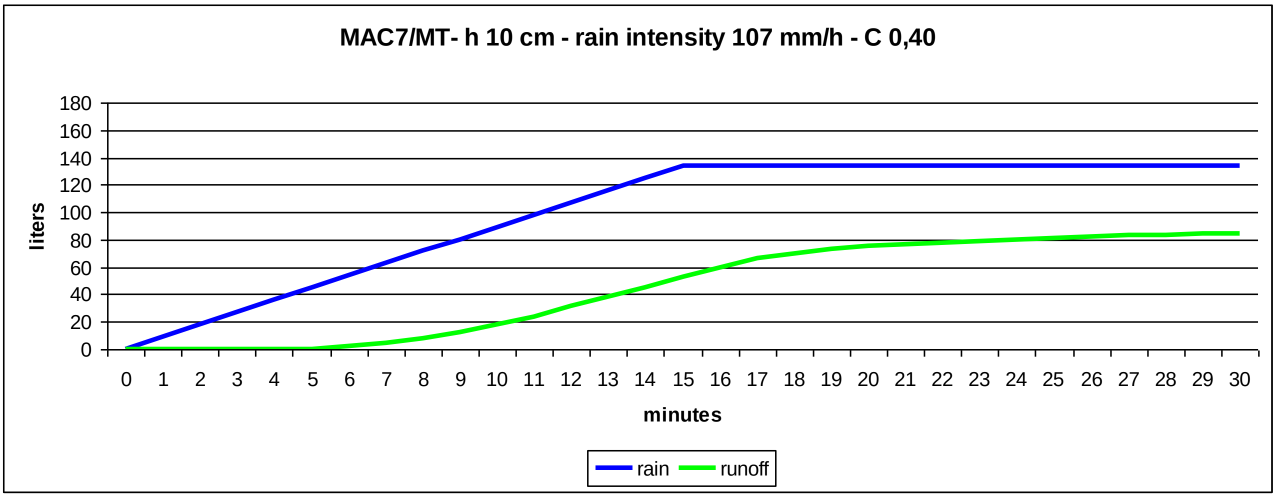
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	10	106	0.47



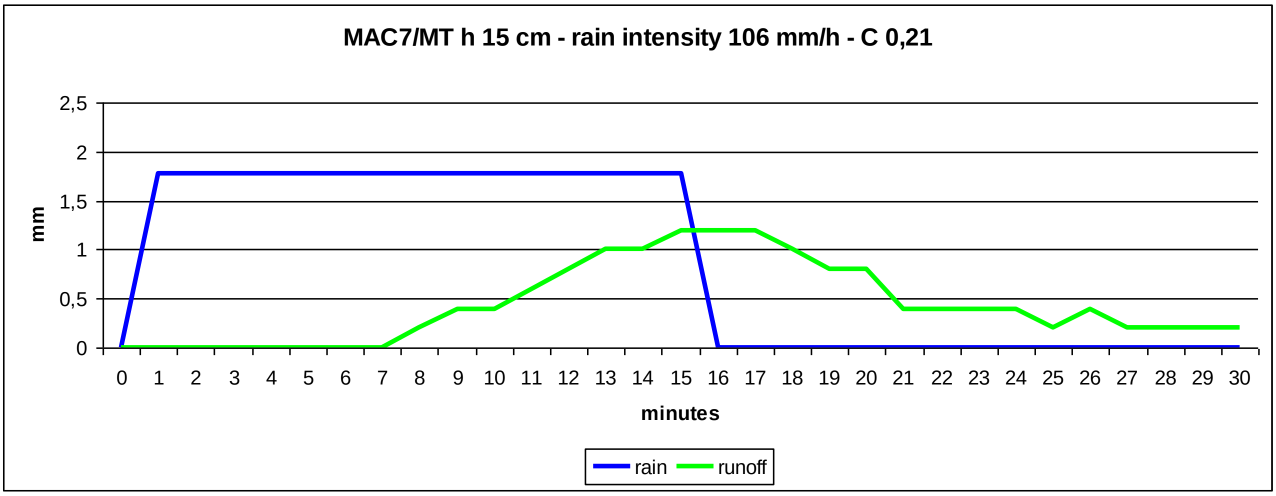


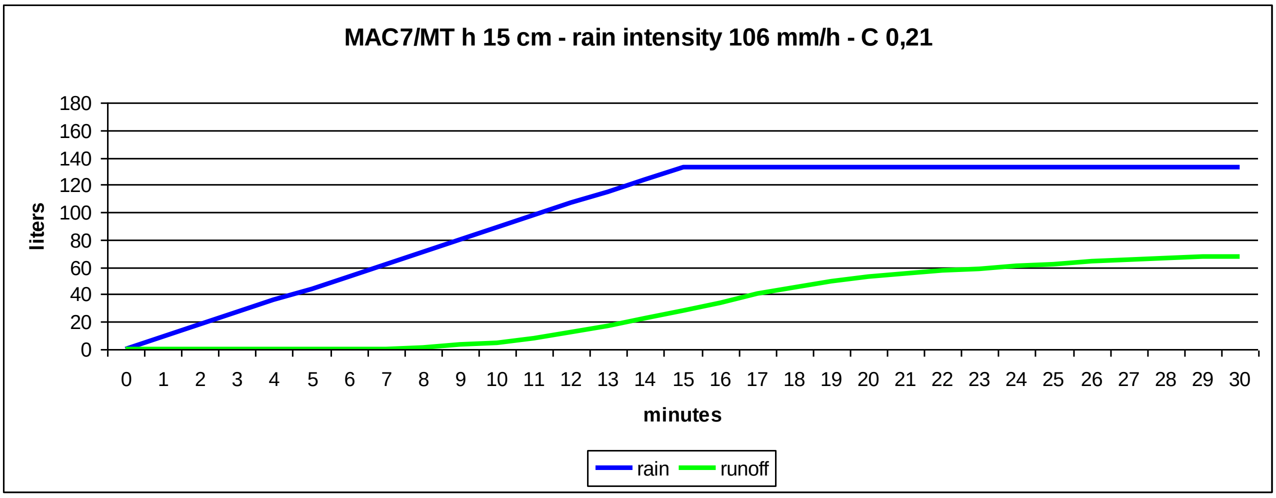
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	10	110	0.44



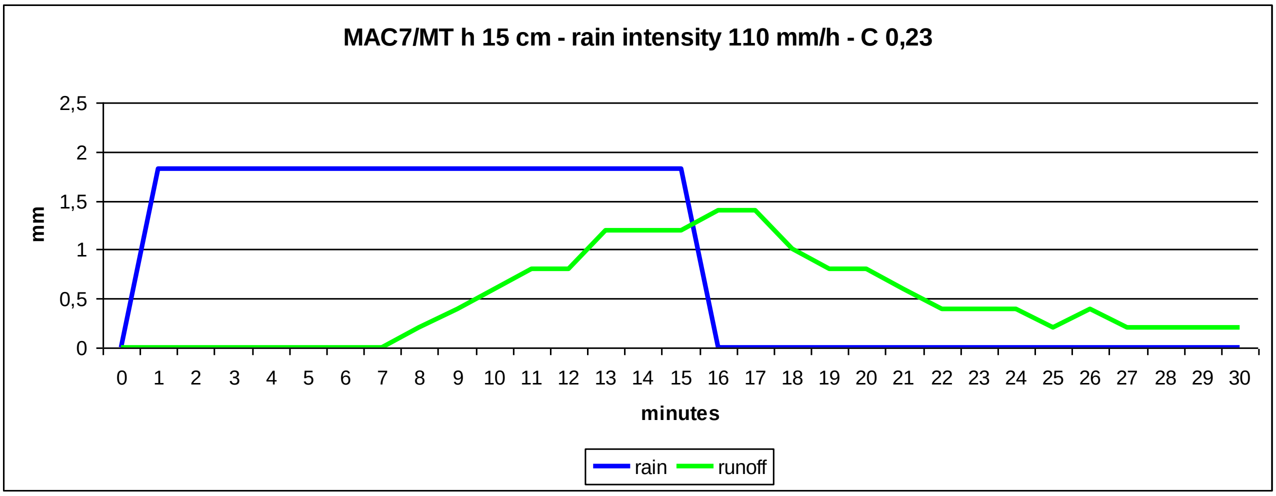


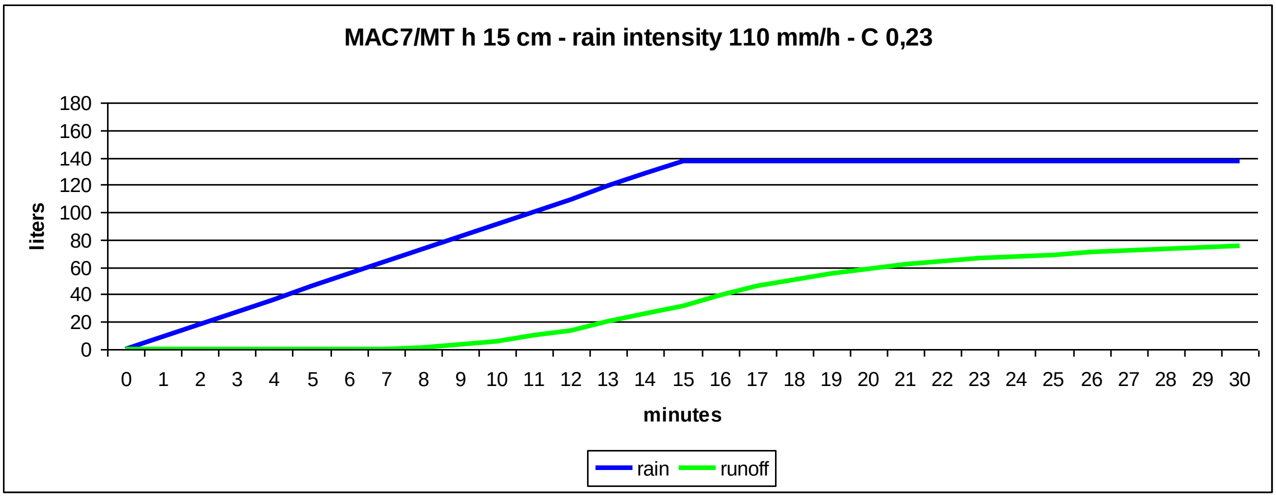
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	10	107	0.40



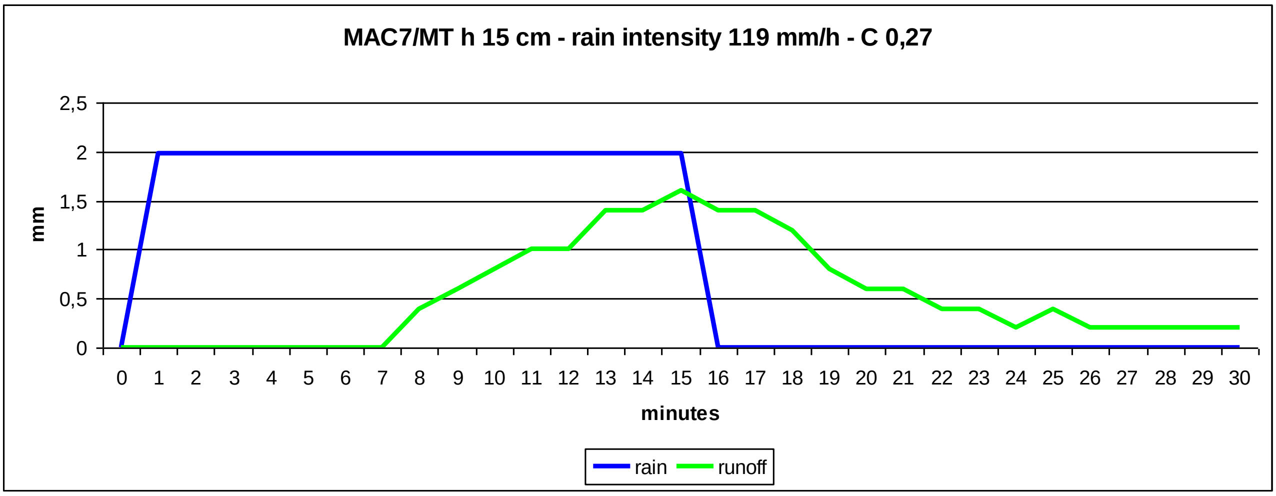


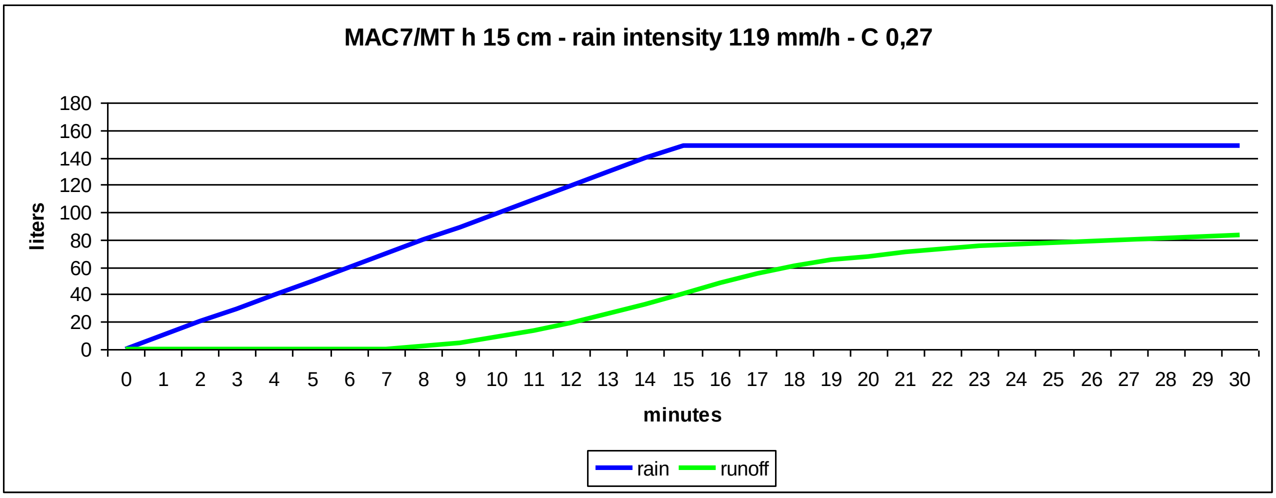
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	15	106	0.21



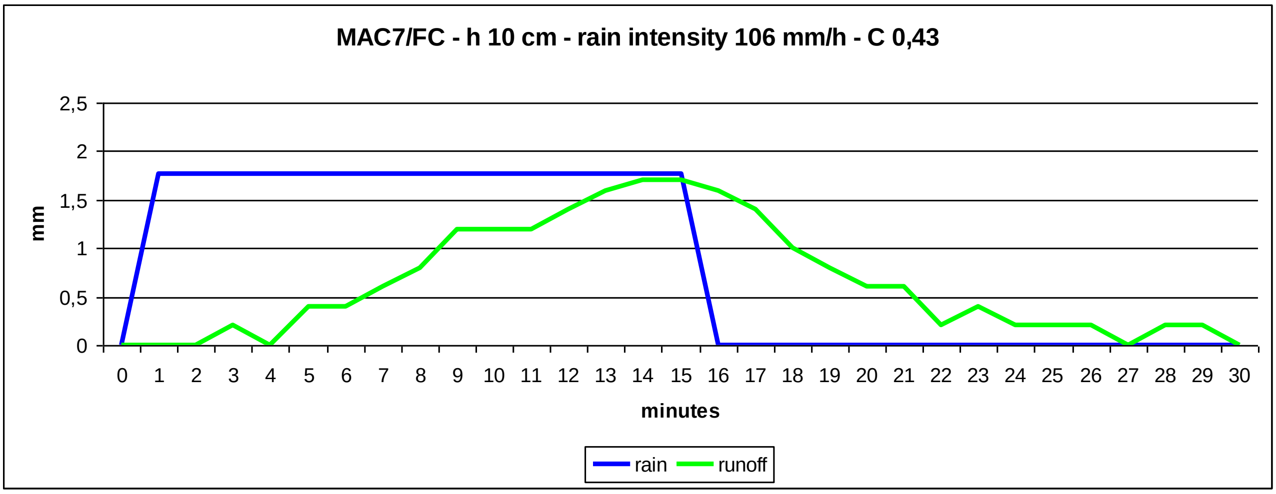


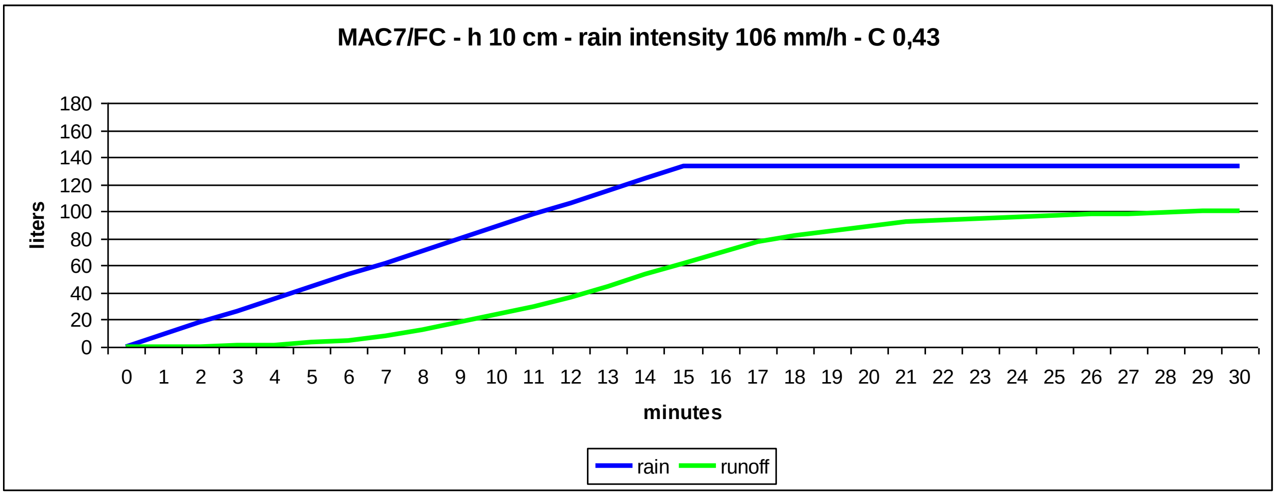
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	15	110	0.23



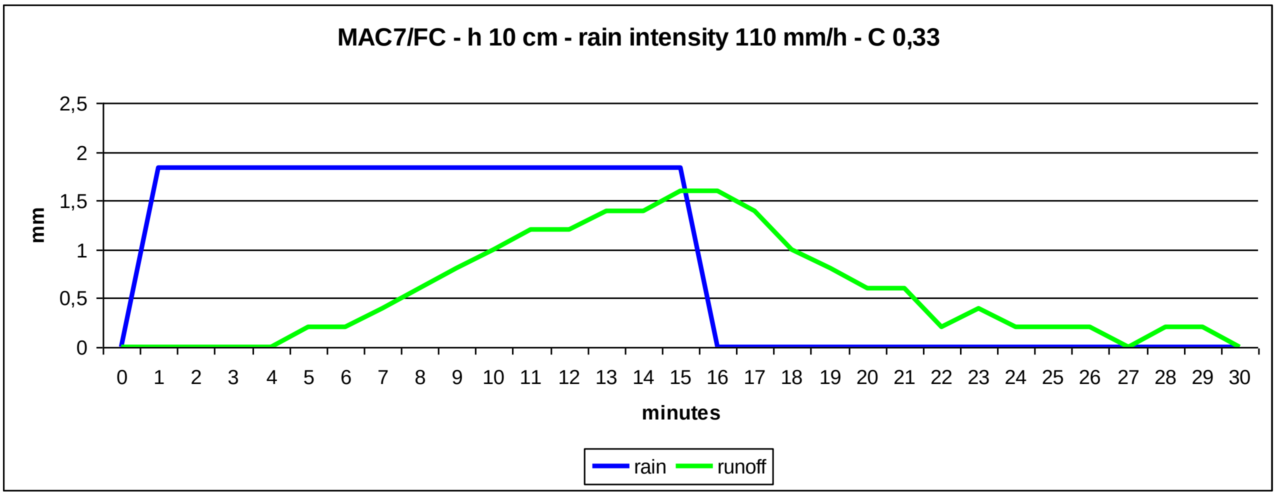


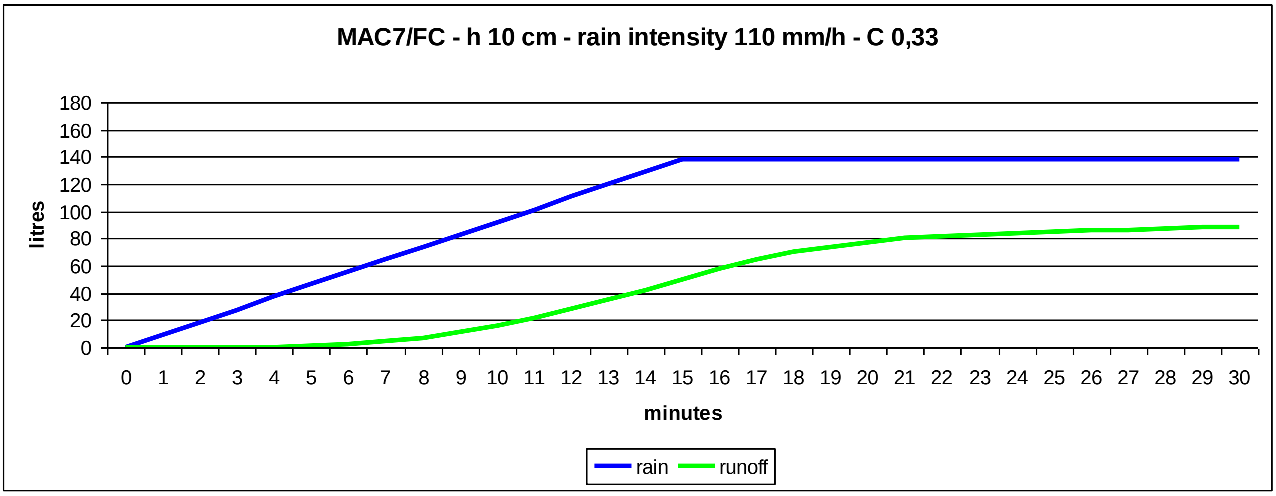
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	15	119	0.27



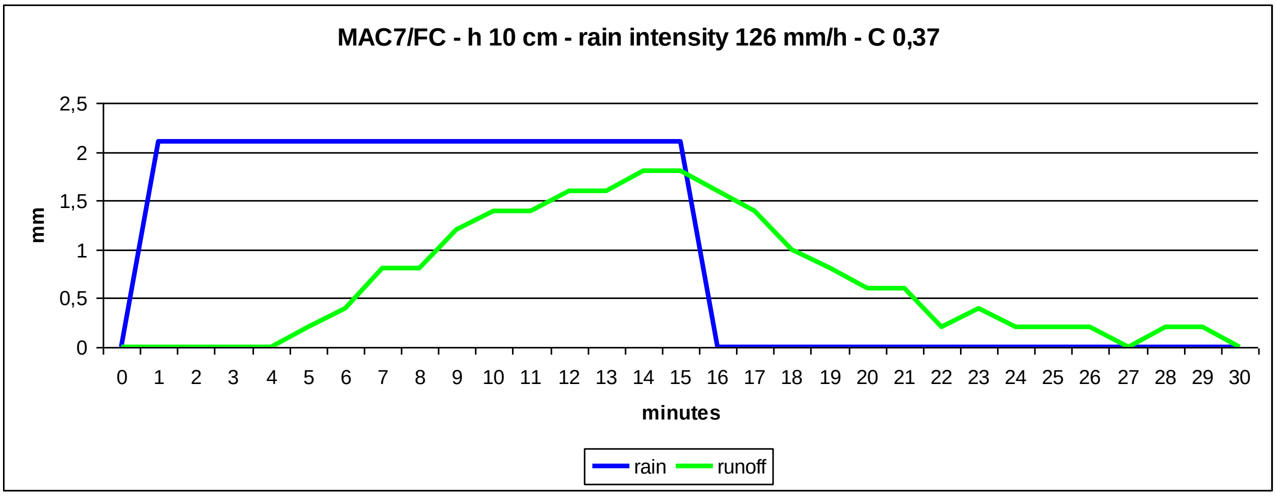


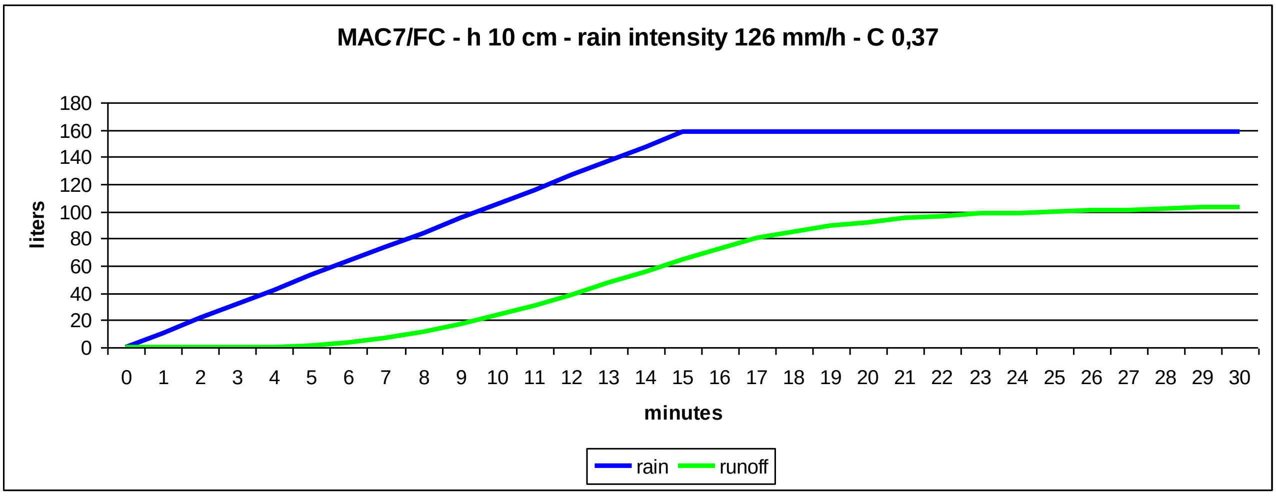
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	10	106	0.43



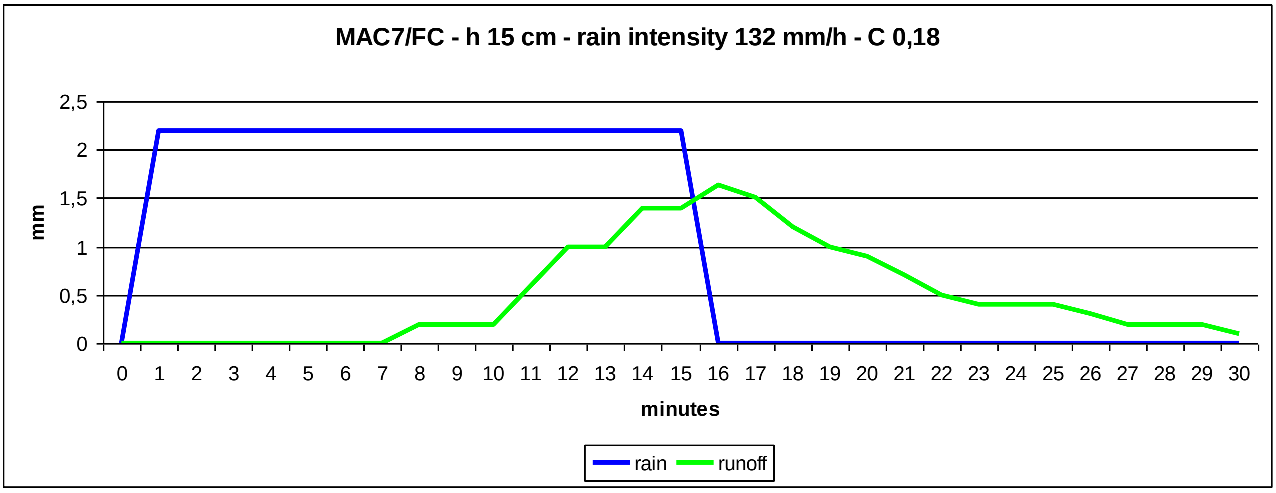


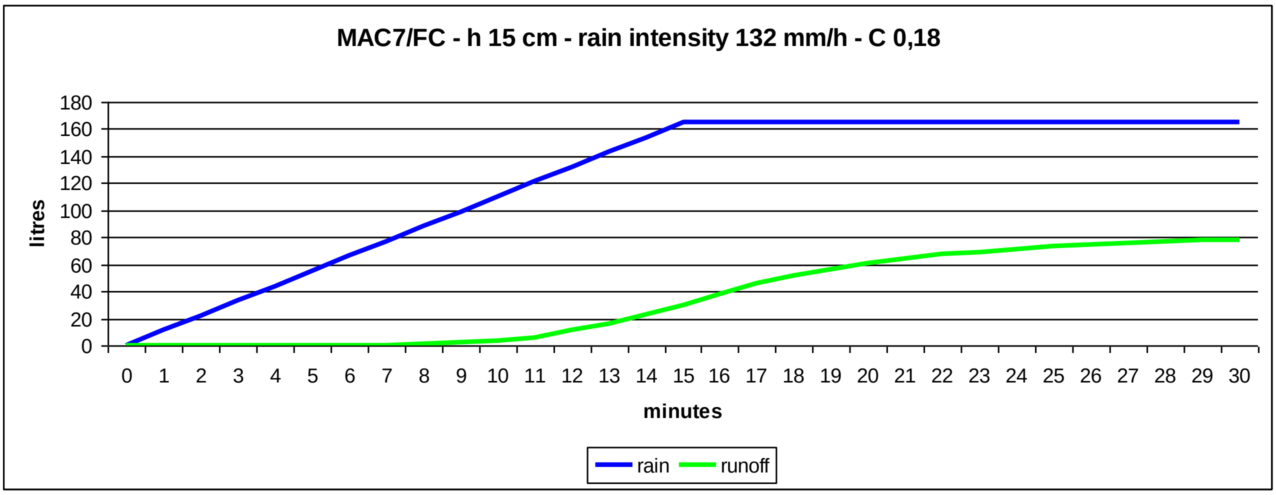
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	10	110	0.33



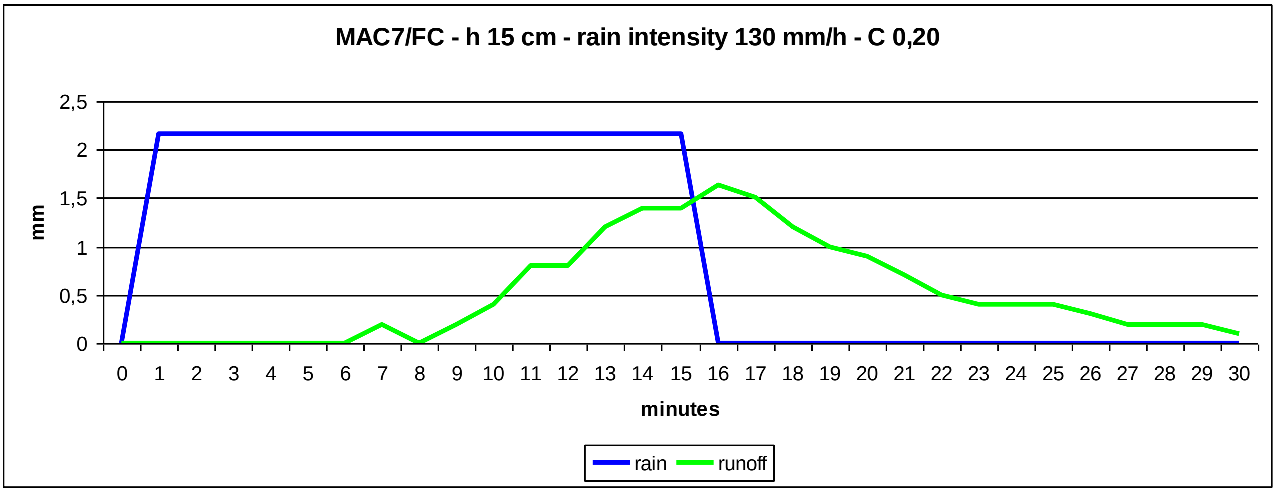


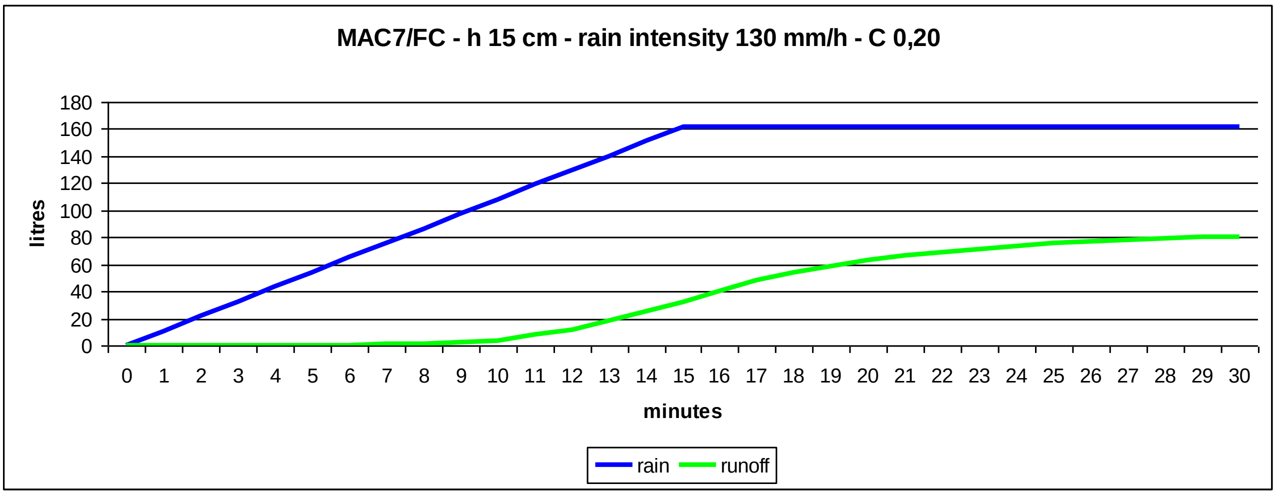
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	10	126	0.37



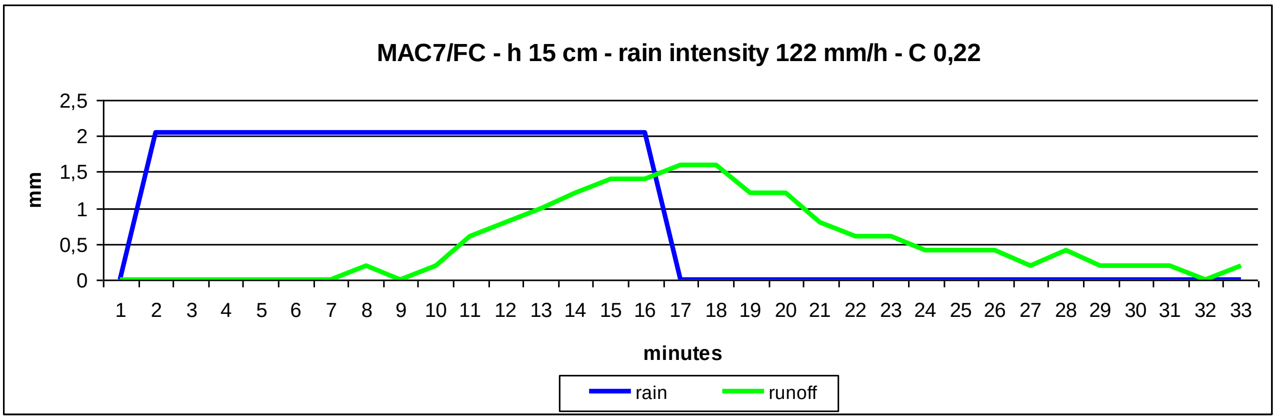


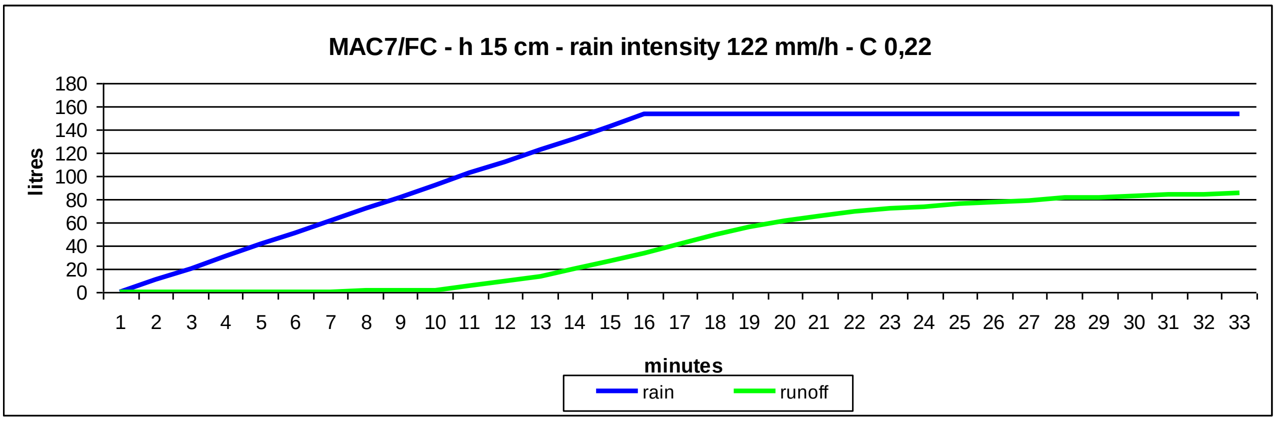
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	15	132	0.18



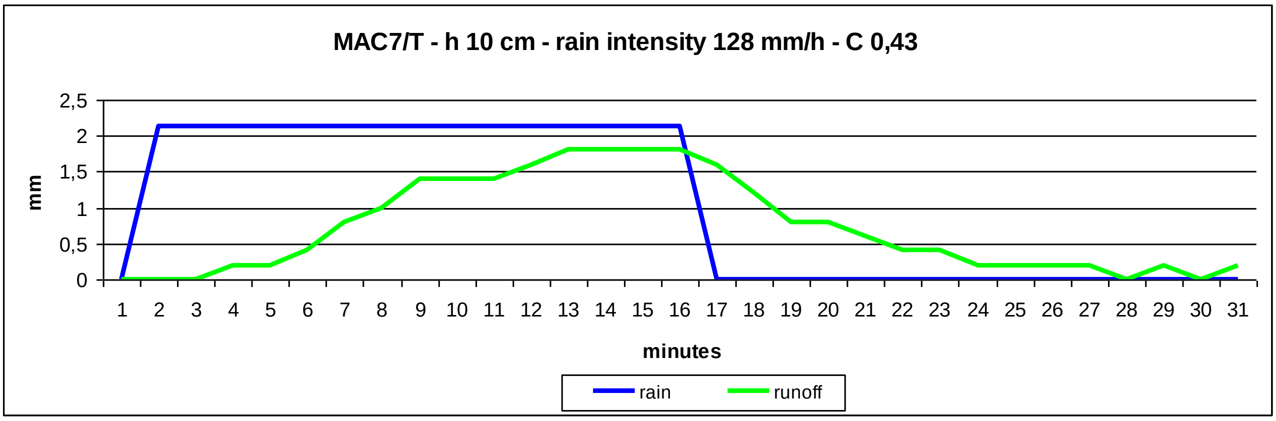


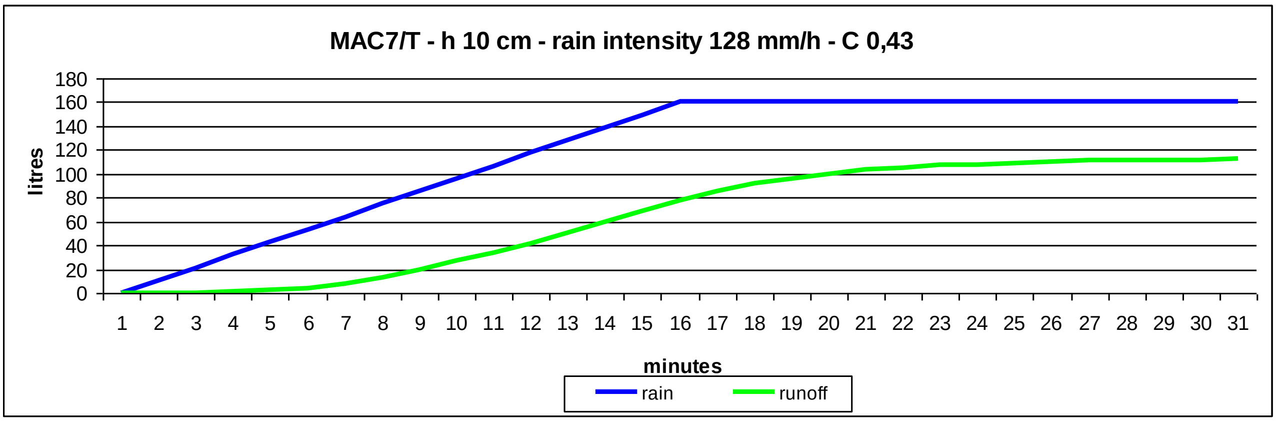
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	15	130	0.20



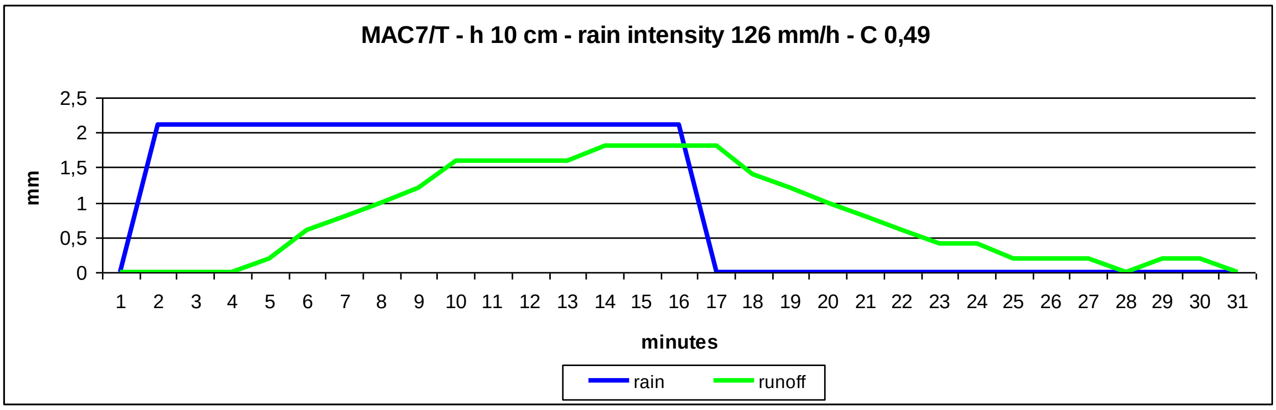


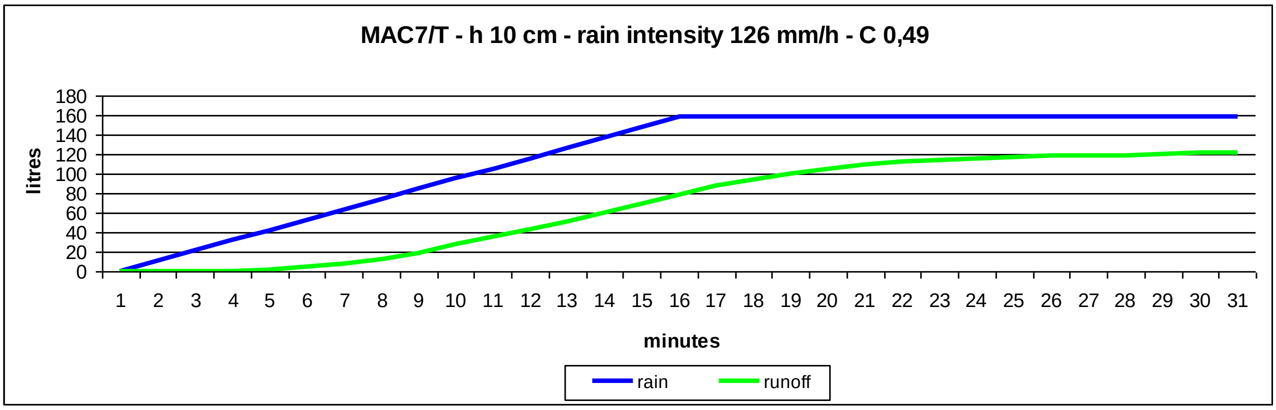
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/FC	15	122	0.22



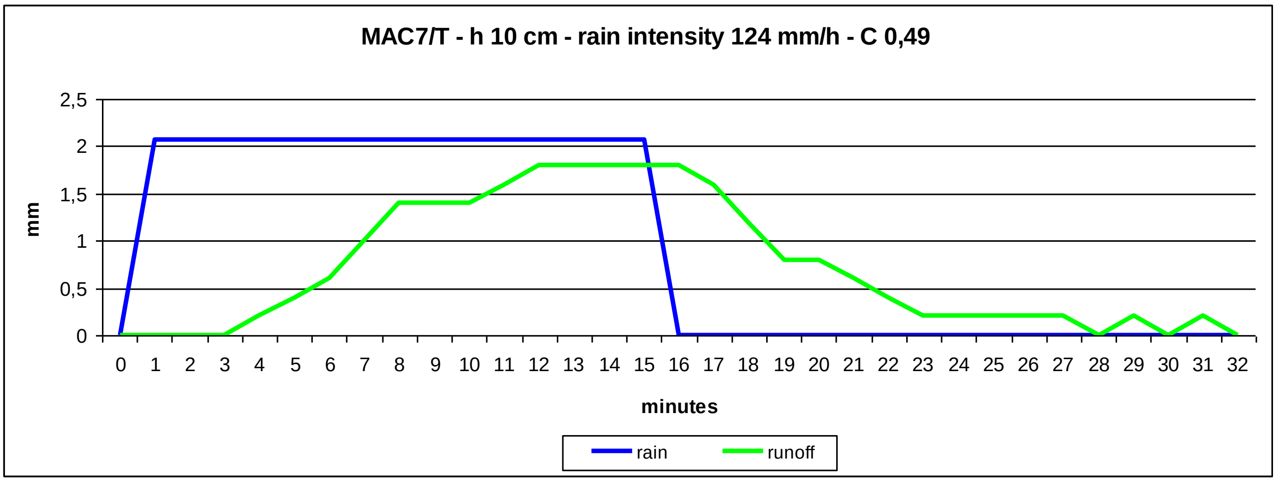


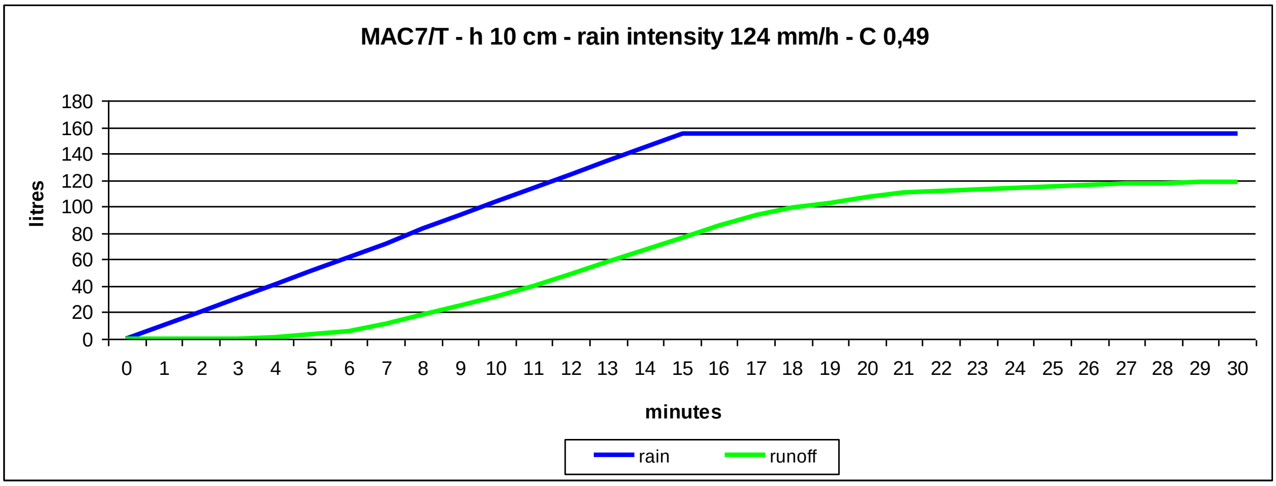
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	10	128	0.43



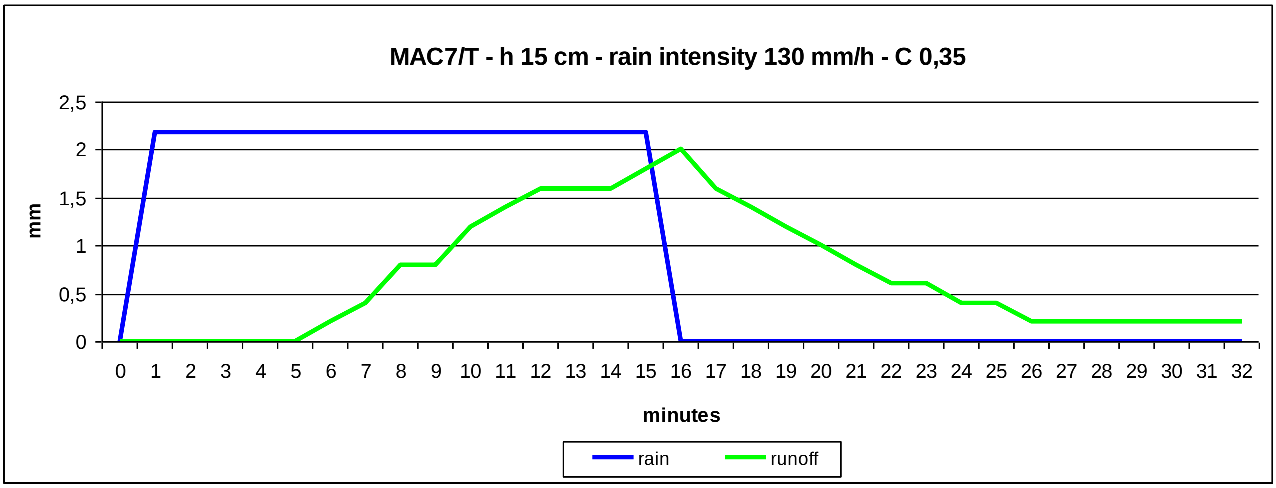


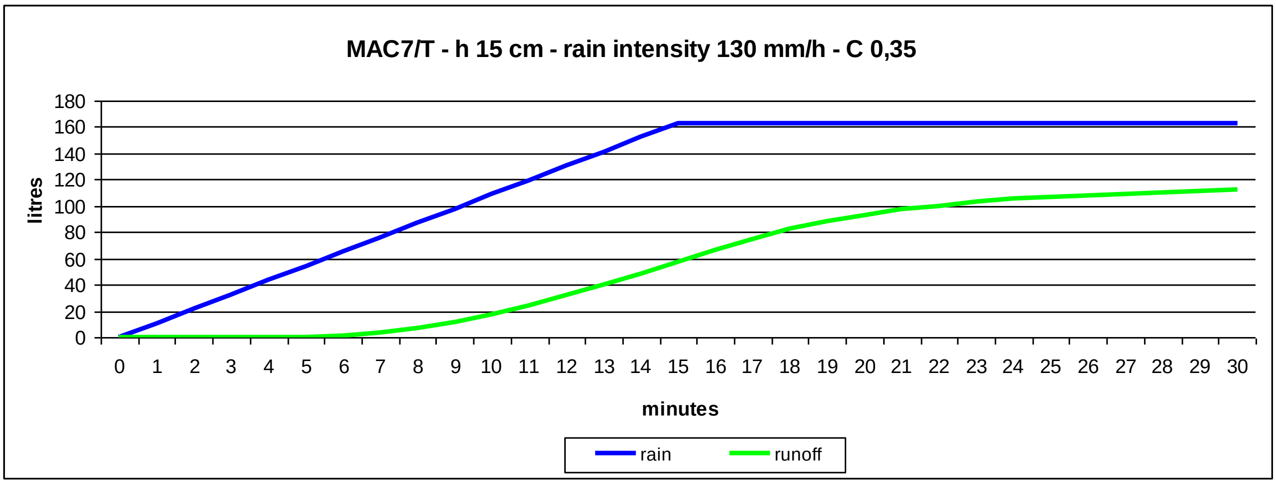
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	10	126	0.49



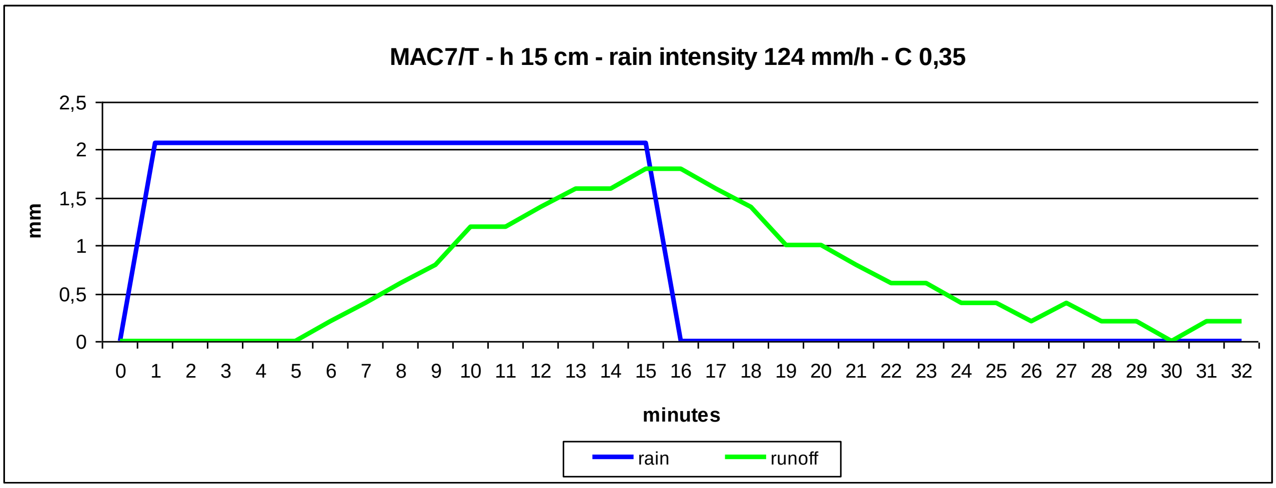


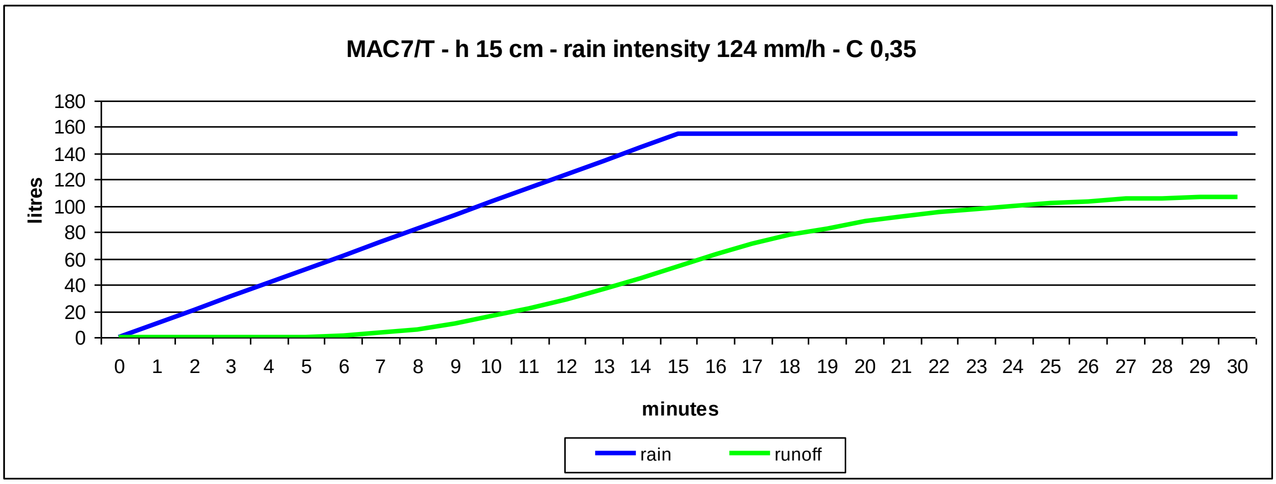
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	10	124	0.49



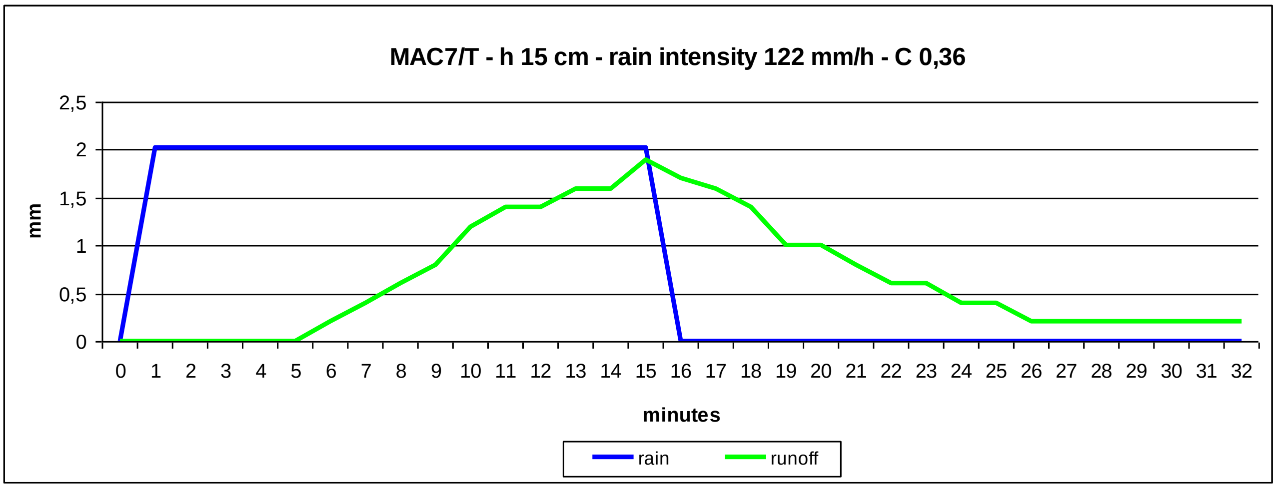


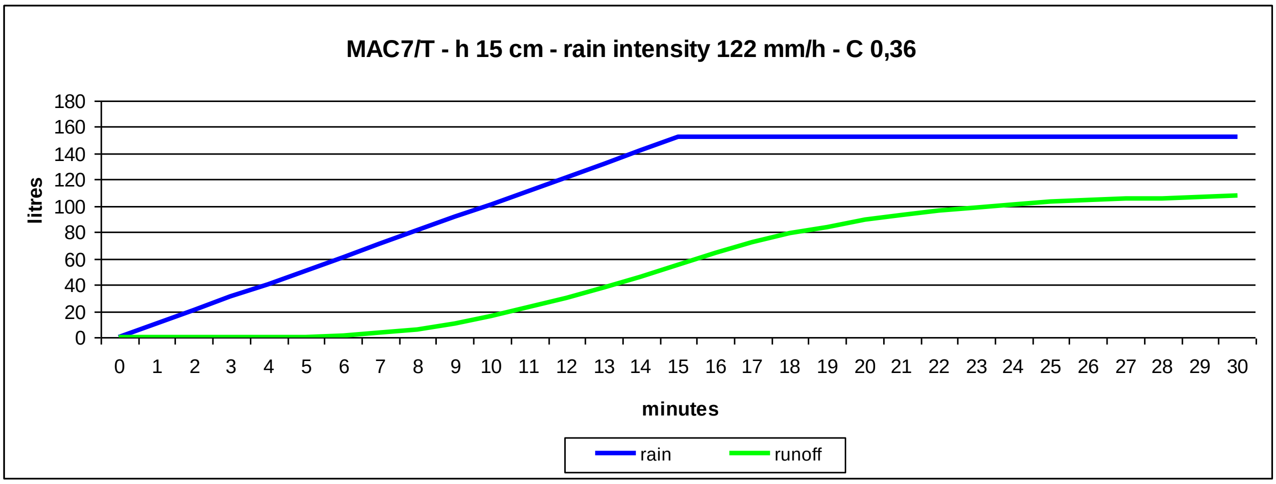
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	15	130	0.35



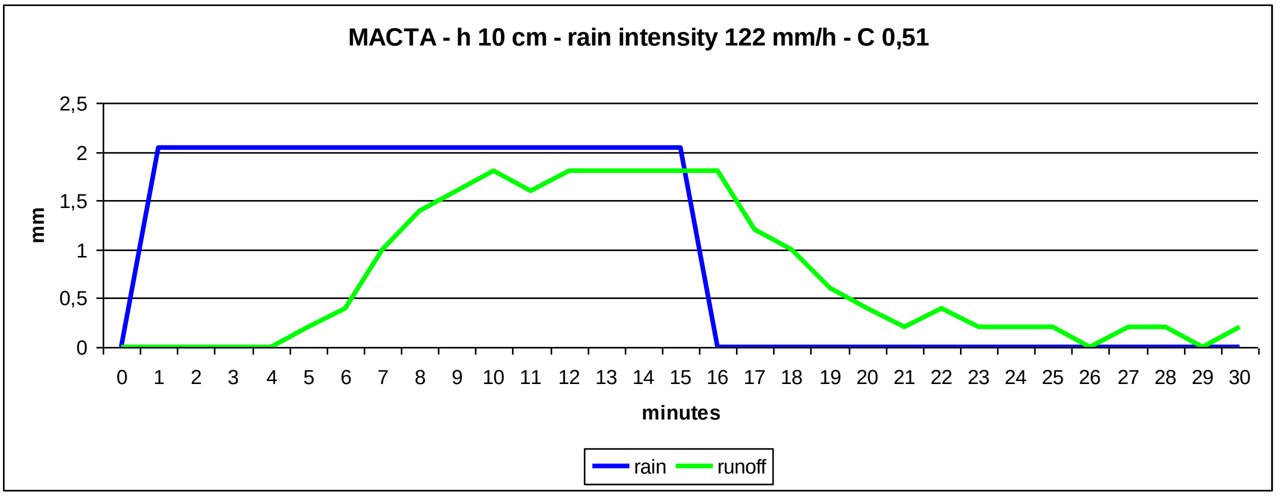


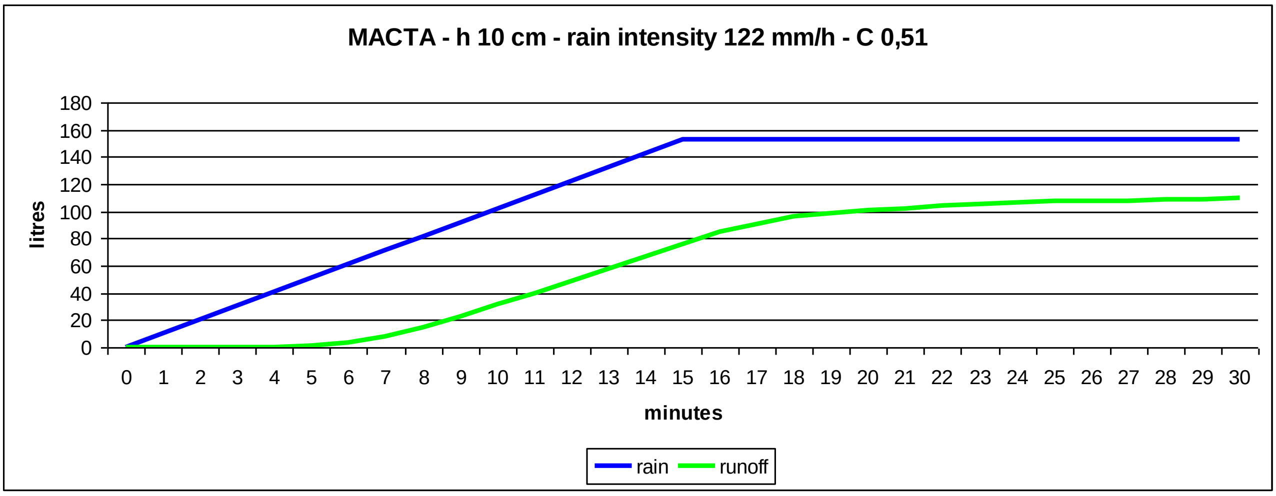
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	15	124	0.35



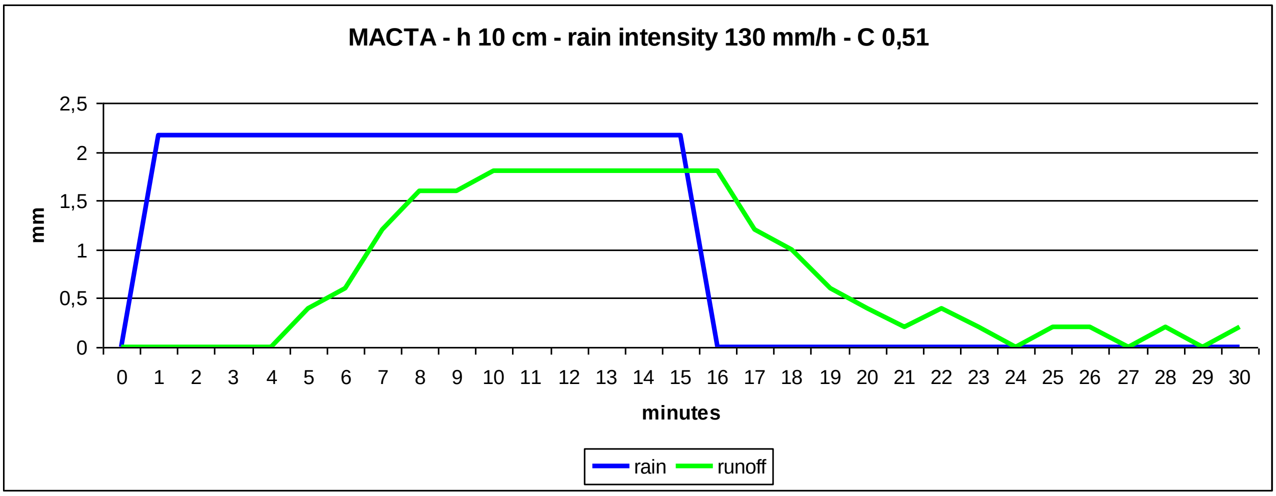


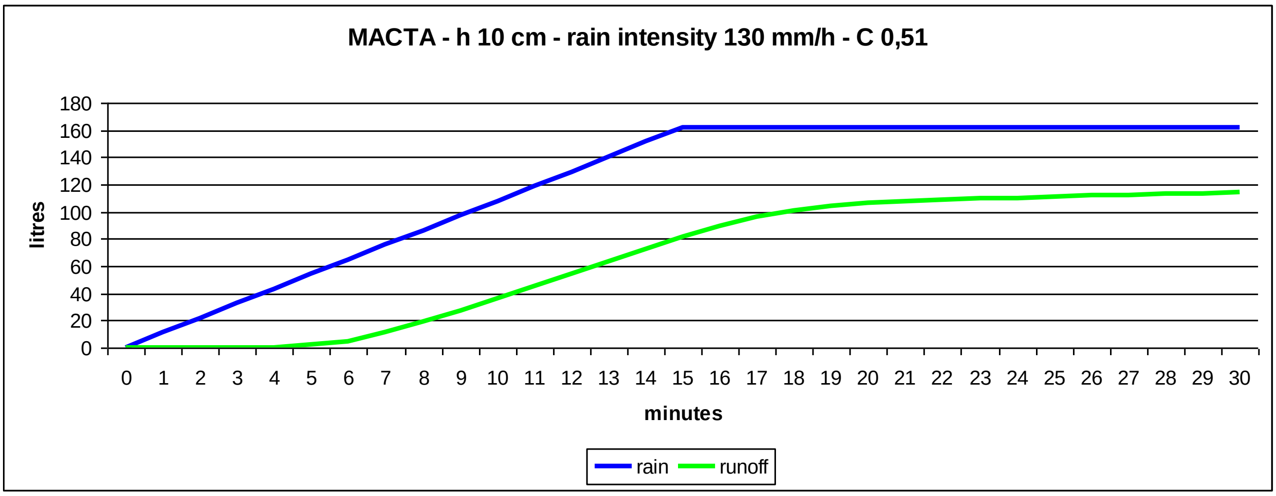
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/T	15	122	0.36



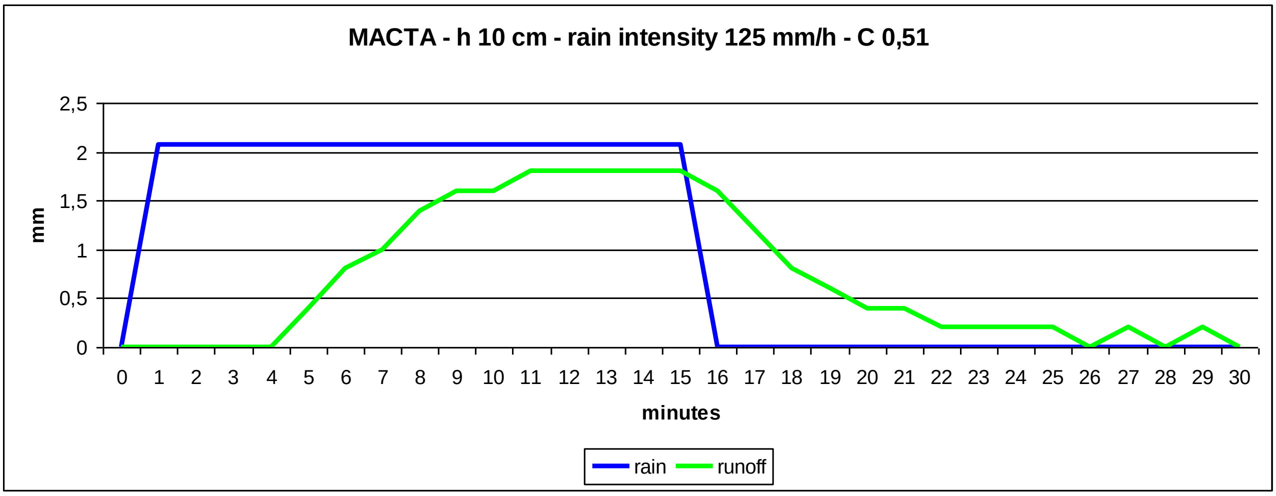


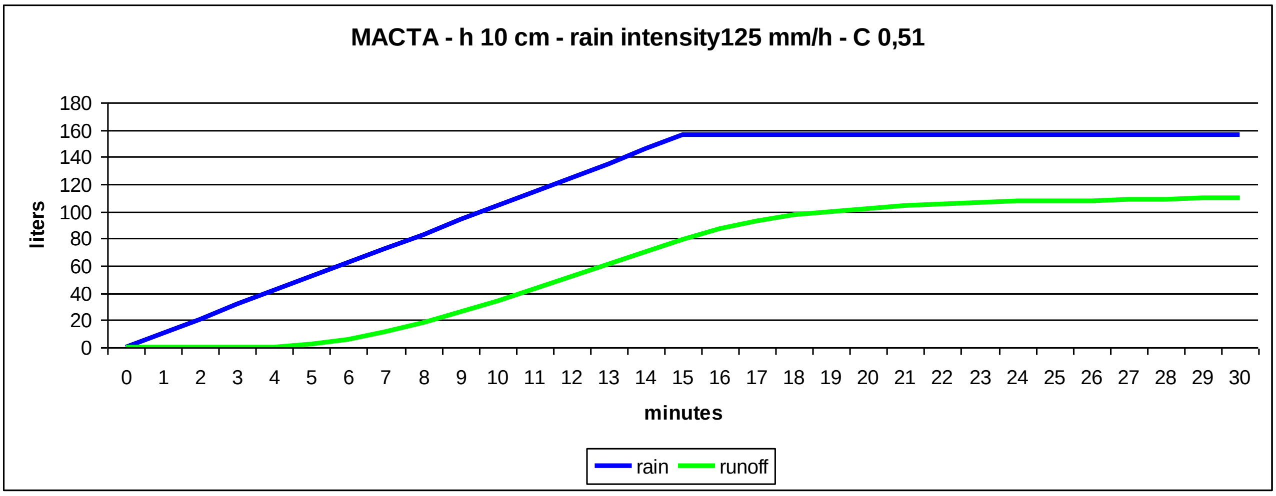
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	10	122	0.51



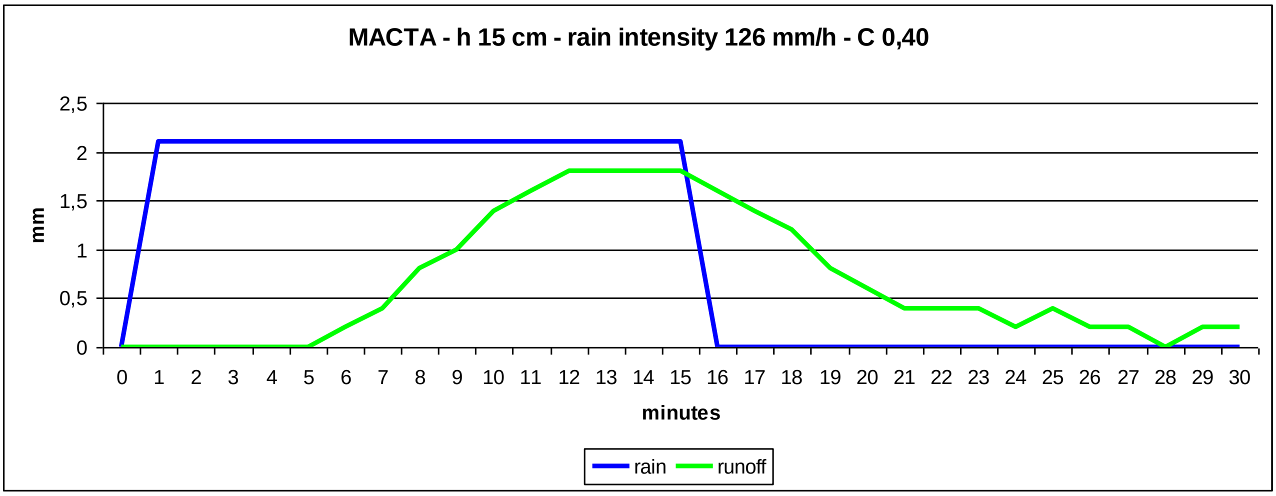


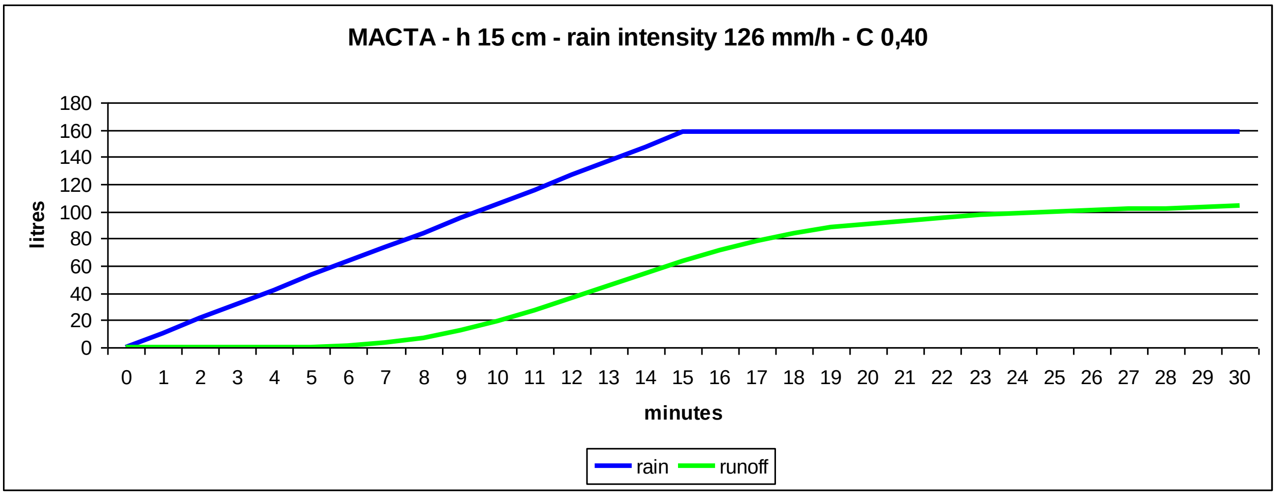
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	10	130	0.51



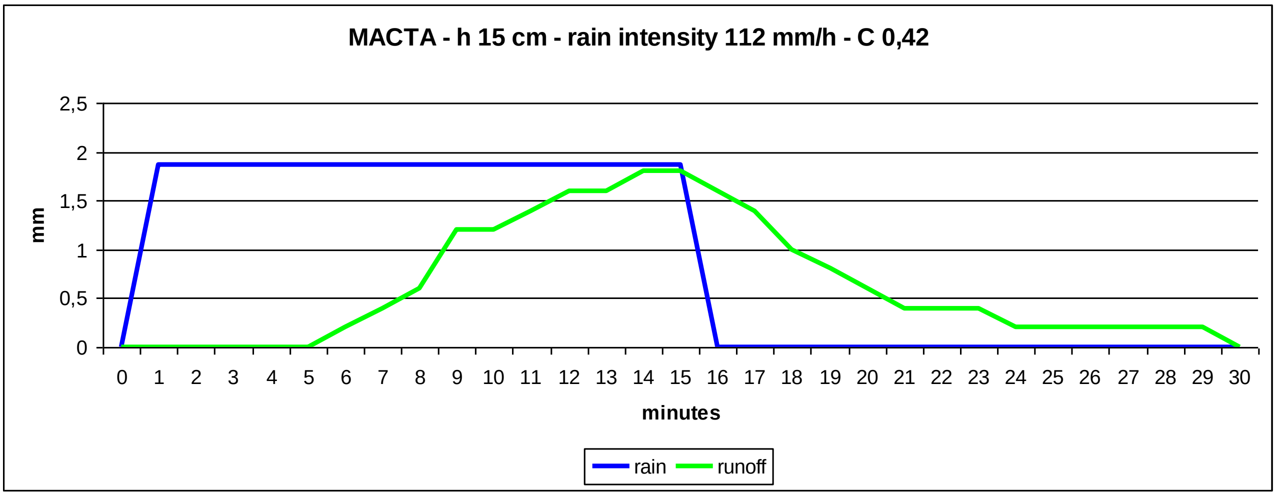


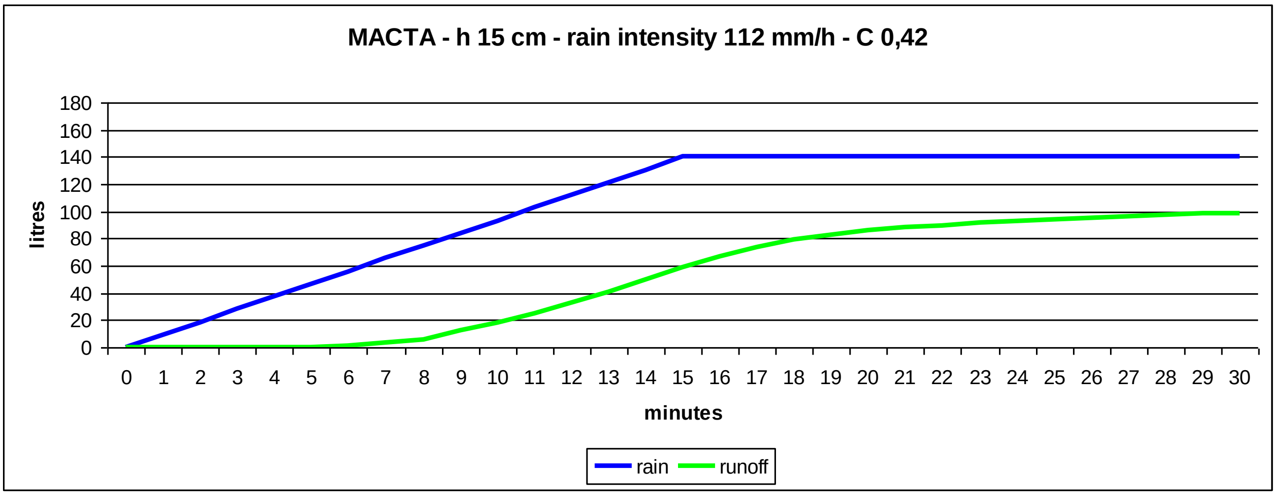
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	10	125	0.51



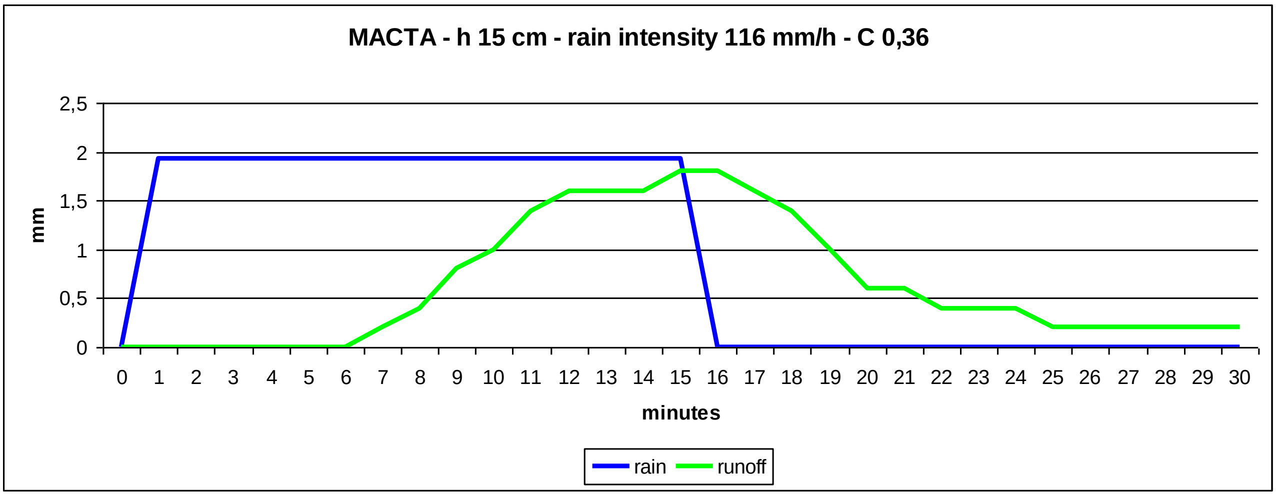


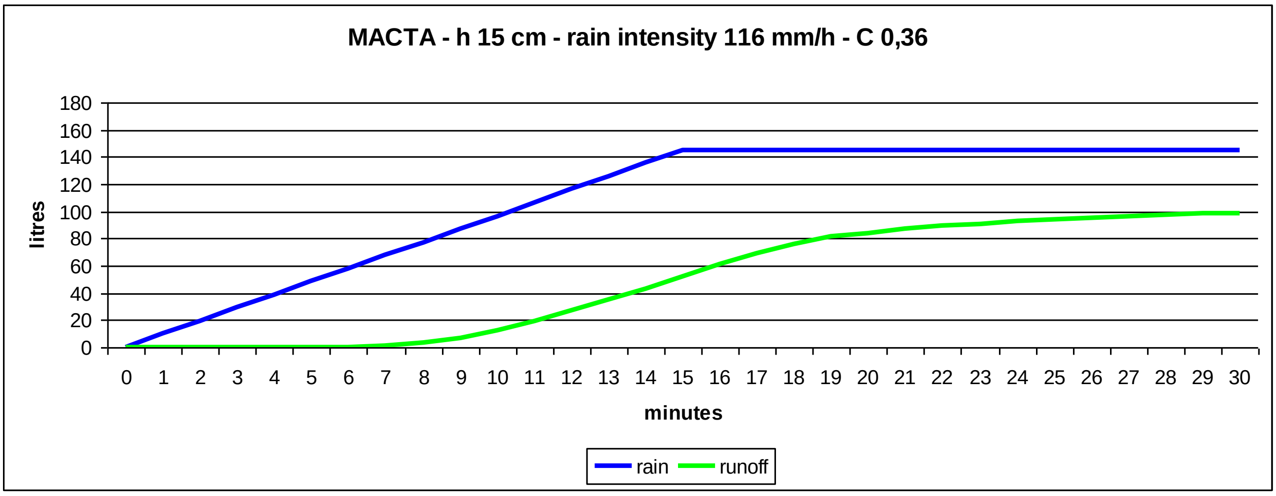
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	15	126	0.40



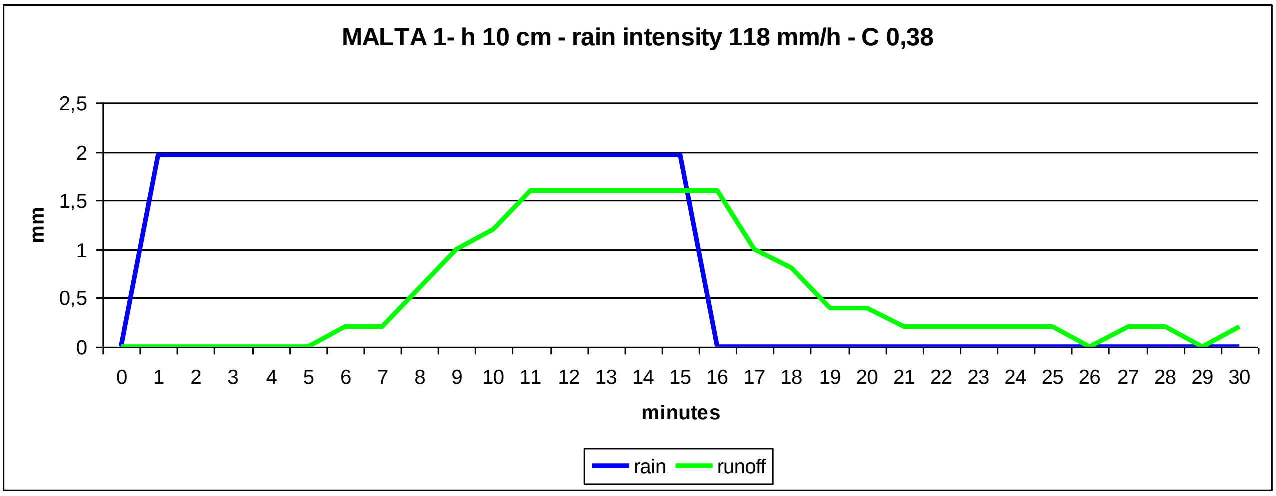


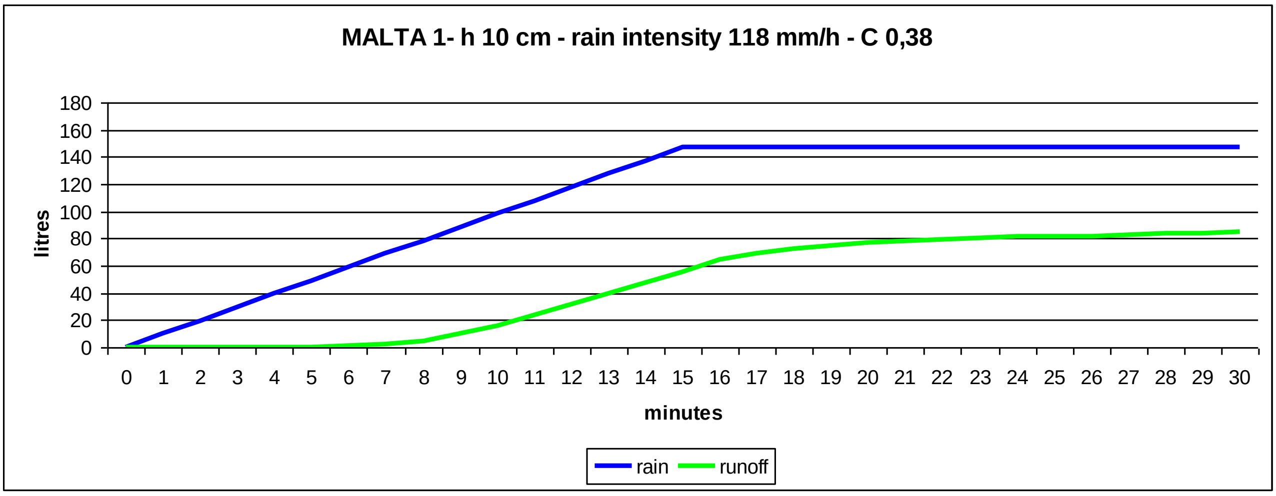
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	15	112	0.42



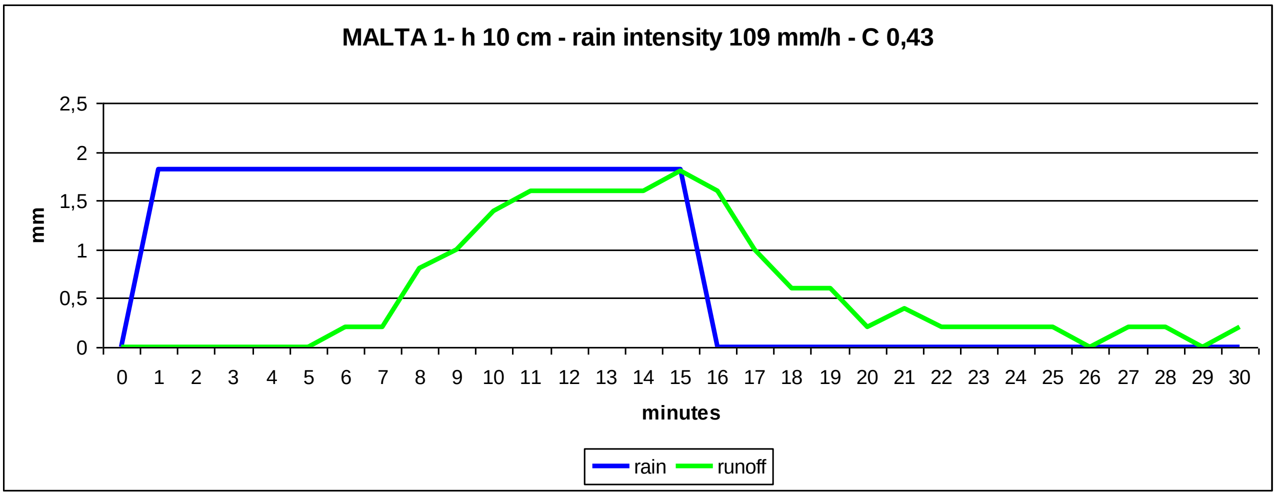


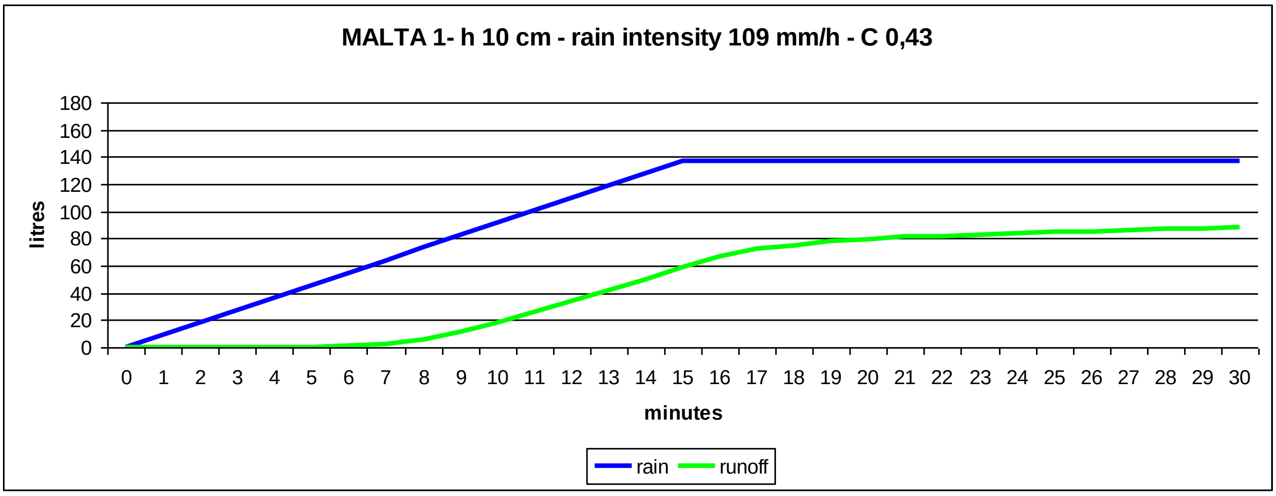
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MACTA	15	116	0.36



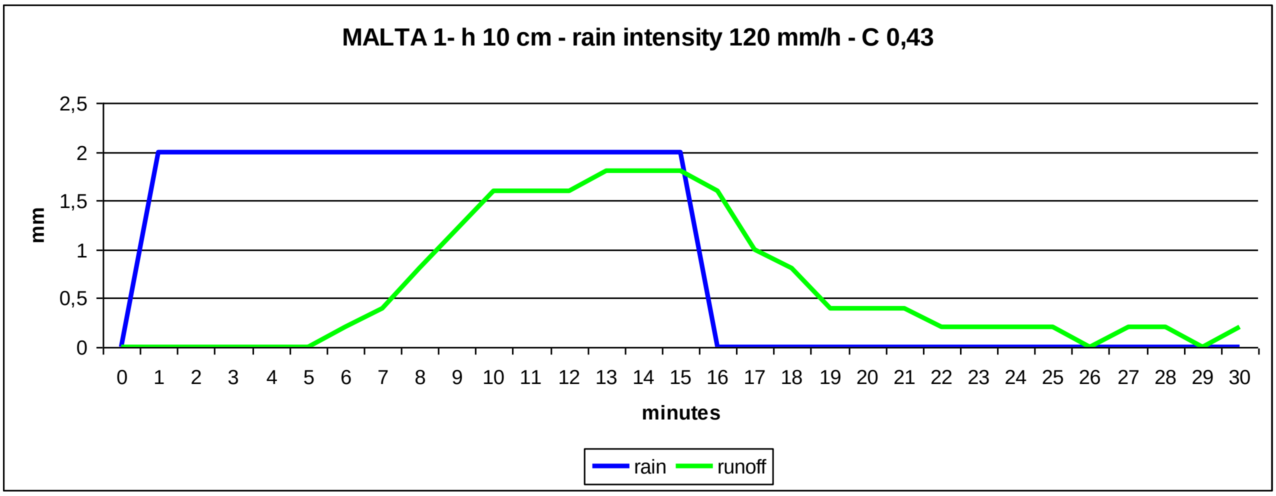


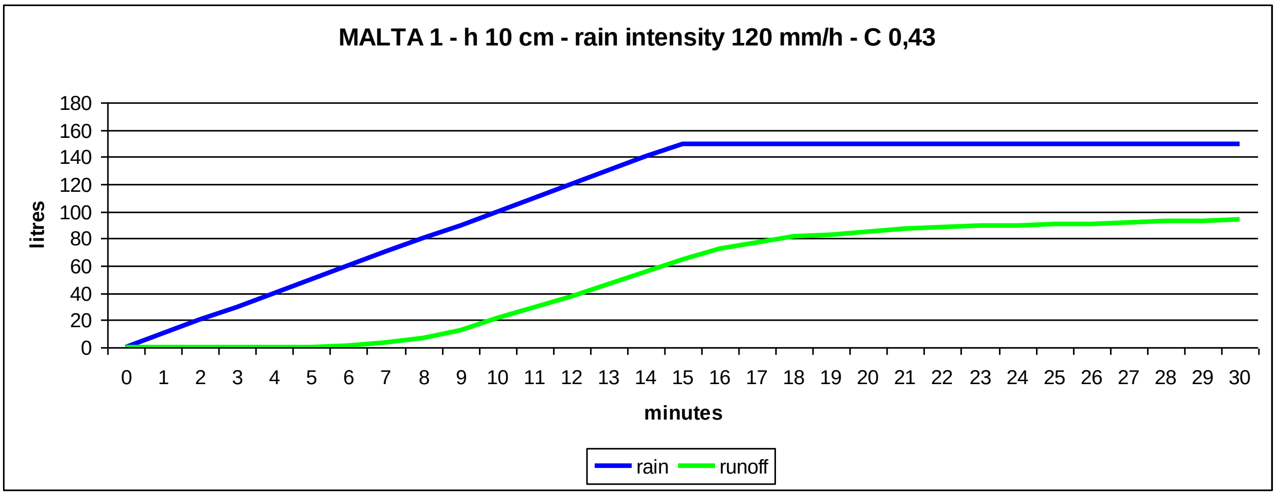
Substrate type	**Substrate depth-cm**	**Rain intensity-mm/h**	**Coefficient**
MALTA 1	10	118	0.38



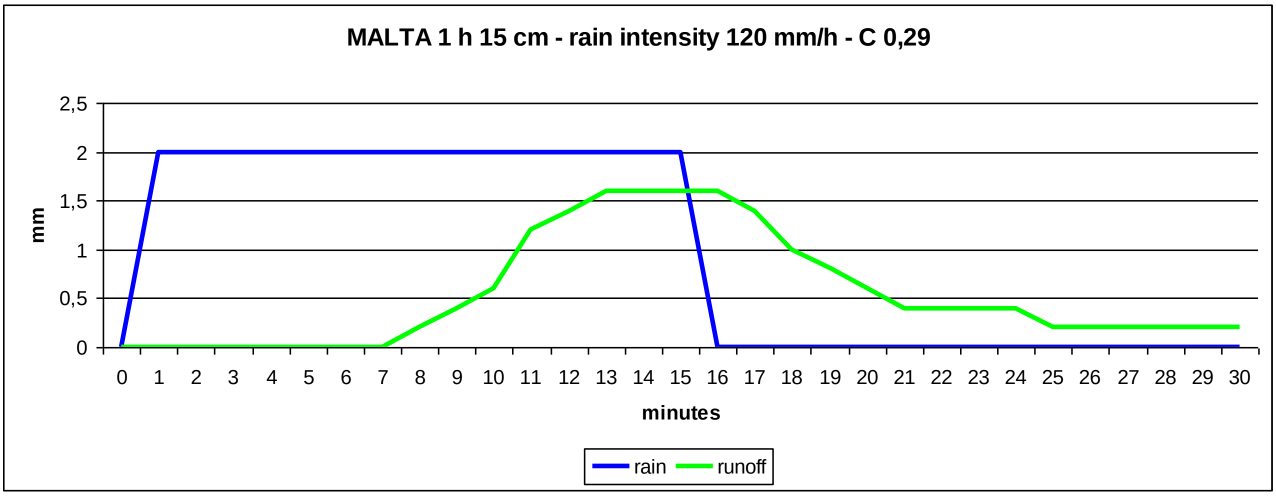


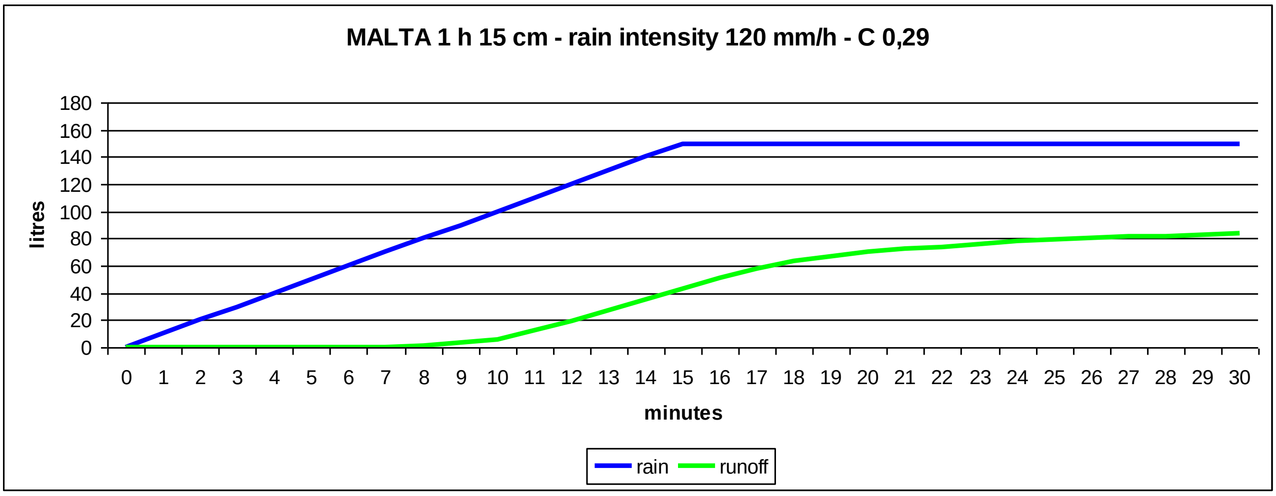
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 1	10	109	0.43



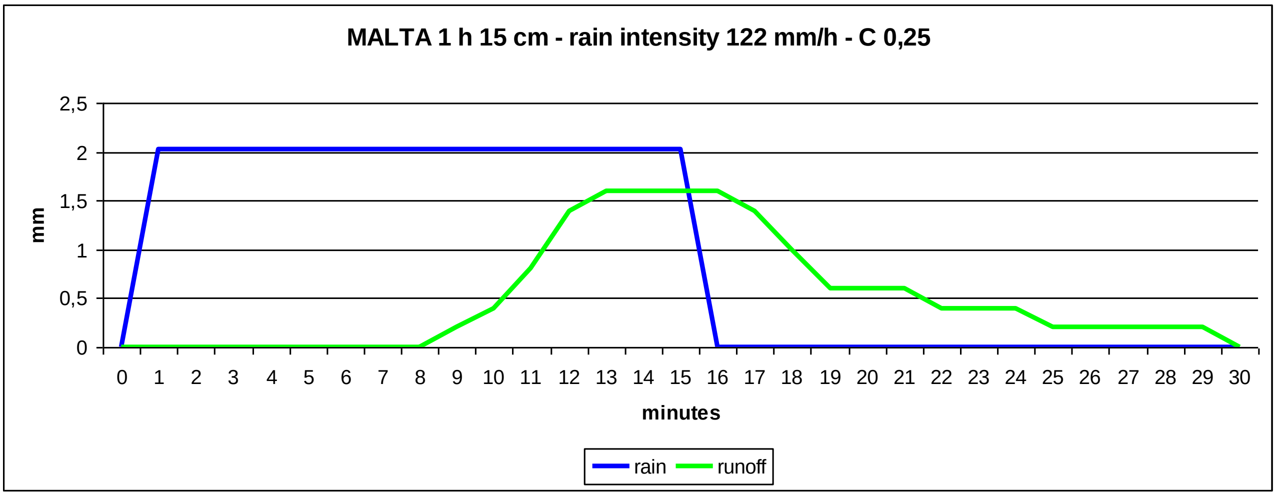


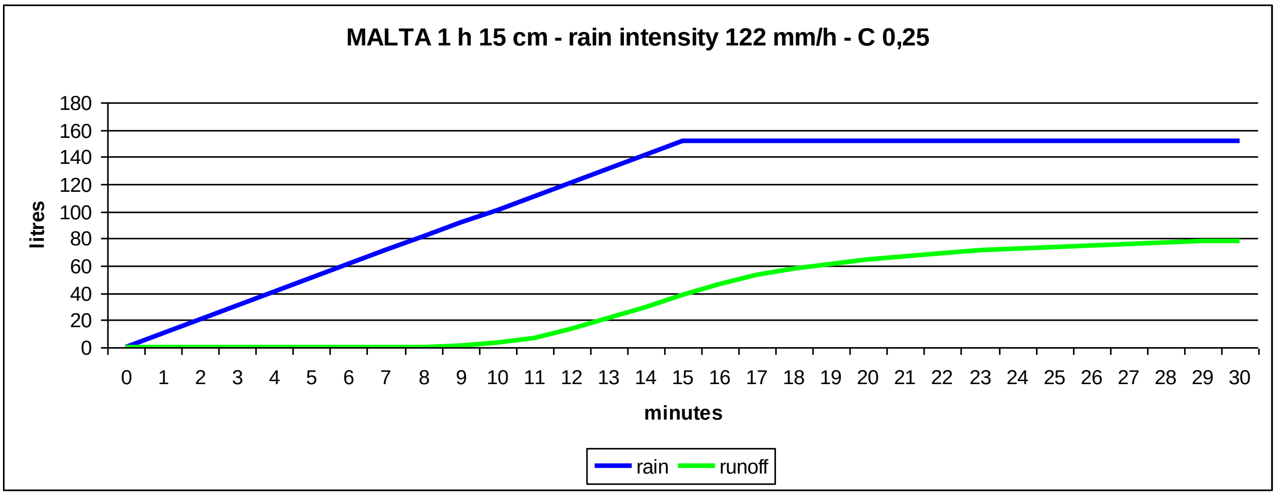
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 1	10	120	0.43



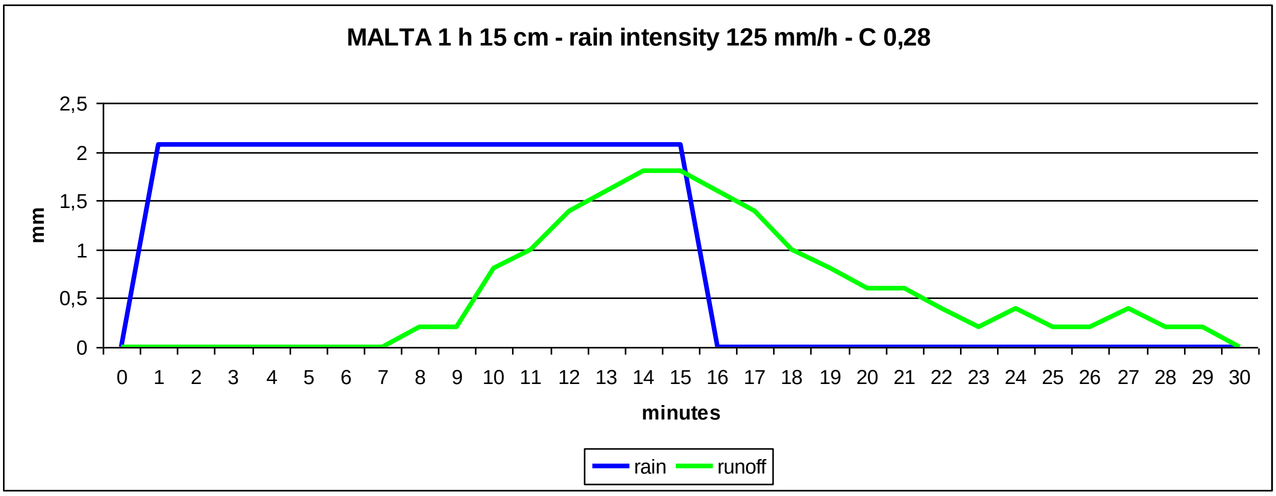


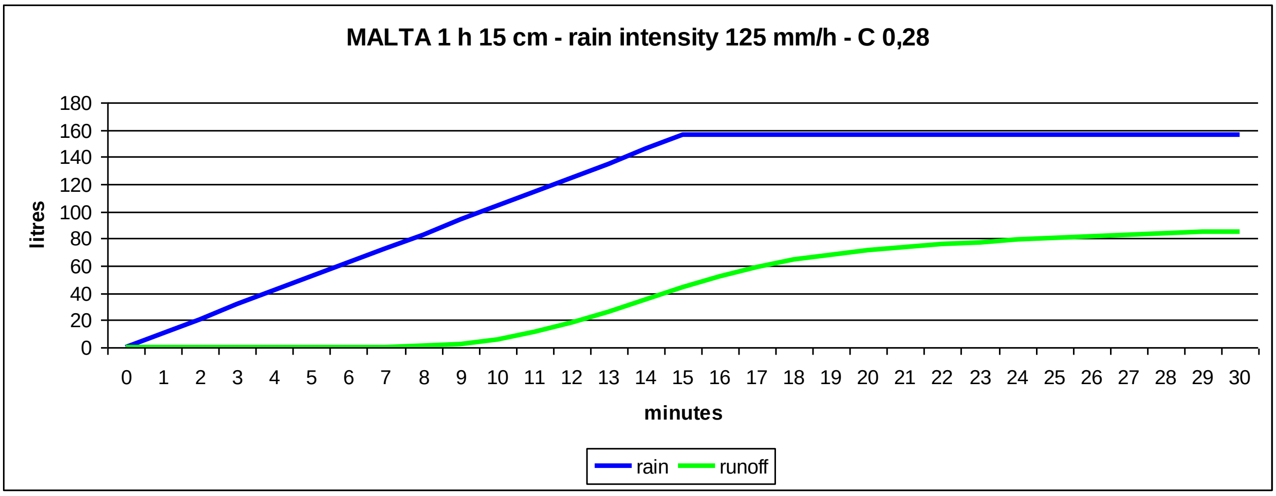
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 1	15	120	0.29



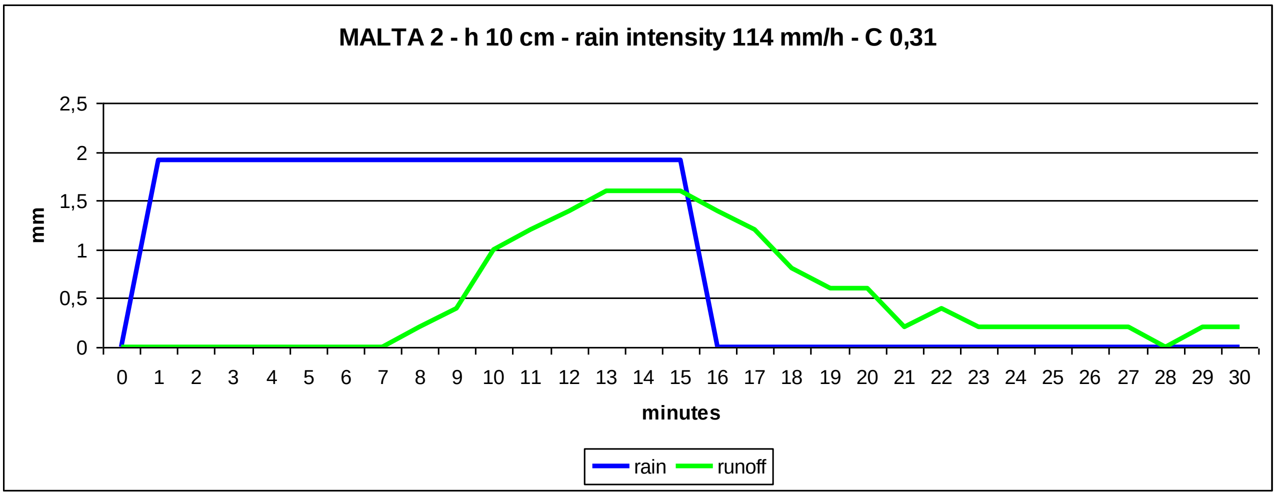


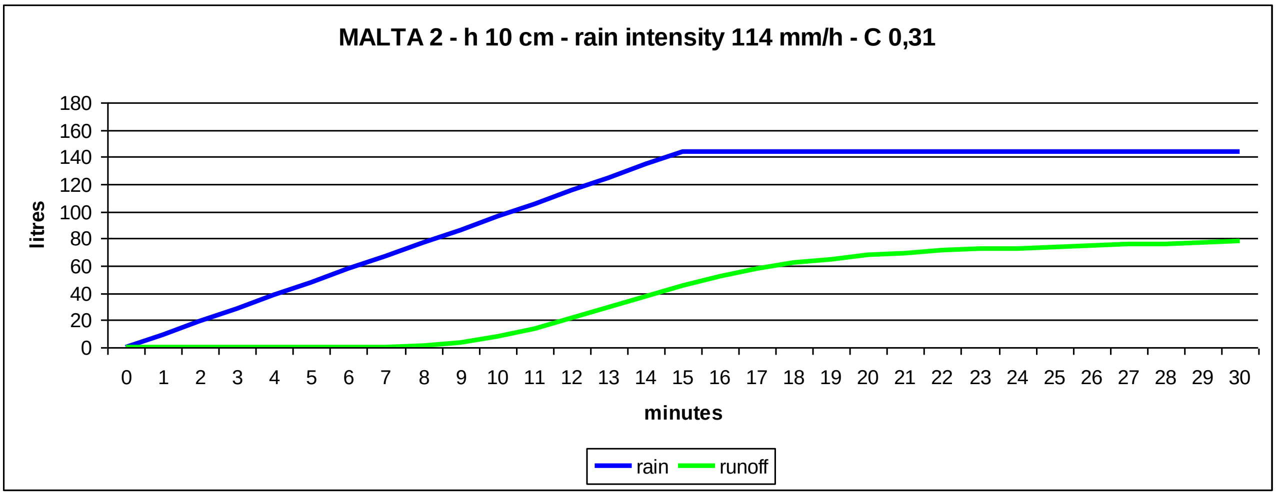
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 1	15	122	0.25



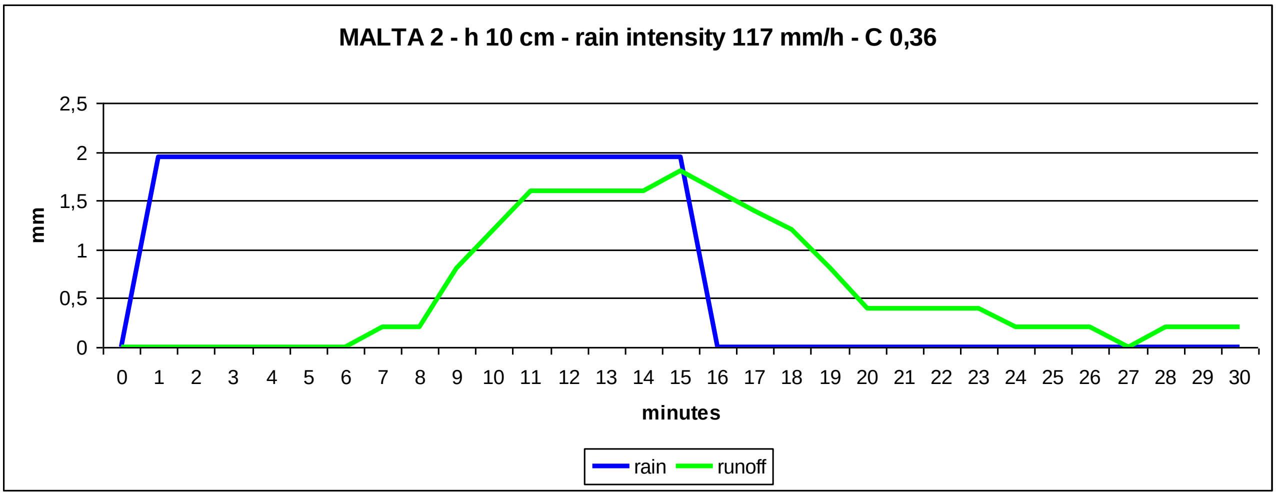


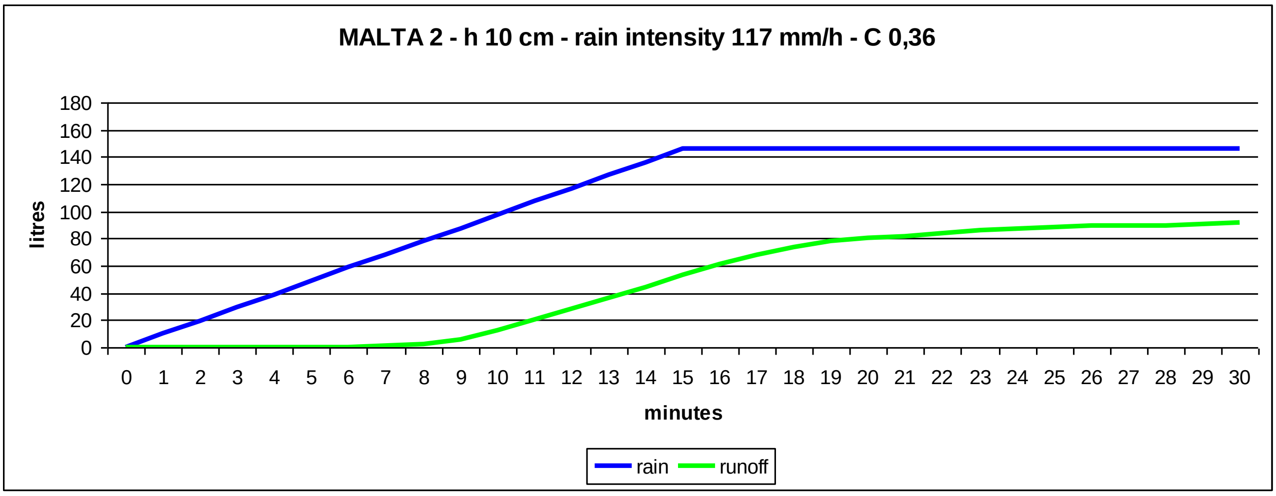
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 1	15	125	0.28



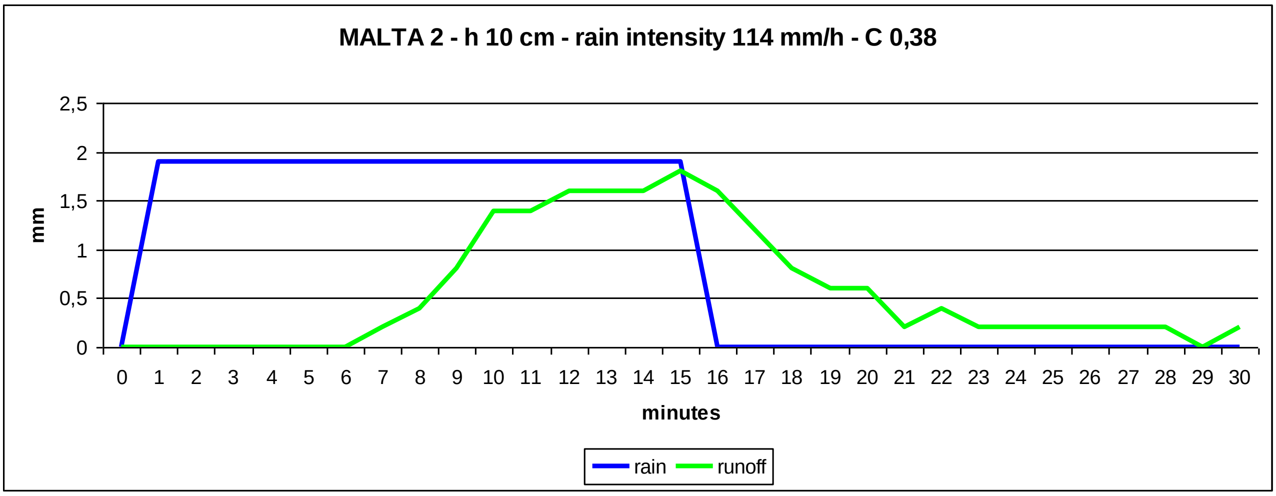


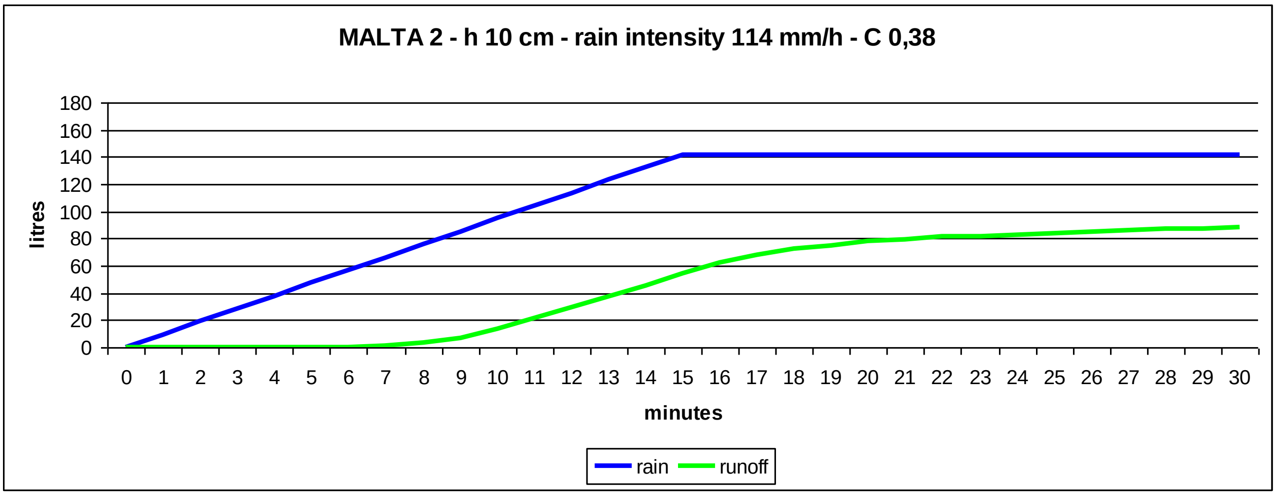
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	10	114	0.31



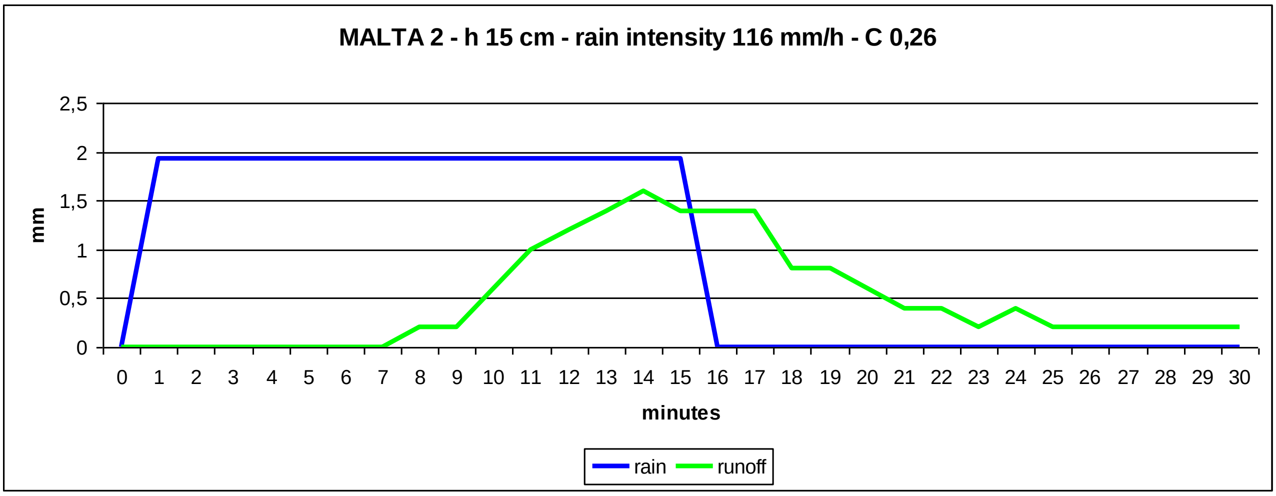


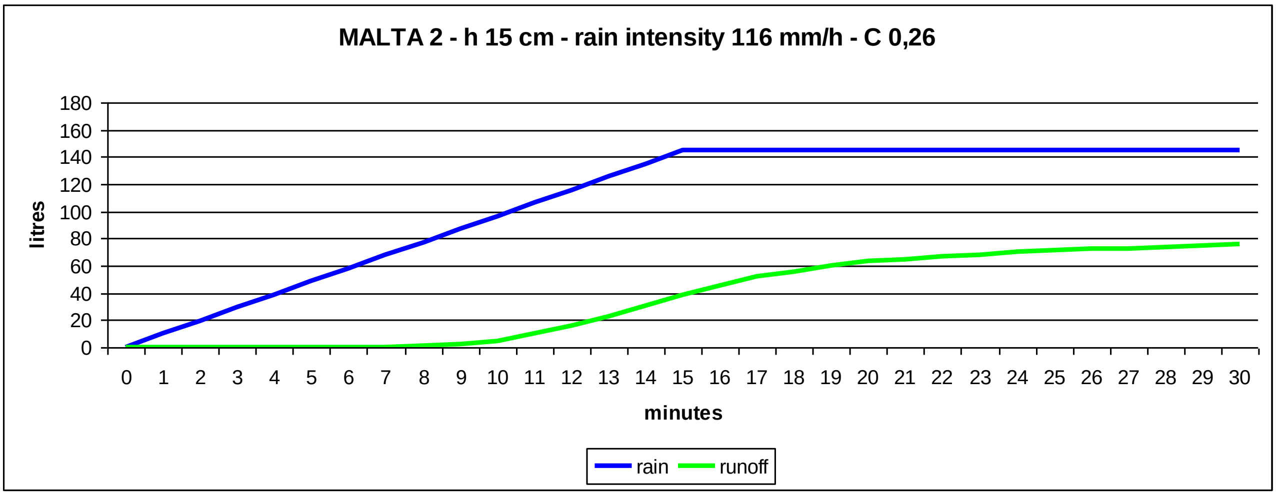
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	10	117	0.36



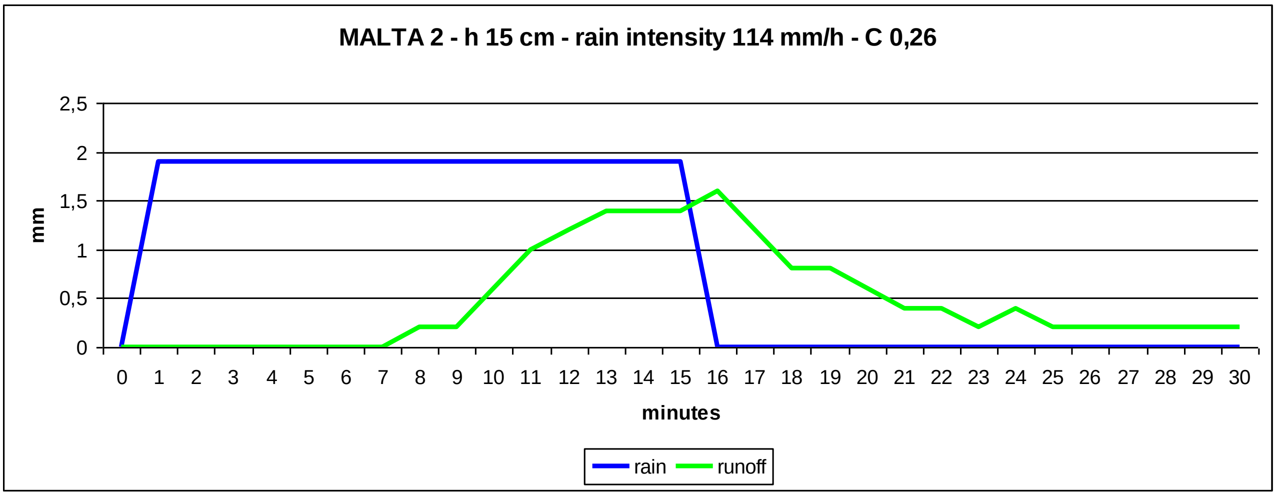


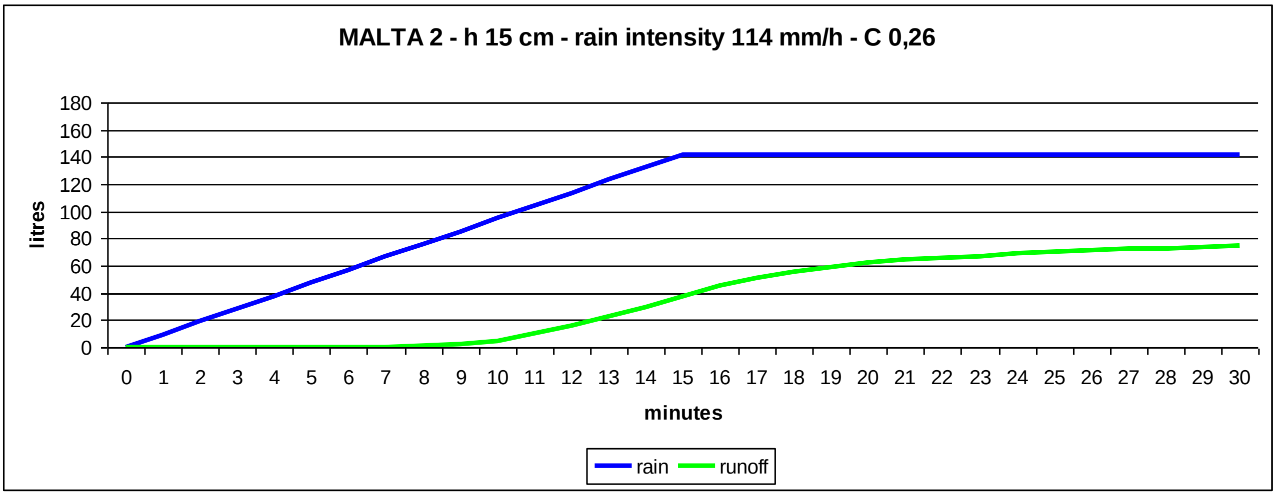
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	10	114	0.38



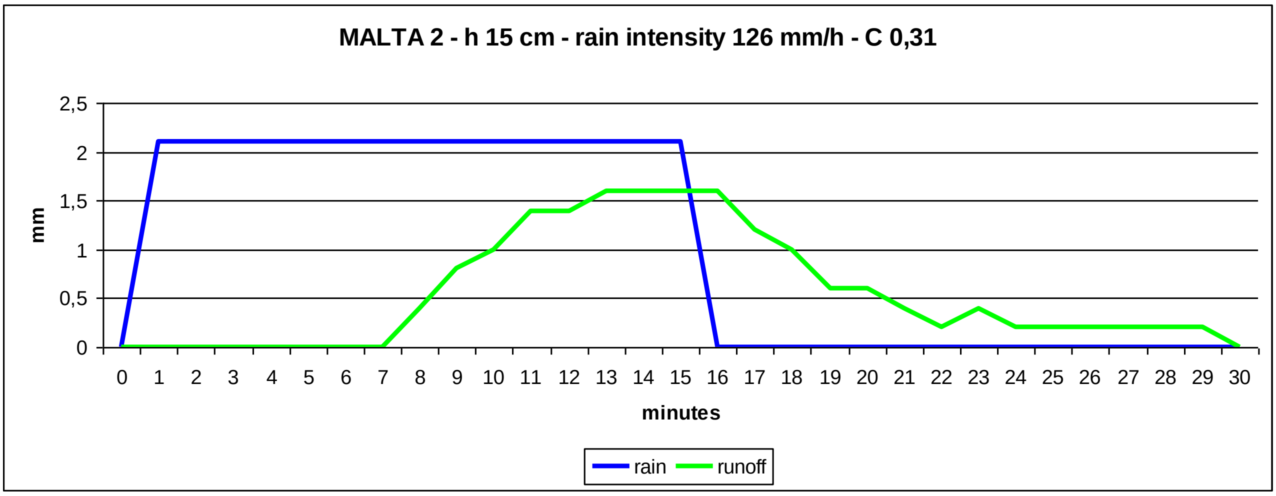


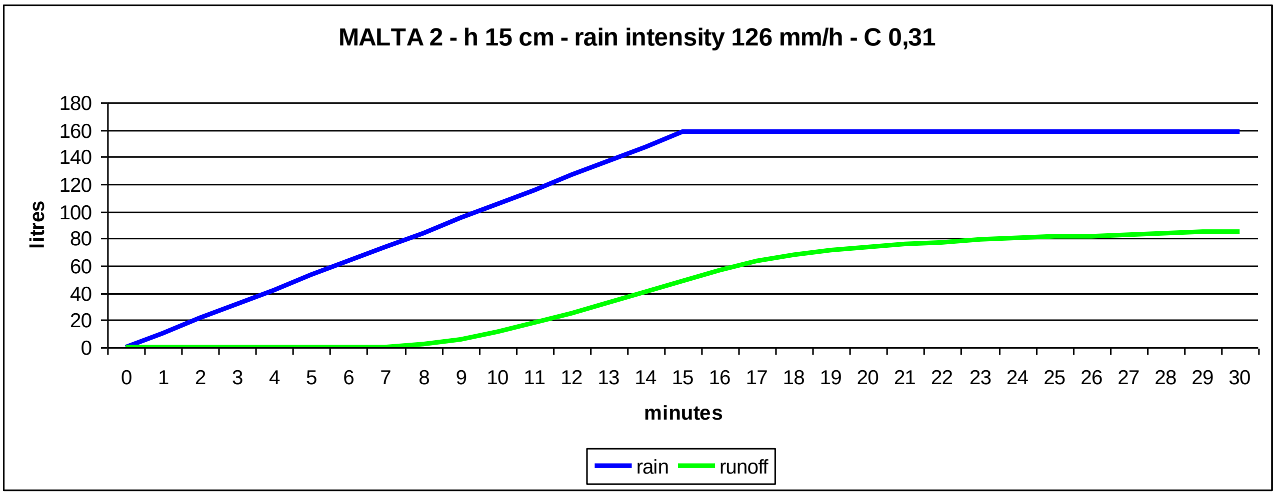
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	15	116	0.26



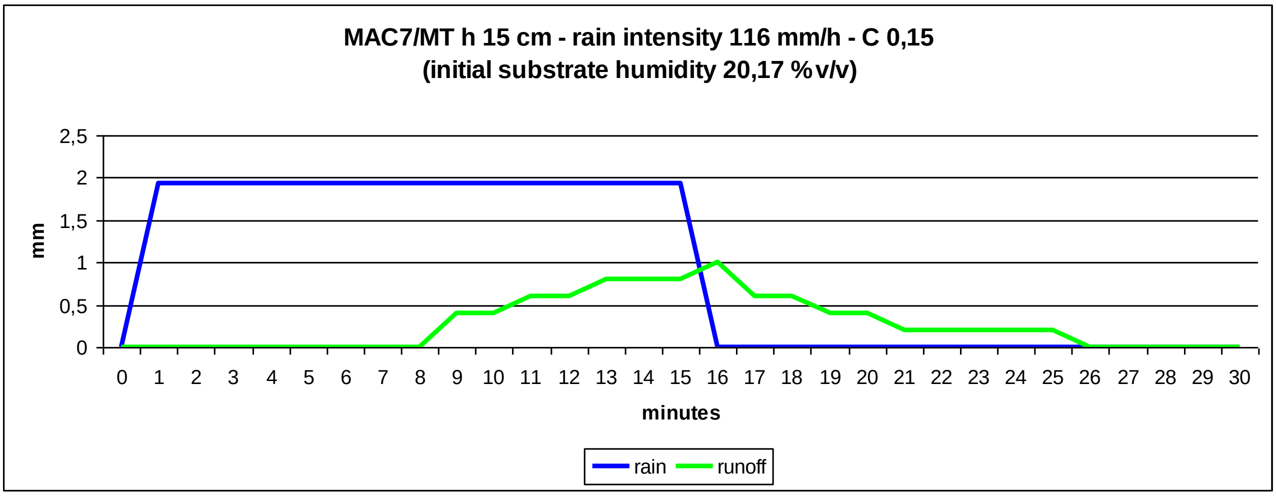


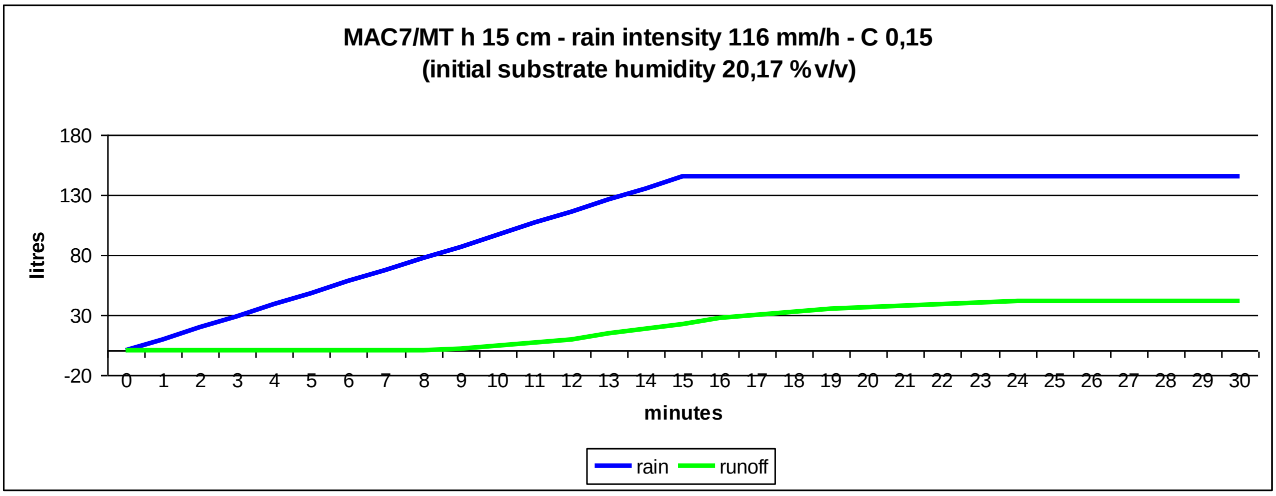
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	15	114	0.26



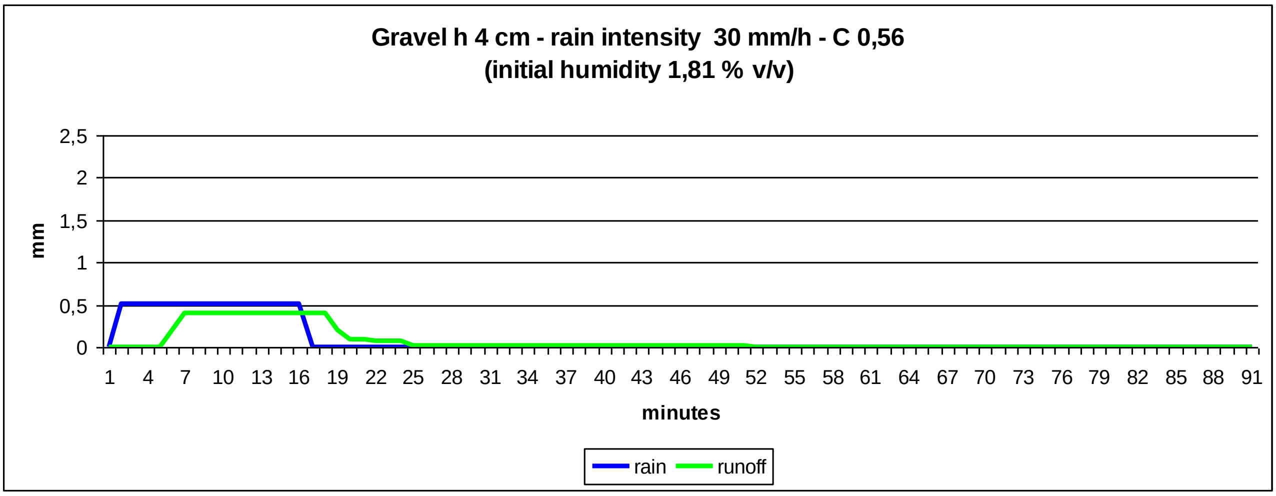


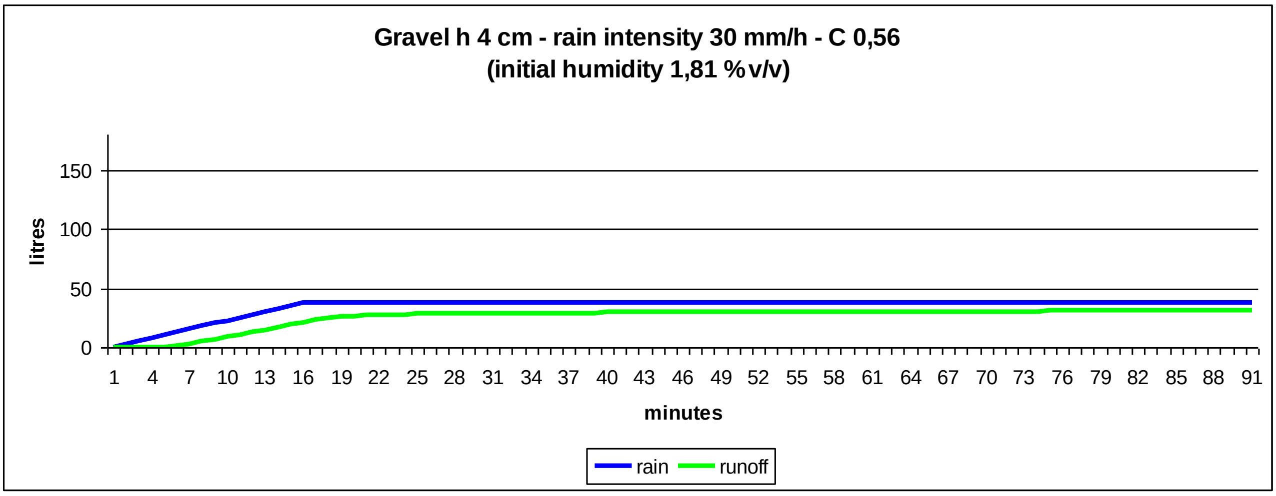
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MALTA 2	15	126	0.31



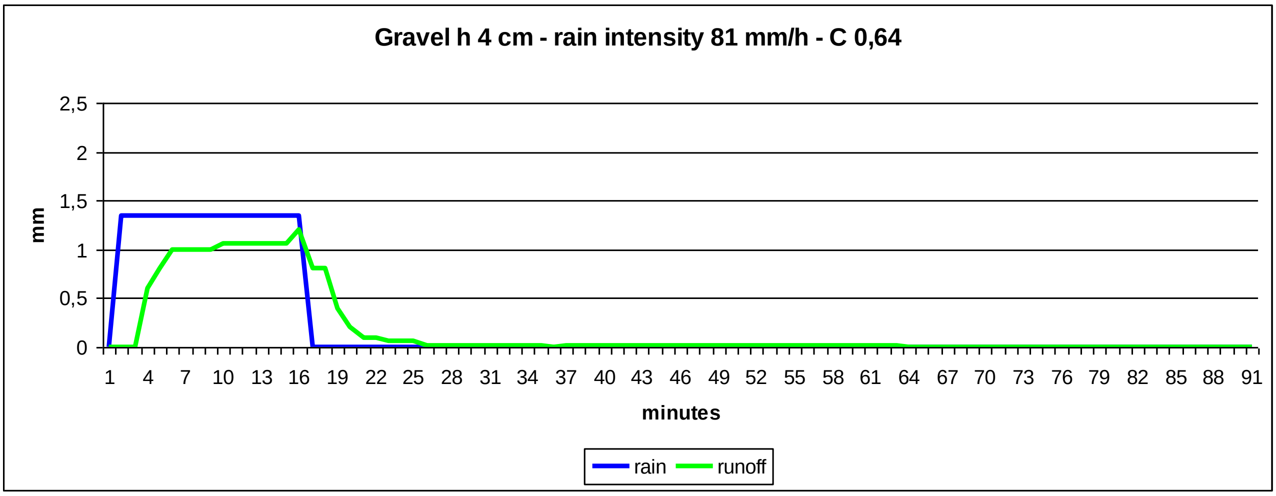


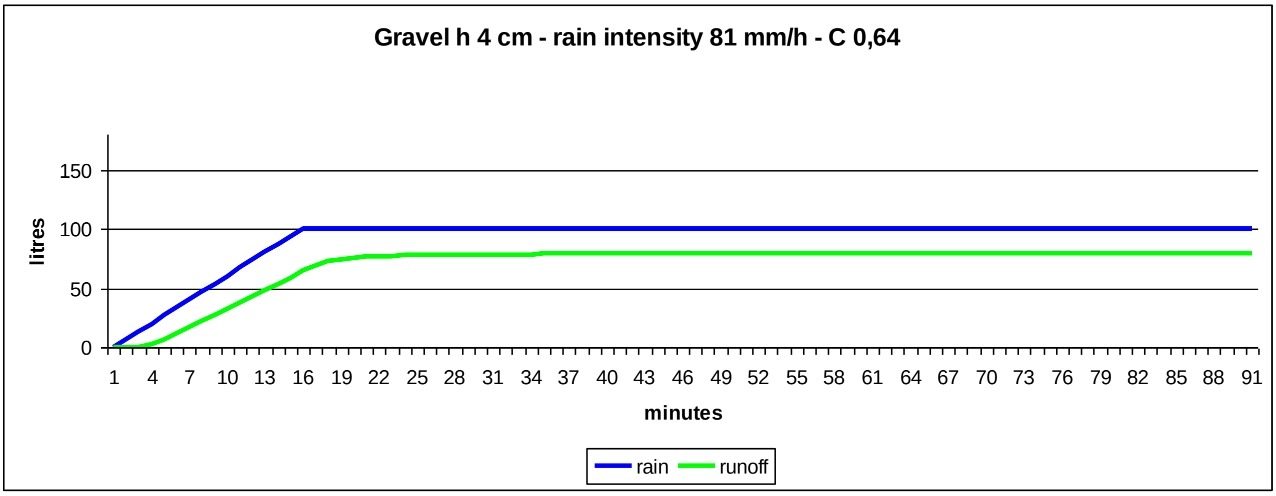
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	15	116	0.15



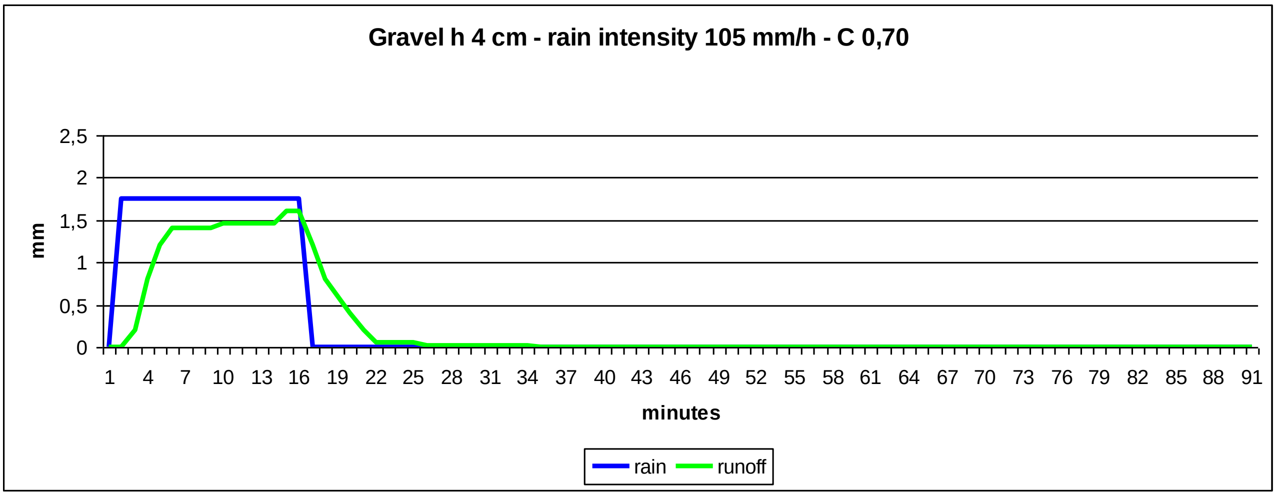


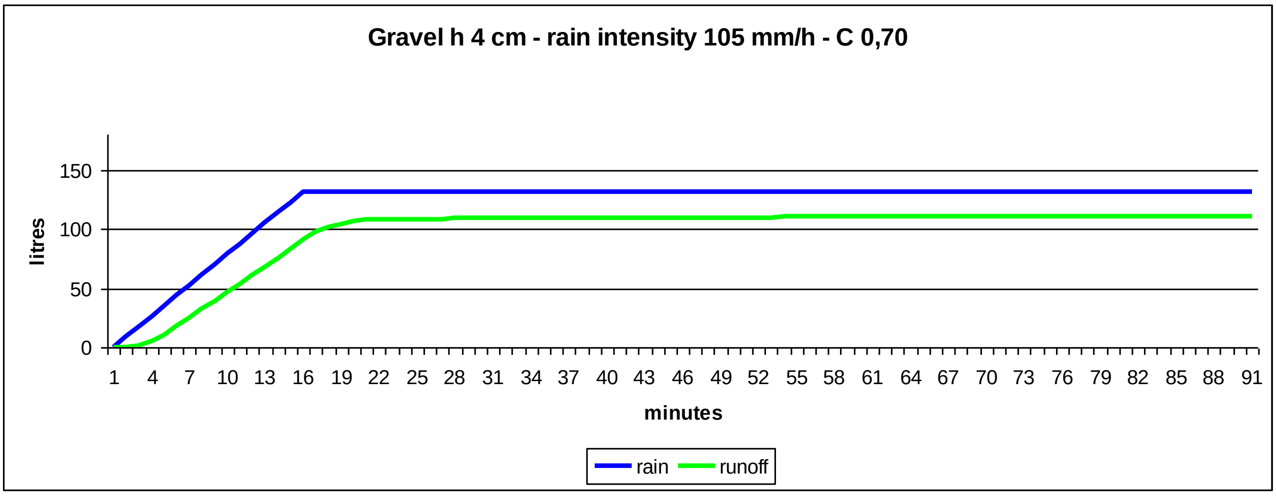
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
Gravel	4	30	0.56



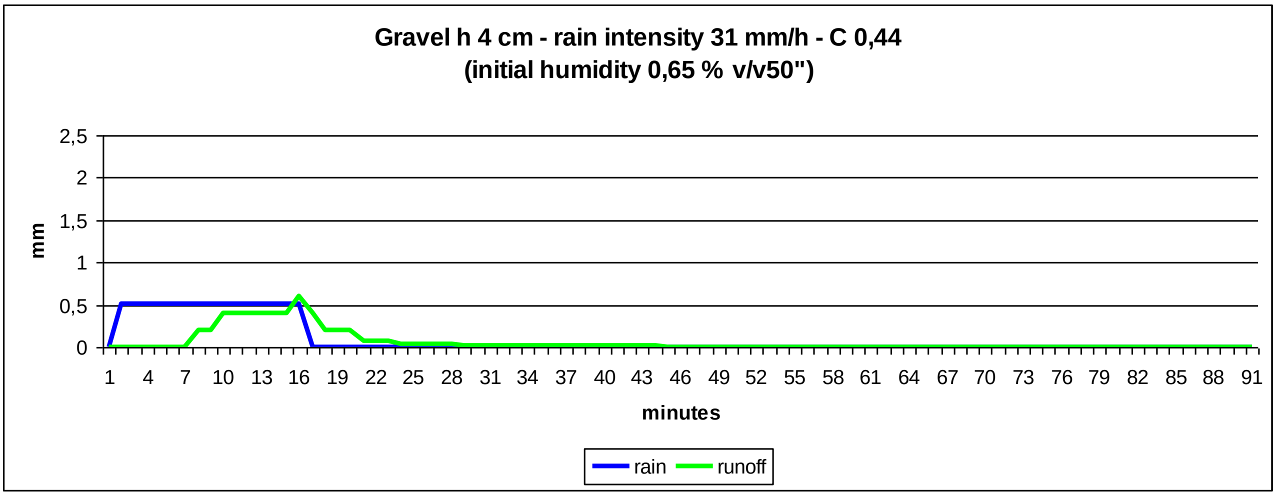


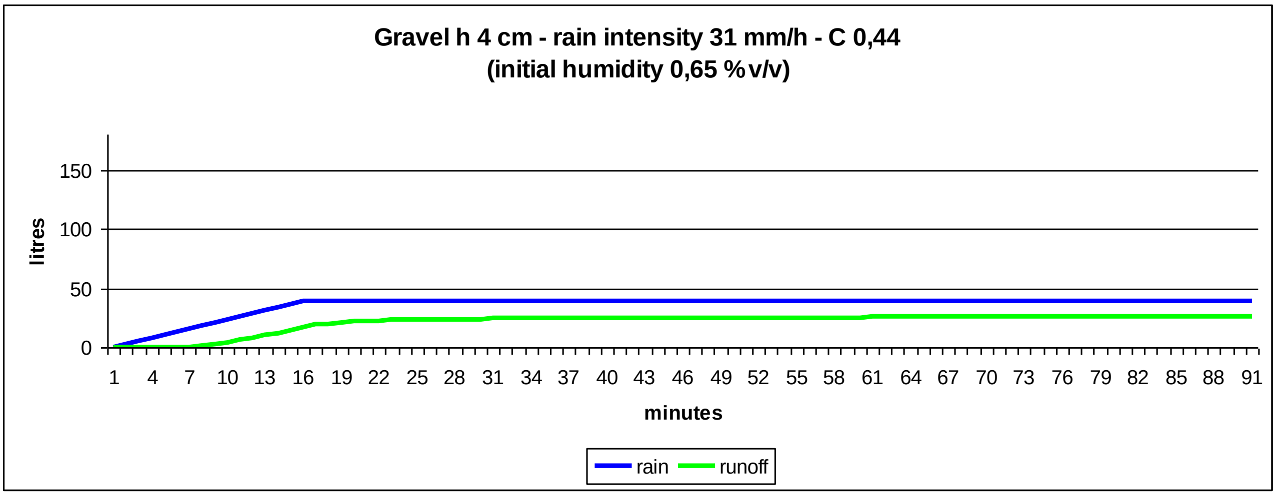
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
Gravel	4	81	0. 46



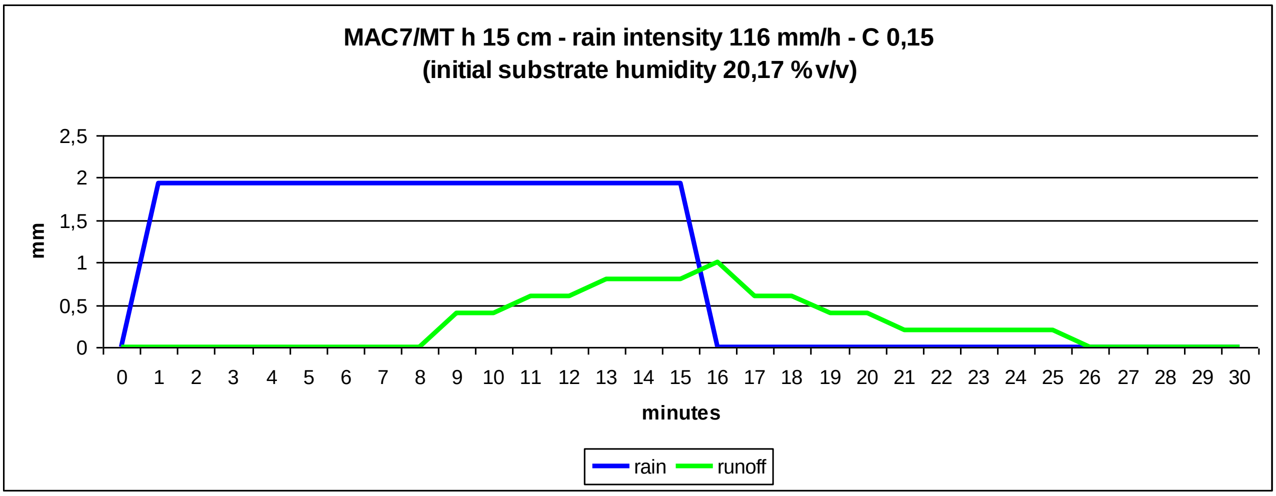


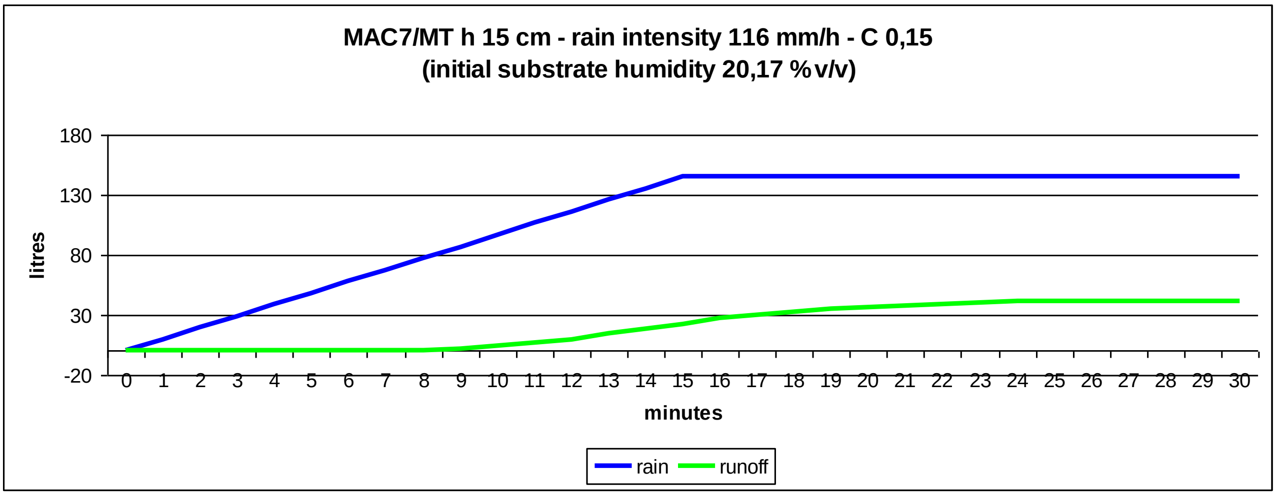
Substrate type	**Substrate depth-cm**	**Rain intensity-mm/h**	**Coefficient**
Gravel	4	105	0.70



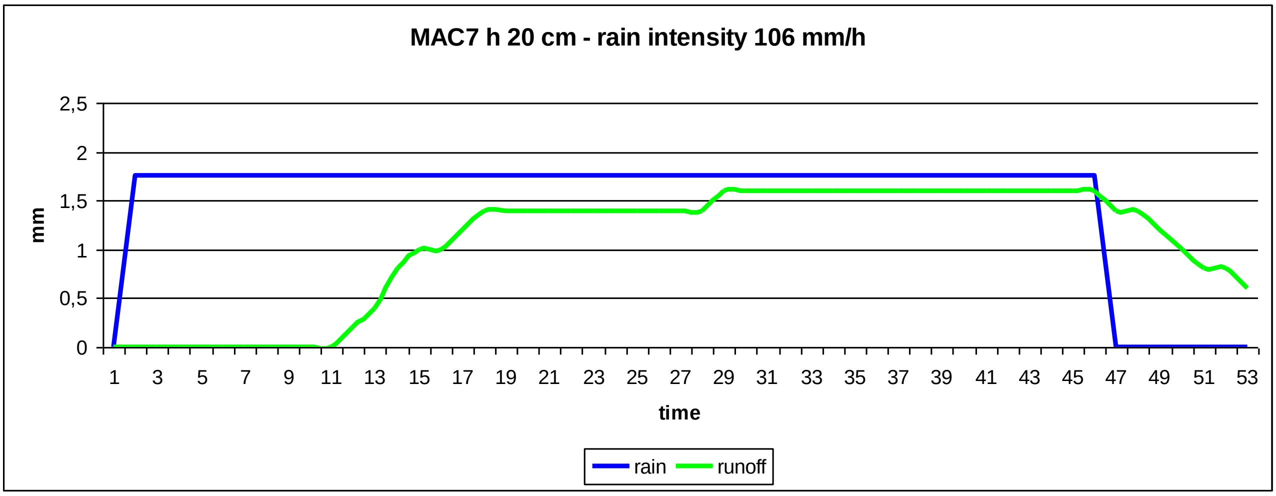


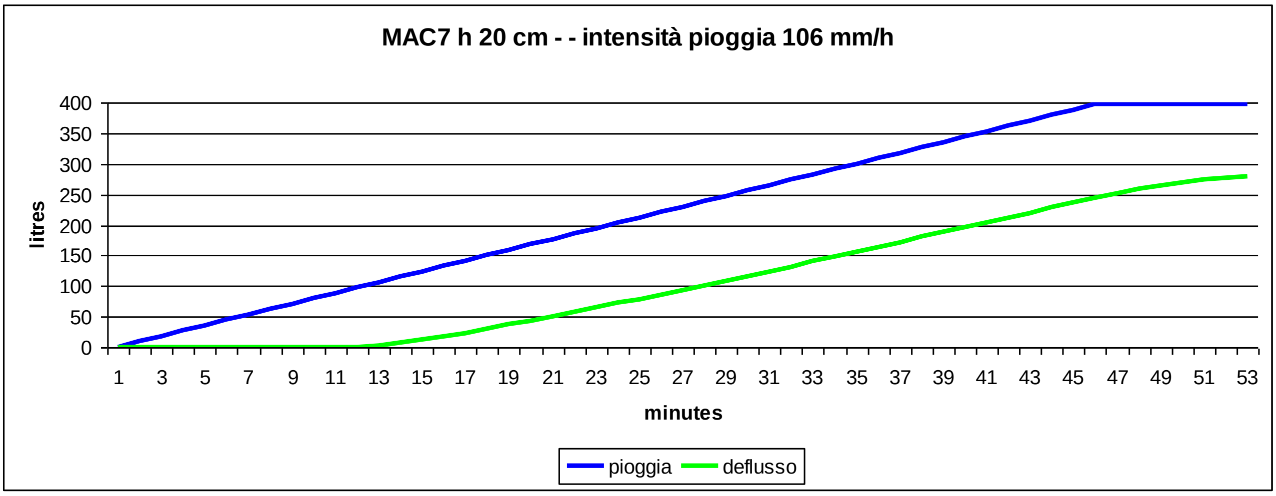
Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
Gravel	4	31	0.44





Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7/MT	15	116	0.15





Substrate type	Substrate depth-cm	Rain intensity-mm/h	Coefficient
MAC7	20	106	

References

Berndtsson , C., 2010. Green roof performance towards management of run-off water quantity and qualtiy: A Review. *Ecological engineering,* 36(4), pp. 351-360.

Burszta-Adamiak, E., 2012. Analysis of stormwater retention of green roofs. *Archives of Environmental Protection,* 38(4), pp. 3-13.

Galdies, C., 2011. *The Climate of Malta: statistics, trends and analysis 1951-2010,* Valletta: NSO.

IchiharaJeffrey, K. & Cohen, P., 2011. New York City property values: what is the impact of green roofs on rental pricing?. *Letters in Spatial and Resource Sciences,* 4(1), p. 21–30.

Jim, C., 2014. Building thermal-insulation effect on ambient and indoor thermal. *Ecological Engineering,* Volume 69, p. 265–275.

MIA, 2016. *Last winter, driest winter on record.* [Online]
Available at: https://www.maltairport.com/last-winter-driest-winter-record/
[Accessed 21 06 2017].

Renterghem, T. V. & Botteldooren, D., 2014. Influence of rainfall on the noise shielding by a green roof. *Building and Environment,* Volume 82, pp. 1-8.

Rowe DB, G. G. D. A., 2012. Effects of green roof media depth on Crassulacean plant succession over seven years. *Landsc Urban Plan ,* Volume 104, p. 310–319.

Rowe, D. B., 2011. Green roofs as a means of pollution abatement. *Environmental Pollution,* Volume 159, pp. 2100 - 2110.

Stovin, V., Vesuviano, G. & Kasmin, H., 2012. The hydrological performance of a green roof test bed under UK climatic conditions. *Journal of Hydrology,* 82(-), pp. 148-161.

Tolderlund, L., 2010. *Design guidelines and maintenance manual for green roofs in the semi-arid and arid west USA..* [Online]
Available at:
https://www.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf
[Accessed 19 06 2017].

Tomalty, R. & Komorowski, B., 2010. The Monetary value of the soft benefits of green roofs, Montreal. *Smart Cities Research Services.*

Washburn, B. E., Swearingin, R. M., Pullins, C. K. & Rice, M. E., 2016. Composition and Diversity of Avian Communities Using a New Urban Habitat: Green Roofs. *Environmental Management,* Volume 57, p. 1230–1239.

Zhao, M. et al., 2014, . Effects of plant and substrate selection on thermal performance of green roofs during the summer. *Building and Environment,* Volume 78, pp. 199-211.

Bibliography

Beck, A. et Al., 2011. Amending greenroof soil with biochar to affect run-off water quantity and quality. Environmental Pollution 159, 2111-2118

Berndtsson , C., 2010. Green roof performance towards management of run-off water quantity and qualtiy: A Review. *Ecological engineering,* 36(4), pp. 351-360.

Brunetti, A. et al, 2006, International Journal of Climatology.

Burszta-Adamiak, E., 2012. Analysis of stormwater retention of green roofs. *Archives of Environmental Protection,* 38(4), pp. 3-13.

Farreny, R. et Al, 2011. Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. Water research 45, 3245-3254

Fondazione Lombardia per l'ambiente, 2008. Progetto Kyoto Lombardia

Galdies, C., 2011. *The Climate of Malta: statistics, trends and analysis 1951-2010,* Valletta: NSO.

Giacomello, E., 2012. Copertura a verde e risorsa idrica. Ricerche di tecnologia dell'architettura. Franco Angeli Editore

IchiharaJeffrey, K. & Cohen, P., 2011. New York City property values: what is the impact of green roofs on rental pricing?. *Letters in Spatial and Resource Sciences,* 4(1), p. 21–30.

ISPRA , 2015. Gli indictaori del Clima in Italia 2014. Stato dell'Ambiente 57/2015

ISPRA , 2016. Gli indictaori del Clima in Italia 2015. Stato dell'Ambiente 65/2016

ISPRA , 2017. Gli indictaori del Clima in Italia 2016. Stato dell'Ambiente 72/2017

Jim, C., 2014. Building thermal-insulation effect on ambient and indoor thermal. *Ecological Engineering,* Volume 69, p. 265–275.

Klein Tank, A.M.G. and Coauthors, 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int. J. of Climatology, 22, 1441-1453

MIA, 2016. *Last winter, driest winter on record.* [Online]
Available at: https://www.maltairport.com/last-winter-driest-winter-record/
[Accessed 21 06 2017].

Renterghem, T. V. & Botteldooren, D., 2014. Influence of rainfall on the noise shielding by a green roof. *Building and Environment,* Volume 82, pp. 1-8.

Rowe DB, G. G. D. A., 2012. Effects of green roof media depth on Crassulacean plant succession over seven years. *Landsc Urban Plan ,* Volume 104, p. 310–319.

Rowe, D. B., 2011. Green roofs as a means of pollution abatement. *Environmental Pollution,* Volume 159, pp. 2100 - 2110.

Stovin, V. et Al, 2015. Defining green roof detention performance. Urban water Journal 14:6574-588

Stovin, V., Vesuviano, G. & Kasmin, H., 2012. The hydrological performance of a green roof test bed under UK climatic conditions. *Journal of Hydrology,* 82(-), pp. 148-161.

Tolderlund, L., 2010. *Design guidelines and maintenance manual for green roofs in the semi-arid and arid west USA..* [Online]

Available at:
https://www.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf
[Accessed 19 06 2017].

Tomalty, R. & Komorowski, B., 2010. The Monetary value of the soft benefits of green roofs, Montreal. *Smart Cities Research Services.*

Washburn, B. E., Swearingin, R. M., Pullins, C. K. & Rice, M. E., 2016. Composition and Diversity of Avian Communities Using a New Urban Habitat: Green Roofs. *Environmental Management,* Volume 57, p. 1230–1239.

Zhao, M. et al., 2014, . Effects of plant and substrate selection on thermal performance of green roofs during the summer. *Building and Environment,* Volume 78, pp. 199-211.