WMO/CIMO Lead Centre “B. Castelli”
on Precipitation Intensity

Italian Met Service – Univ. of Genoa

ASSESSMENT OF SIMPLE FARMER RAIN GAUGES USED IN THE WMO METAGRI OPS PROJECT

FINAL REPORT

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The scientific responsible of the Lead Centre
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1 - Information and motivation

The WMO Secretariat recently advised of the need for revision of the technical specifications for the ‘farmer’s rain gauge’ used in the METAGRI OPS project to make it more suitable for the purpose, and for the provision of technical specifications for a rain gauge with enhanced capacity, to be used in the Gulf of Guinea area or in similar regions. On October, 20th 2014, the President of CIMO (the WMO Commission for Instruments and Methods of Observations) formulated a proposal of cooperation between the METAGRI OPS representatives and staff of the WMO Secretariat (Agro-meteorology Division of the WMO Climate and Water Department, Dr Robert Stefanski and Dr José Camacho) and the WMO/CIMO Lead Centre “B. Castelli” on Precipitation Intensity.

In the collaboration proposal, the CIMO President referred to improving the actual design of simple plastic rain gauges for farmers, as used in the METAGRI project, proposing that the Lead Centre would address the quality assessment of the rain gauges, refinement of their technical specifications and the development of standardized procedures for their deployment and use.

In perspective, the design of a specific rain gauge with enhanced capacity and improved performance is also necessary; therefore, a revision of the technical specifications of this farmer’s rain gauge has been requested. The new technical specifications will be provided at a later stage to the instrument producers in order to incorporate a more reliable and efficient tool into future actions. These technical specifications would be also valid for other agricultural projects in Africa or other regions of the world. The new simple rain gauges are intended to serve mainly as tools for the management of food production at the single farmer’s level, but, once minimal requirements for rainfall observations are defined and operational, the rainfall data collected by the single farmers through these rain gauges could contribute to the enhancement of NMHSs databases.

This would respond directly to the call from the 65th Session of the WMO Executive Council that encouraged a coordinated effort to support farmers in the use of simple rain gauges to improve the networks of rainfall observations in areas where there are gaps. It would be a contribution to the objectives of the WMO Integrated Global Observing System (**WIGOS**) and the Global Framework for Climate Services (**GFCS**).

The CIMO President also recalled that the sixteenth session of the Commission for Instruments and Methods of Observations (**CIMO-16**, 10 – 16 July 2014, St. Petersburg, Russian Federation) agreed to collaborate on the development of practices for use of simple rain gauges in national volunteer observation networks to support agro-meteorological applications. He invited the CIMO Lead Centre to cooperate with the involved NMHSs in the evaluation of the rain gauges by technical consultations, laboratory tests and field intercomparisons. The matters are closely related to the area of expertise of the WMO CIMO Italian Lead Centre, which, according to its Terms of Reference, should be instrumental in CIMO efforts to bridge gaps between countries by assisting CIMO in conducting training and capacity building.

In this context, a new cooperation started at a meeting in Vigna di Valle, Italy, 11 - 12 February 2015, between the CIMO Lead Centre and METAGRI OPS consisting in, but not necessarily limited to, performing the technical evaluation of the simple rain gauges in the laboratory and in the field. It also includes providing guidance on how to conduct intercomparisons and how to carry out the data analysis, advise on possible improvements (material, design, etc.) to rain gauges and possible alternative rain gauges suitable for the project and related applications, and to develop best practices for the installation, use and maintenance (if required) of such simple rain gauges.

The work performed at the Lead Centre consisted in a preliminary laboratory assessment of instrument accuracy, held in 2015 at the rain gauge laboratory of the University of Genoa (I), for a set of gauges provided by the METAGRI OPS. Following the laboratory tests, an intercomparison campaign was held using the same gauges at the field test site of the Lead Centre in Vigna di Valle (Rome, I). This final report aims to describe the activities performed during the cooperation and to synthesise the results achieved. It also provides guidance material for improving the measurement accuracy and fostering standardization.

2 - Background information

2.1 Overview of the METAGRI project

The METAGRI project was developed under the framework of the Western Africa Conference of Directors of National Meteorological and Hydro-meteorological Services (WADC) with the funding support of the State Agency for Meteorology in Spain (AEMET), the Norwegian Government and other donors. In response to a need expressed by WADC at their meeting in Las Palmas from 17 to 19 October 2007, the Kingdom of Spain and AEMET, acting through the World Meteorological Organization (WMO), funded climate-related seminars (i.e. Roving Seminars) for weather, climate and farmers in West Africa. The project started in 2008 and was initially operated in 14 Western African Countries which participated in three-phases seminars (METAGRI I, II and III): Burkina Faso, Niger, Mali, Mauritania and Senegal for the I phase; Benin, Cape Verde, The Gambia, Guinea, Guinea-Bissau and Togo for the II phase and Côte d’Ivoire, Ghana and Nigeria for the phase III.

The METAGRI project was developed with the aim to increase the interaction between the NMHSs and rural farmers while at the same time providing assistance at the local level by distributing rain gauges among the farmers participating in the seminars. The project was developed with a view to empowering the farmers with agro-climate information to better manage meteorological and climate-related risks for sustainable agricultural production. Farmers taking management decisions using agro - meteorological information have enjoyed significant gains in yields and income. For instance, studies showed that the effective use of this information has increased crop yields by 20% to 325% for most crops compared to “non-agromet” farms who did not receive the information.

The National Meteorological Service of Mali developed the concept of roving seminars on weather and climate with farmers in West Africa 25 years ago, and the METAGRI project also aimed to spread this experience from Mali to other West African countries. Over the four year period from 2008 to 2011, more than 7000 people participated in the seminars of which almost 80% were rural farmers and the rest were from meteorological services, agricultural extension agencies and other national technical institutions. Almost a thousand women – who are often the backbone of the farming community – were trained to better use weather and climate information. Over 7100 simple plastic rain gauges have been distributed to rural farmers by NMHSs in the region since 2008.

After an extensive review of these activities at a meeting held in Bamako, Mali, 26 – 30 September 2011, the METAGRI-OPERATIONAL (METAGRI OPS) project was introduced to improve the performance of the Roving Seminars as requested by the Conference of Directors of Western Africa NMHS. New components as training, development of communications skills, feedback and evaluation tools and institutional strengthening were introduces. The new project started in 2012 and three new countries were included into the project activities from 2012. These were Liberia, Sierra Leone and Chad, bringing the number of countries involved in the project to 17. The Ministry of Foreign Affairs of the Norwegian Government provided funding for the project, but there were also a substantial contributions from the Government of Greece and minor contributions from AEMET and WMO regular budget.

METAGRI OPS consisted of four components. The first component focused on development of operational improvements on the Roving Seminars such as review of the performance of the plastic rain gauge, analysis of weather and climate risks related with agriculture, integration of traditional knowledge and production of basic manual on Roving Seminars. The second component directly targeted capacity building within NMHSs to improve their skills in crop modeling, use of remote sensing data and products and GIS tools. The third component aimed at facilitating interactions among NMHS, final users and institutional users/partners. In this regard, collaborations between NMHSs and the media at national, regional and local level are encouraged, including development of a communications strategy for effective dissemination of agro-meteorological products. The fourth component was related with development of feedback information process and the evaluation of the overall METAGRI OPS scheme through assessment of impacts and users' satisfaction.

METAGRI OPS was concluded in 2015, during the Final Technical Workshop that took place from 23 to 25 November in Abidjan, Côte d'Ivoire where a detailed review of activities performed in the project was provided. The outcome of this workshop was a draft follow-up project proposal that would be refined and finalized after the workshop to be sent for discussion and approval to the next Conference of Directors of Western African NMHSs.

2.1 The WMO/CIMO Lead Centre on Precipitation Intensity

CIMO-XV agreed with the proposal to establish CIMO Testbeds and Lead Centres to promote collaboration between CIMO and relevant NMHSs in testing, development and standardization of meteorological instruments and systems performance for the benefit of all WMO Members. They would utilize and build on both existing state-of-the-art facilities and specific expertise available at NMHSs for the provision of guidance to all WMO Members, while providing recognition by CIMO of state-of-the-art facilities and expertise available in the designated Testbeds and Lead Centres. Also, their significant contribution towards developing guidance for WMO Members, and their impact on the WMO observing systems, was recognised.

The Lead Centre "Benedetto Castelli" on Precipitation Intensity (www.precipitation-intensity.it) was designated by the WMO/CIMO in September 2010 with the aim of providing specific guidance about instrument calibration and their achievable accuracy, performing laboratory and field tests and developing research/technical activities about the measurement of precipitation intensity and the related data analysis and interpretation.

The Lead Centre is a joint initiative of the Italian (Air Force) Meteorological Service and the University of Genova (Italy), and operates in three different sites: the Field Test site in Vigna di Valle (Rome – I), the Precipitation Laboratory at the University of Genova (Genoa – I), the Mountain site at the top of Mt. Cimone (Modena– I).

The CIMO LC-PrIn maintains the capability to perform dynamic calibration, metrological confirmation and intercomparison of rain intensity gauges in the laboratory, with suitable equipment for laboratory calibration, the traceability of its measurement standards and measuring instruments, therefore providing support for certification of the instruments' performance as a suitable Independent Third Party Organisation. It also maintains a set of gauges acting as a working reference for field measurements of rainfall/snow intensity.

The CIMO LC-PrIn conducts research on suitable equipment and procedures for routine field testing of network precipitation gauges, which would be recommended for the standardization of field calibrations of precipitation gauges during operational use. It develops suitable devices and technical procedures to improve the testing capabilities following the results of the WMO Field Intercomparison of RI gauges, the interpretation of the influence of measurement errors on meteo-hydrological applications and correction procedure for historic data series, as well as post-processing techniques for automatic correction of the measured rain intensity. To this aim, it has the necessary testbed and equipped facility to perform regular field measurement campaigns or international/regional comparisons with the purpose to test the performance of different measuring principles for rainfall intensity (RI) and the effects of laboratory calibrations mentioned above on the measured intensities.

The CIMO LC-PrIn collaborates and cooperate with relevant CIMO Expert Teams in developing guidance material WMO regional instrument centres (RICs) and other international testbeds for the organization and participation in field tests for specific purposes or in international/regional intercomparisons. It also proposes standards on precipitation intensity measurements for consideration in WMO and ISO technical committees, reports on all significant tests to the CIMO community, through publication of IOM reports and publications in scientific journals, technical support and vocational training and periodic training courses on general and specific issues related to liquid/solid rainfall intensity measurements.

3 - Instruments under test

The experimental activity carried out by the WMO-CIMO Lead Centre “B.Castelli” on Precipitation Intensity (LC) has been focused on four manual rain gauge models. The following list provides the gauges specifications and a general comment.

3.1 Model 1 - San Isidro (Argentina)

The instrument characteristics have been determined by considering the specifications provided by the manufacturer and measurements made in our laboratory.

• Collector area: 100 cm^2 • Measuring rage: 0-136 mm • Sensitivity: 1 mm between 0 and 20 mm and 2 mm between 20 and 136 mm.	 Fig 3.1: The San Isidro rain gauge in the LC laboratory

3.2 Model 2 – Stratus (US)

The manufacturer has provided the following instrument specifications.

• Collector area: 101.16 cm^2 (4”^{2}) • Measuring rage: 0-254 mm • Sensitivity: 0-2 mm between 0 and 25.4 mm and 2 mm between 25.4 and 254 mm.	 Fig3.2: The Stratus rain gauge in the LC laboratory

3.3 Model 3 – 100cm2 (MALI)

The instrument characteristics have been determined experimentally since they were not available at the time of testing.

- Collector area: 100 cm^2
- Measuring rage: 0-136 mm
- Sensitivity: 1 mm between 0 and 20 mm and 2 mm between 20 and 136 mm.

Fig 3.3: The 100 cm^2 rain gauge in the LC laboratory

3.4 Model 4 – 50 cm2 (EU)

The instrument characteristics have been determined experimentally since they were not available at the time of testing.

- Collector area: 50 cm^2
- Measuring rage: 0-50 mm
- Sensitivity: 1 mm for the whole measuring range

Fig. 3.4: The 50cm^2 rain gauge in the LC laboratory

4 - Laboratory Tests

4.1 Method and procedures

We performed a first assessment of the accuracy of cumulated precipitation measurements as achievable using the simple farmers' rain gauges in the controlled environmental conditions of the Lead Centre Rain Gauge Laboratory. The focus of the tests was to:

- assess the difference between the precipitation amount reported by the graduated scale and the reference precipitation (instrument calibration and assessment of residual errors);
- evaluate the uncertainty associated with the interpretation of the measurement by the operator.

We have been measuring the volume of water evaporated over the test duration in a Pyrex graduated cylinder, in order to account for actual evaporation in the results.

As for the calibration tests, we divided the measurement range into at least 10 sub-intervals and performed a number of statistically independent repetitions of the experiment by changing the operator in charge of reading the graduation marks. A calibration curve was obtained for each instrument by interpolating the measured amount of precipitation (mm) as a function of the reference value with a linear expression and calculating the determination coefficient. An evaluation of the residual error after correction using the calibration curve is also reported below by plotting the relative percentage error as a function of the reference amount of precipitation.

The assessment of the uncertainty associated with the operator role in collimating the water level with respect to the graduation marks was also performed by computing the standardized error (-) of the measurements performed by four different persons for any given precipitation amount.

The analysis of the four rain gauges is corroborated by a comparative verification of the specifications mentioned in the WMO/CIMO Guide to Meteorological Instruments and Methods of Observation (Guide N° 8). The main recommendations used to characterize the four rain gauges under test are summarized as follows (WMO Guide N° 8, section 6.3.1.1) :

1. The rim of the collector should have a sharp edge and should fall away vertically inside, and should be steeply bevelled outside.
2. The area of the orifice should be known to the nearest 0.5 per cent.
3. The collector should be designed to prevent rain from splashing in and out. This can be done by having the vertical wall sufficiently deep and the slope of the funnel sufficiently steep (at least 45 per cent)
4. The construction should be such as to minimize wetting errors
5. The container should have a narrow entrance and be sufficiently protected from radiation to minimize the loss of water by evaporation
6. The measuring cylinder should be clearly marked to show the size or the type of gauge with which it is to be used.
7. The diameter should be less than 33 per cent of the rim of the gauge
8. The graduations should be finely engraved
9. The graduations should be marks at 0,2 mm intervals
10. The graduations should be clearly figured lines at each whole millimeter
11. To measure small precipitation amounts with adequate precision

4.2 Results

4.2.1 Calibration curves

The following pictures show an optimal agreement between the experimental measurements vs. the reference precipitation data and linear trend lines. Each panel reports the angular coefficient of the linear regressions and the associated determination parameter.

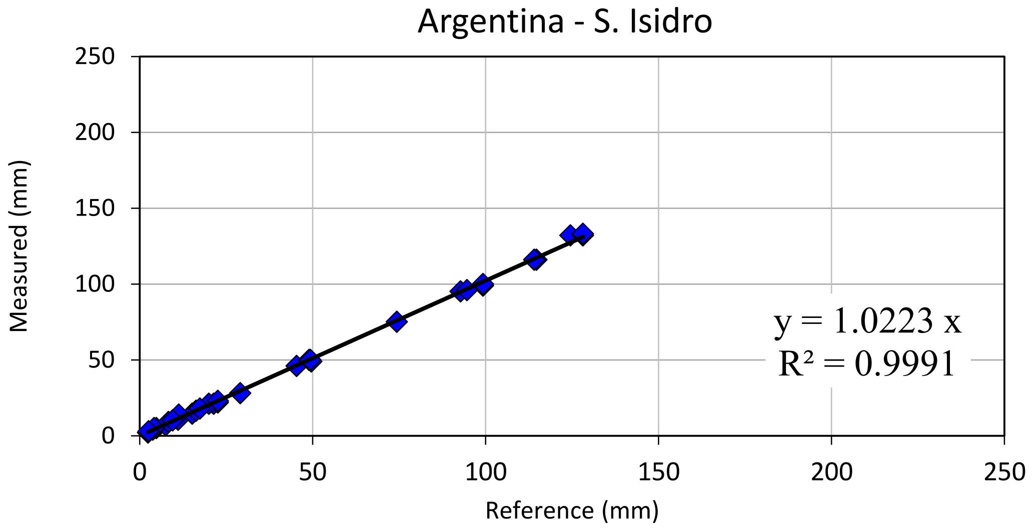


Fig 4.2 Scatter plot of the measured vs. reference precipitation amount (mm) and linear regression (calibration curve) for the San Isidro gauge.

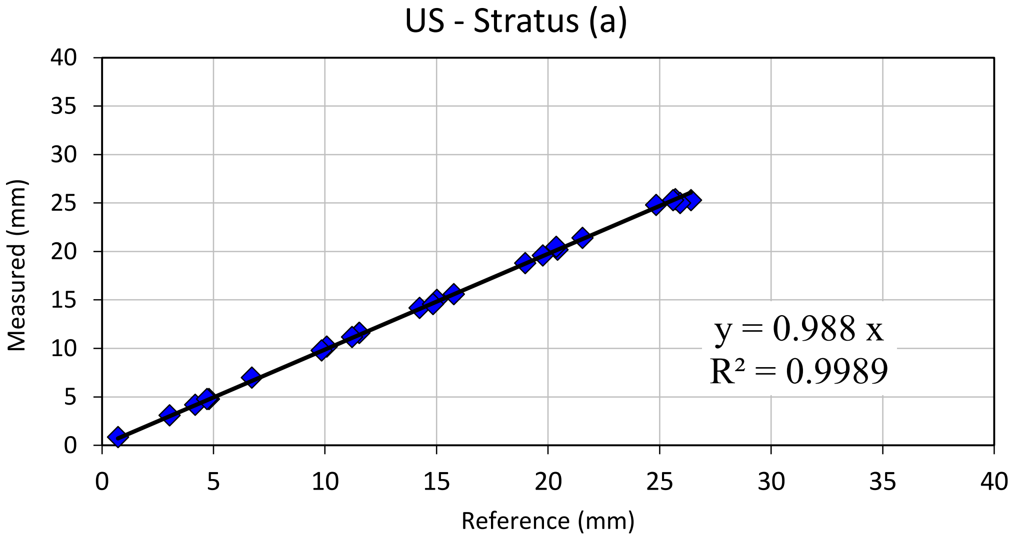


Fig 4.3 Scatter plot of the measured vs. reference precipitation amount (mm) and linear regression (calibration curve) for the Stratus gauge (internal diameter).

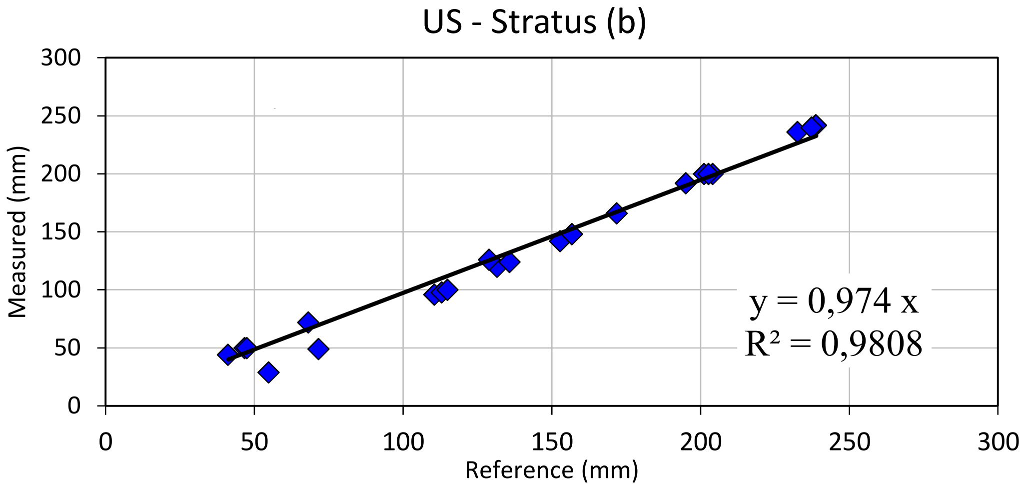


Fig 4.4 Scatter plot of the measured vs. reference precipitation amount (mm) and linear regression (calibration curve) for the Stratus gauge (external diameter).

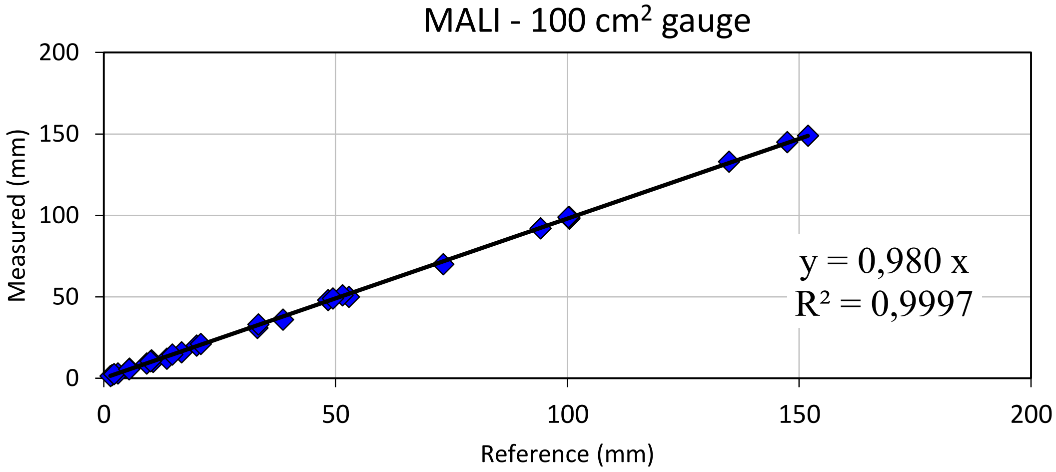


Fig 4.5 Scatter plot of the measured vs. reference precipitation amount (mm) and linear regression (calibration curve) for the 100 cm2 Mali gauge.

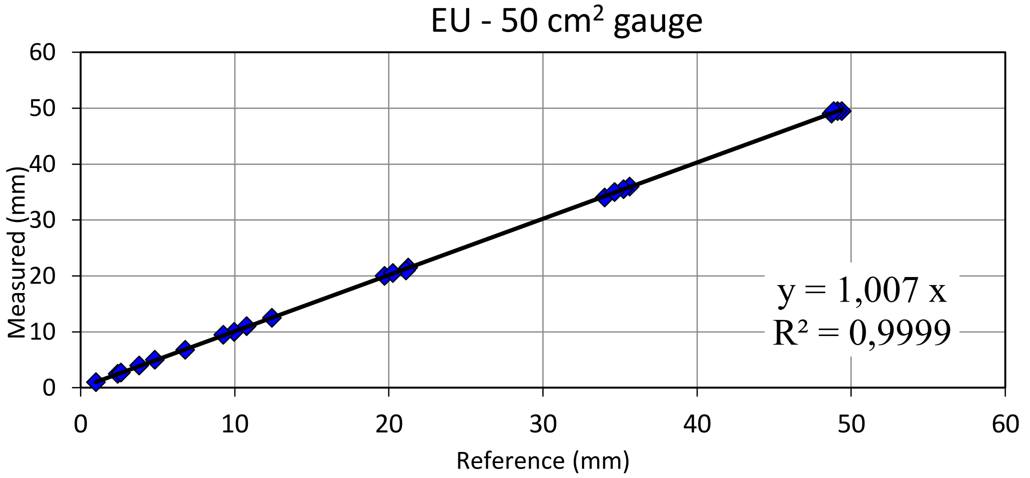


Fig 4.6 Scatter plot of the measured vs. reference precipitation amount (mm) and linear regression (calibration curve) for the 50 cm2 gauge.

4.2.2 Measurement errors

The measurement error (%) has been computed according to the following expression

$$error\ (\%) = \frac{(h_m - h_{ref})}{h_{ref}} 100$$

where h_m (mm) is the measurement of the manual gauge and h_{ref} (mm) is the actual precipitation amount. The scatter plots of the measurement errors of each gauge are shown in Figures 4.7-4.11 and can be compared to the +/- 5% limit recommended by the CIMO guide 8 annex 1.D - measurement uncertainty operational requirements and instrument performance. The requested measurement uncertainty of +/- 5% refers to precipitation intensity larger than 2 mm/h but, in lack of specifications for this type of rain gauges, the same limits are considered in this analysis.

For the San Isidro gauge, the CIMO guide limits are respected only for reference precipitation amounts between 40 and 120 mm.

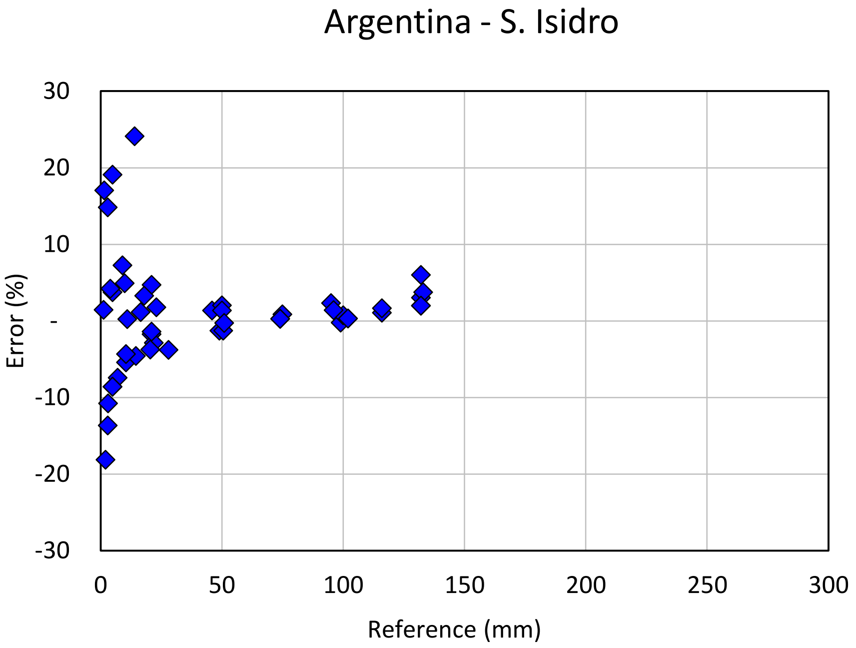


Fig 4.7 Residual errors [%] for the San Isidro gauge vs. the reference precipitation amount after calibration.

The internal cylinder of the Stratus gauge is characterized by errors not exceeding +/- 5% when the reference precipitation amount is larger than 4 mm, while the external cylinder shows the same behaviour for a reference rain amount larger than 150 mm.

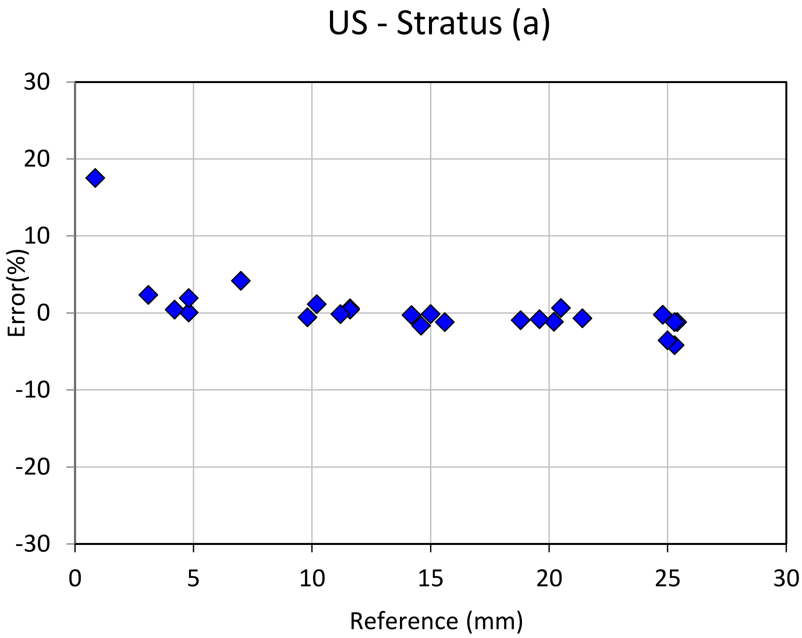


Fig 4.8 Residual errors [%] for the Stratus (internal cylinder) gauge vs. the reference precipitation amount after calibration.

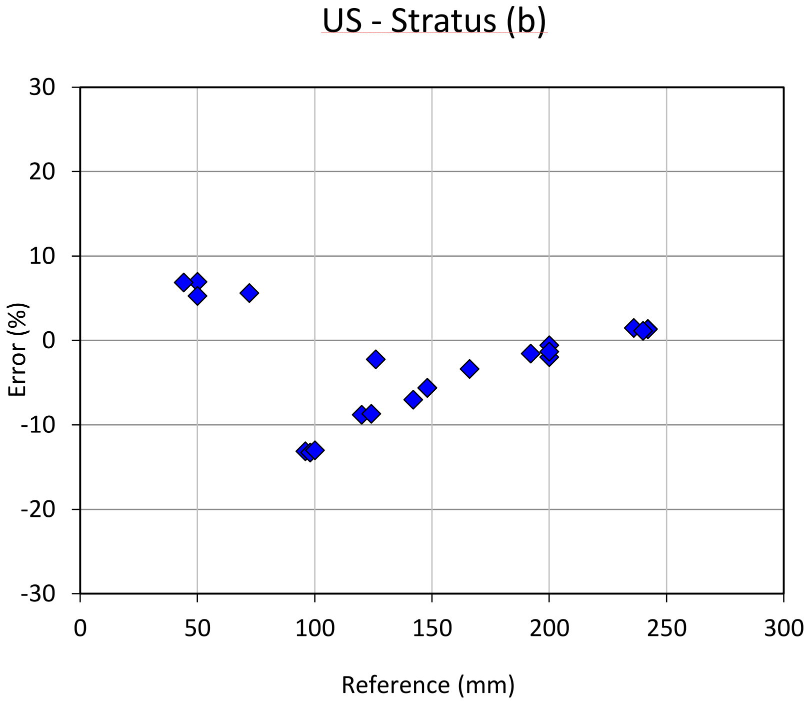


Fig 4.9 Residual errors [%] for the Stratus gauge (external cylinder) vs. the reference precipitation amount after calibration.

The 100cm^2 Mali gauge respects the +/- 5% limit when the reference precipitation is larger than 70 mm, while the residual errors of the 50 cm^2 gauge do not exceed the CIMO limits throughout the whole range.

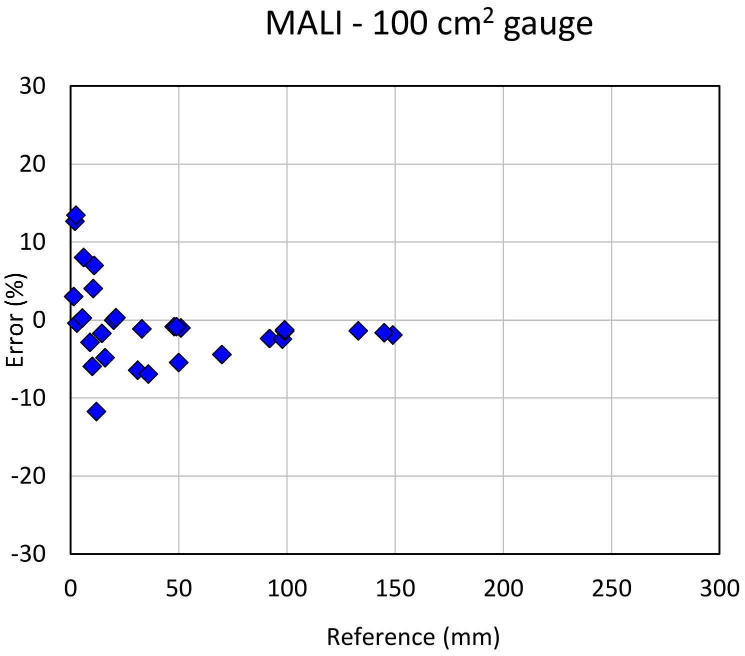


Fig 4.10 Residual errors [%] for the 100 cm2 Mali gauge vs. the reference precipitation amount after calibration.

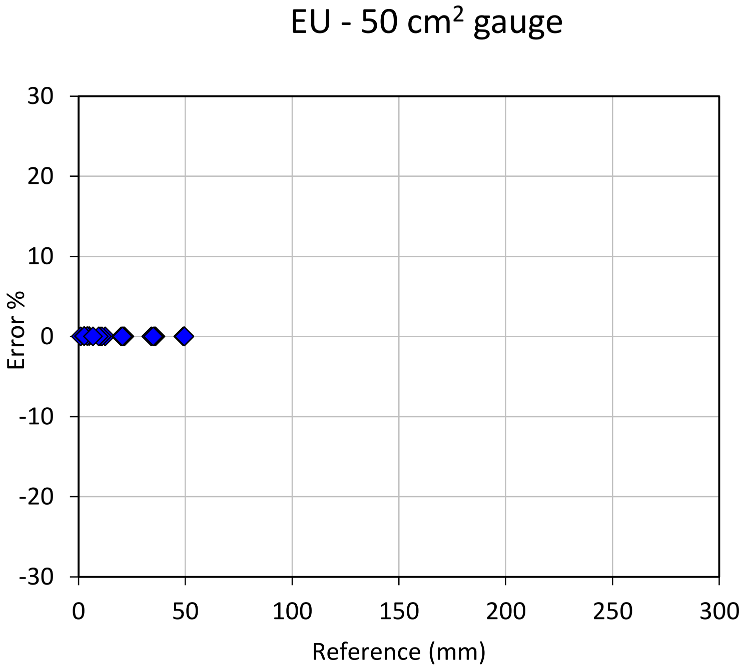


Fig 4.11 Residual errors [%] for the 50 cm2 Mali gauge vs. the reference precipitation amount after calibration.

4.2.3 Operator error

We report here the standardized error of the measurements [mm], normalized with the reference, for the various operators employed, as represented by different colours in Figures 4.12 to 4.16.

For all the tested instruments, the operator error is not negligible near to the lower limit of the reference rainfall range. In this region, the San Isidro and the Stratus gauge show higher values of the standardized error, while the best performing gauge with respect to this source of uncertainty is the 50 cm^2 model. Furthermore, the San Isidro gauge and the external cylinder of the Stratus gauge are characterized by significant values of the standardized errors also at high rain depth values.

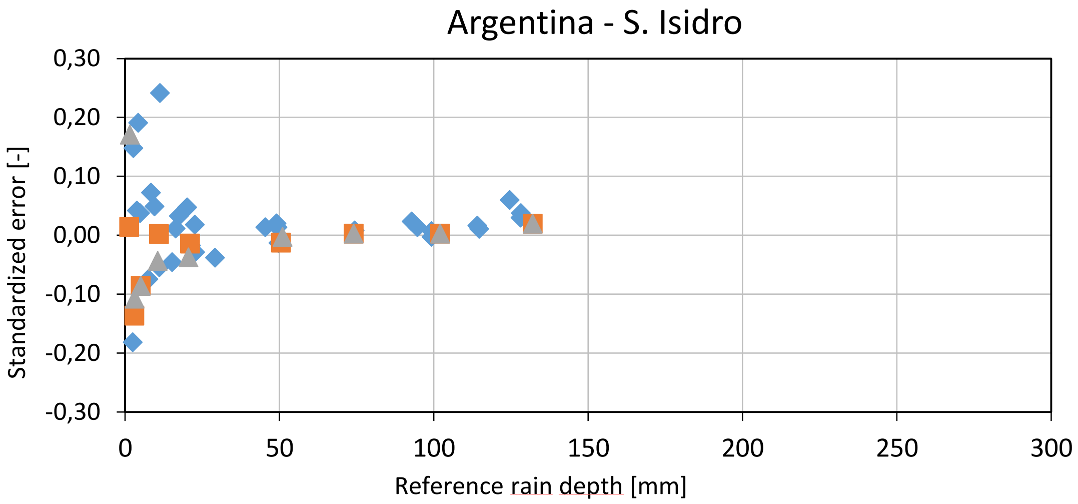


Fig 4.12 Standardized error [-] vs. the reference rain depth (mm) of different operators for the San Isidro gauge. The standard deviation is equal to 0.07.

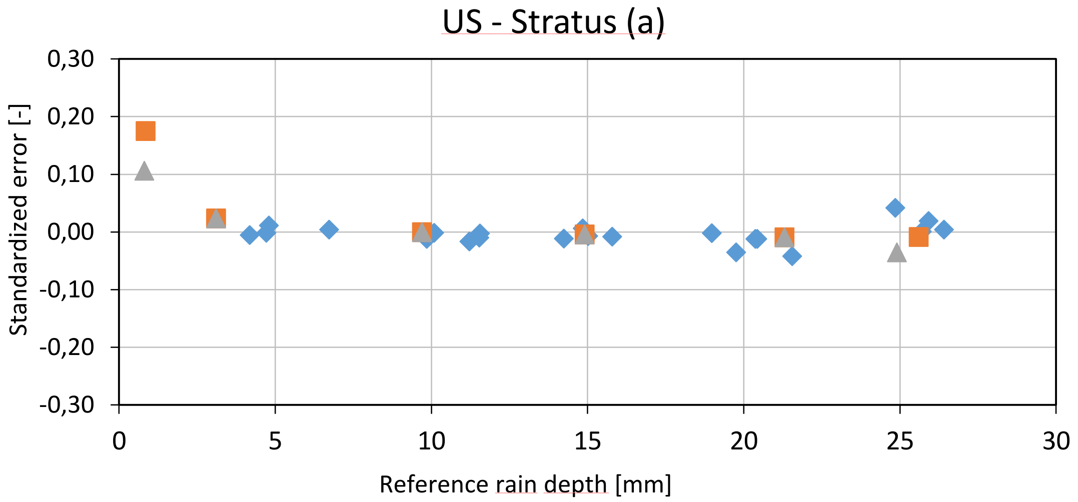


Fig 4.13 Standardized error [-] vs. the reference rain depth (mm) of different operators for the Stratus gauge (internal cylinder). The standard deviation is equal to 0.04.

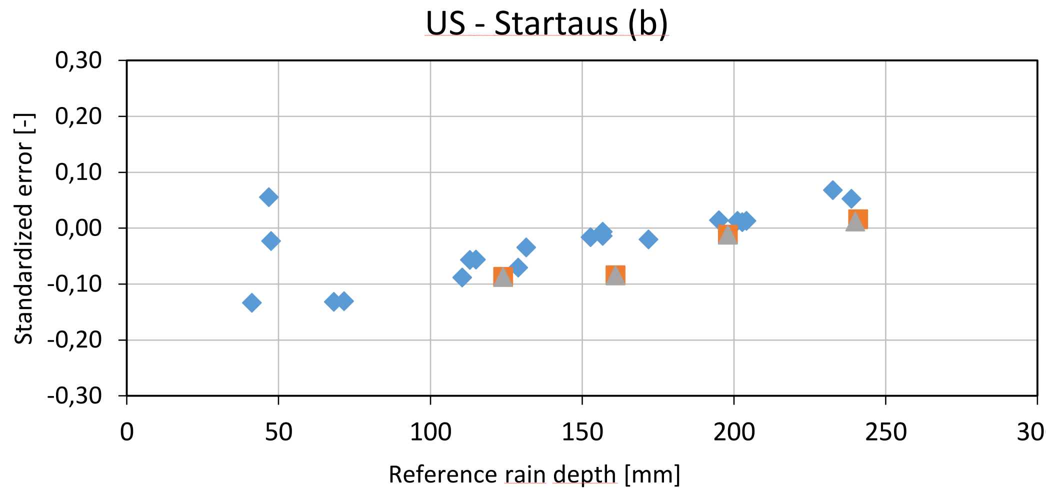


Fig 4.14 Standardized error [-] vs. the reference rain depth (mm) of different operators for the Stratus gauge (external cylinder). The standard deviation is equal to 0.09.

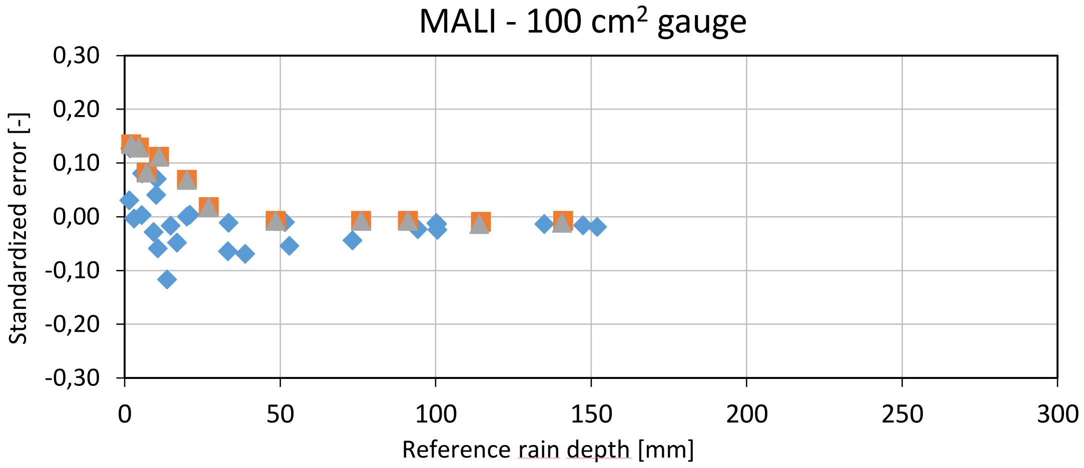


Fig 4.15 Standardized error [-] vs. the reference rain depth (mm) of different operators for the 100cm2 Mali gauge. The standard deviation is equal to 0.06.

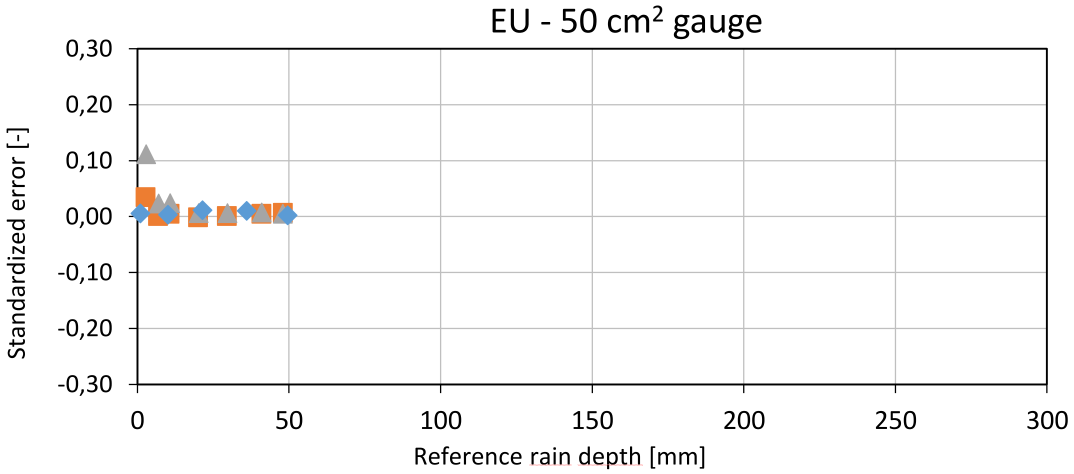


Fig 4.16 Standardized error [-] vs. the reference rain depth (mm) of different operators for the 50cm2 gauge. The standard deviation is equal to 0.01.

Figure 4.17 summarizes the standard deviation of the reading errors performed by different operators in a comparative form for all the tested gauges, showing that the best agreement between the observations occurs for the 50 cm^2 gauge, while larger reading uncertainties arise for the external cylinder of the Stratus gauge.

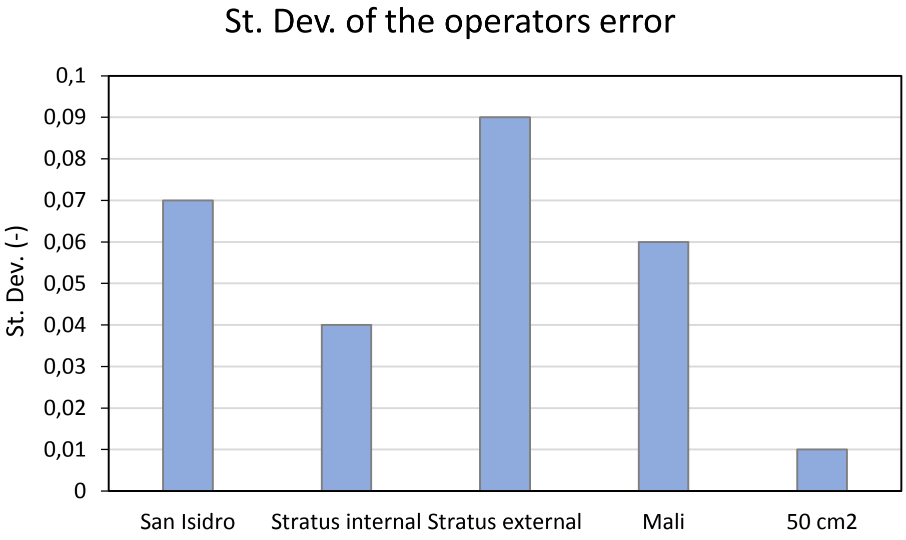


Fig 4.17 Comparison of the standard deviations [-] of the reading errors of precipitation measurements performed by different operators.

4.3 Compliance with WMO specifications

The compliance of the four instruments with the WMO general specifications (WMO) is summarized in Table 4.1. Because of a lack of information on materials, it has not been possible to evaluate the following specifications:

- The construction of the orifice should be such that this area remains constant while the gauge is in use.
- The measuring cylinder should be made of clear glass or plastic having a suitable coefficient of thermal expansion.

Scores between 0 and 5 were assigned to each of the 11 recommendations analysed, for a maximum total score of 55. The total score, rescaled to a 0-10 range, was assumed as the WMO compliance index for the instrument according to the WMO Guide N° 8.

	WMO requirement	Scores			
		S. Isidro	Stratus	100 cm^2	50 cm^2
1	The rim of the collector	5	5	5	4
2	The area of the orifice	3	5	3	3
3	The collector design to prevent splashing	3	3	5	3
4	Minimizing wetting errors.	2	4	1	2
5	Narrow entrance to minimize the evaporation	2	5	2	2
6	The measuring cylinder should be clearly marked	2	5	5	4
7	The diameter should be less than 33	2	5	3	3
8	The graduations should be finely engraved.	2	5	4	5
9	The graduations should be marks at 0,2 mm	0	3	0	0
10	The graduations clearly figured lines at millimetre	3	3	4	4
11	To measure small precipitation	4	5	5	3
	Index I_{WMO}	5	8.7	6.7	6

Tab. 4.1 Comparative evaluation of the rain gauge specifications mentioned in the WMO/CIMO Guide N° 8 to Meteorological Instruments and Methods of Observation (WMO, 2010).

5 – Field Tests

5.1 Site climatology

The field intercomparison of METAGRI simple plastic rain gauges was held in Italy at the Air Force Technical Centre for Meteorology (ITAF-CTM). The Centre is located in Vigna di Valle (42.083 N, 12.217 W), on the top of a hill at 266 meters a.s.l.; it is close to Bracciano Lake and 12 km far from an isolated mountain chain in north direction (600-900 m a.s.l.).

The location is generally characterized by a wind regime of dominant flows during the year from S-SW (warm-humid air masses) and from N-NE (cold-dry air masses). The most intense rainy period is from October to December, however spring and summer intense events are also possible. During the rainy period or in strong spring events, the maximum recorded rainfall intensity (RI [mm/h]) last at least 20-30 minutes and generally depends on rain thunderstorms and showers due to combination of cold and warm fronts mainly coming from SE-SW. The worst weather conditions normally occur when perturbations meet a strong Lake humidity condition (beginning of autumn, early spring, hottest summer days). The situation is similar during summer: intense precipitation events (but less frequent) occur mainly with dominant winds from E and from Rome "hot island" zone (50 km from Vigna di Valle).

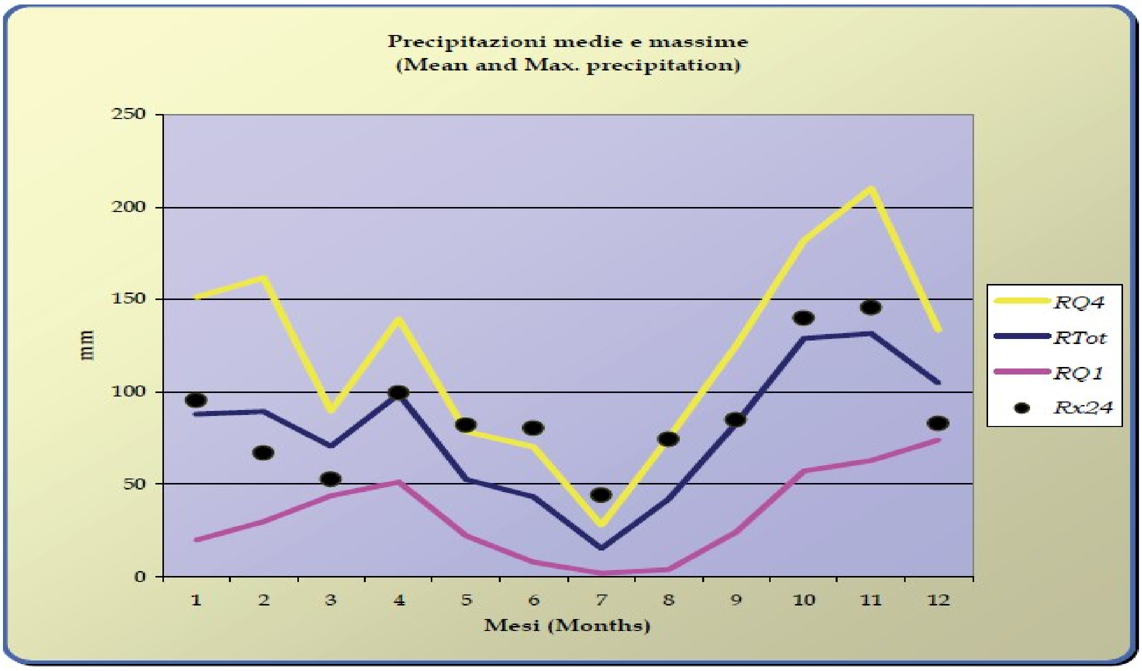
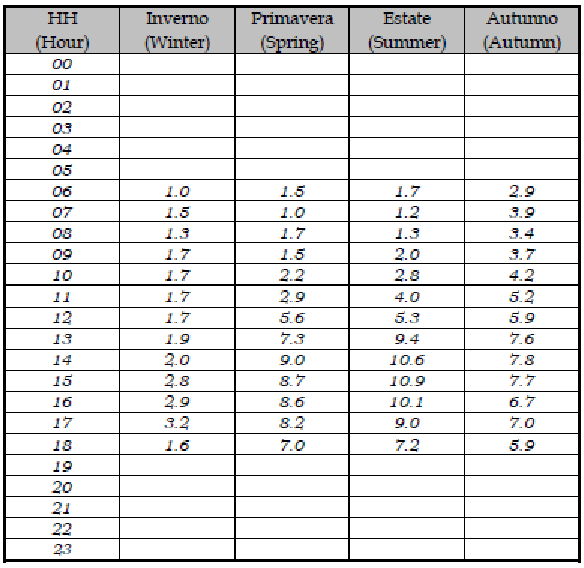


Fig. 5.1 monthly mean precipitation [RTot] and maximum precipitation [Rx24]

During precipitation events, an average wind speed of 5m/s is generally recorded, except in cases of enhanced Tower Cumulus (TCU) clouds or Cumulonimbus (CB) outflows (stronger winds) that usually precede intense showers for several minutes.

The following table represents the occurrence (%) of cumulonimbus clouds over the last 30 years for each season.



HH (Hour)	Inverno (Winter)	Primavera (Spring)	Estate (Summer)	Autunno (Autumn)
00				
01				
02				
03				
04				
05				
06	1.0	1.5	1.7	2.9
07	1.5	1.0	1.2	3.9
08	1.3	1.7	1.3	3.4
09	1.7	1.5	2.0	3.7
10	1.7	2.2	2.8	4.2
11	1.7	2.9	4.0	5.2
12	1.7	5.6	5.3	5.9
13	1.9	7.3	9.4	7.6
14	2.0	9.0	10.6	7.8
15	2.8	8.7	10.9	7.7
16	2.9	8.6	10.1	6.7
17	3.2	8.2	9.0	7.0
18	1.6	7.0	7.2	5.9
19				
20				
21				
22				
23				

Fig. 5.2 Occurrence of cumulonimbus clouds over Vigna di Valle in the last 30 years for each season

The Metagri rain gauges were installed within the field test site of ITAF-CTM, and more specifically over the *Lead Centre on Precipitation Intensity* intercomparison area, as reported in Fig. 5.3. Such area, entirely dedicated to field intercomparisons of any kind of precipitation gauges, is a flat 400 m^2 grass field equipped with 34 concrete platforms, 4 corner-platforms and 30 evenly distributed platforms, as in Fig. 5.4. Each platform is supplied with power (AC and VDC), serial communication converters, 8 free and 8 coupled high quality double shielded acquisition cables and low voltage threshold discharge protections.

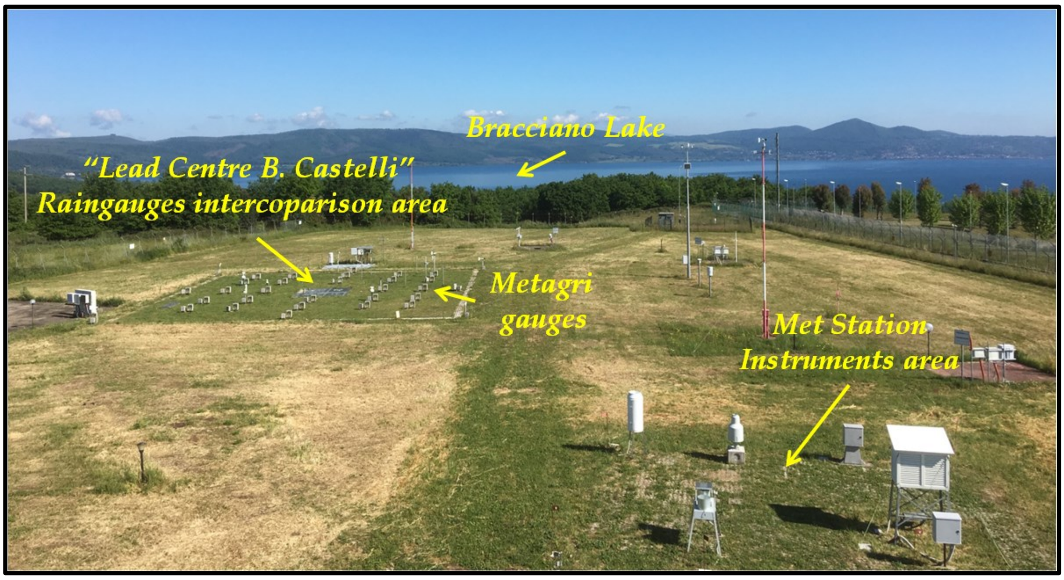


Fig. 5.3 Air Force Technical Centre for Meteorology - Vigna di Valle Field Test Site - Italy

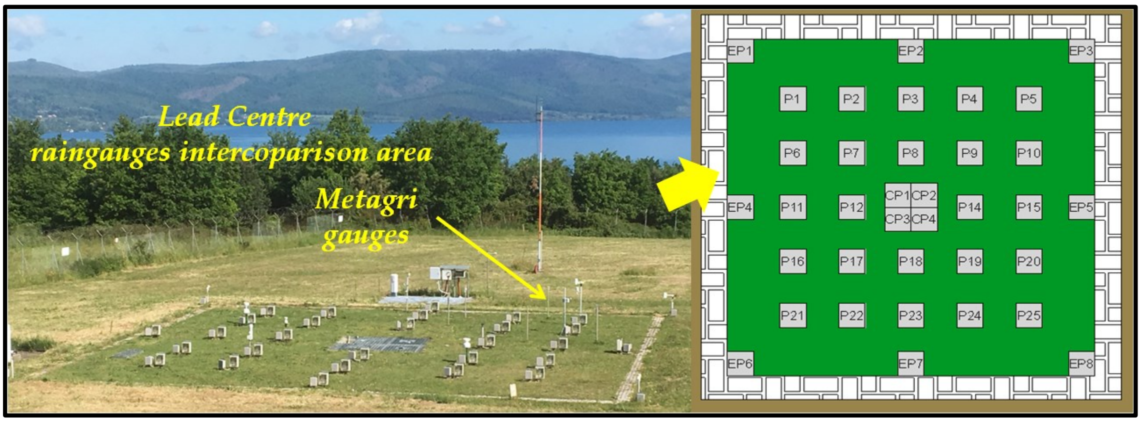


Fig. 5.4 Lead Centre "B. Castelli" on Precipitation Intensity – Intercomparison area

The intercomparison site is equipped with a group of four precipitation gauges installed in pits according to the ISO-EN standard 13798 (namely "Specification for Reference Raingauge Pits"). The Reference Raingauge Pits (RRGP) are located in the centre of the intercomparison area and indicated with "CP_i" labels as shown in figure 5.4. The four precipitation gauges in their pits represents the "field working references" or, alternatively, the "standard group" for field reference precipitation measurements.

5.2 Field installation

Five simple plastic precipitation gauges (also referred as "Metagri raingauges" in the text) have been selected by WMO and sent to the Lead Centre "B. Castelli" on Precipitation Intensity in Italy. After the laboratory tests in Genova, (Italy), they were installed in the field test site in April 2015 for a seasonal intercomparison. The name and models of these plastic gauges are provided in the following list, including their collecting area:

- STRATUS (USA), collecting area = 81.153 cm^2 (delayed installation, June 2015);
- SAN ISIDRO (Argentina), collecting area = 100 cm^2
- EU (Europe), collecting area = 50 cm^2
- MALI-Ghana (MALI), collecting area = 100 cm^2
- MALI-Ethiopia[1] (MALI), collecting area = 100 cm^2

The METAGRI rain gauges have been installed on a flat area covered by grass, on stainless steel masts at 1,8 meters over the ground, close to the field references and to each other (approx. 3 meters). Their field position layout is represented in figure 5.5.

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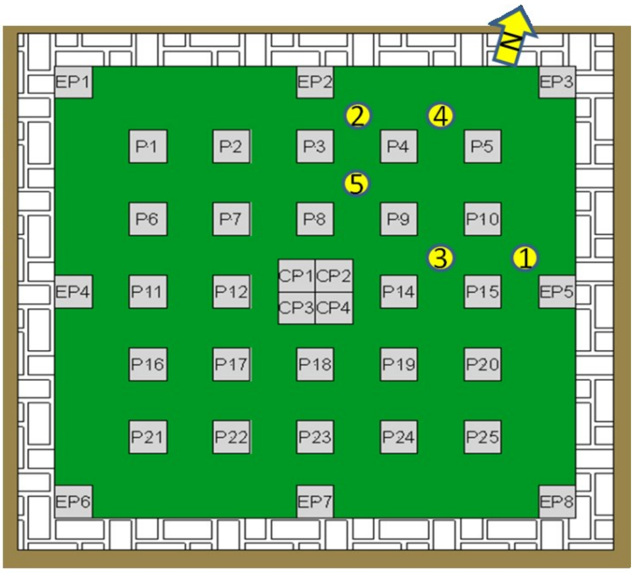
[1] This gauge is the same plastic model MALI-G but produced in MALI for Ethiopia.

1 US - Stratus **2 San Isidro** **3 EU – 50 cm2**

4 MALI - Ghana **5 MALI - Ethiopia**



20 m

Fig. 5.5 METAGRI simple plastic rain gauges and their installation layout during the field intercomparison in Italy (1-5). P_i are concrete platforms for rain gauge installations. EP_i are platforms for ancillary data. Field working references located in CP_i positions (pits).

5.3 Reference Rain Gauge Pits (RRGP)

A reference can be defined as a virtual device based on a set of measuring instruments and, according to VIM (the Vocabulary in Metrology), a working reference is a calibrated set of instruments used for controlling/making comparison with measuring instruments.

According to the CIMO Guide (*WMO, 2010*), the main feature of a reference gauge design is to reduce or control the effect of wind on the catch, which is one of the most serious influence factor for gauges. The use of one single reference instrument in a field intercomparison should be avoided, so a set of working reference gauges was set up in 2011 by the *Lead Centre "B. Castelli"* and is regularly used in field intercomparisons. Their combined readings provide the best possible estimation of the reference precipitation in the field. This group of reference instruments has been established through a suitable selection of potential reference gauges that demonstrated high quality performance in laboratory and in the field, both during the previous WMO intercomparisons (*Lanza, 2005b*; *Vuerich, 2009*) and during more recent investigations performed by the *Lead Centre "B. Castelli"*. The working references were installed in a pit according to the EN-13798:2010 "*Specification for a Reference Rain Gauge Pit*", as adopted by ISO, to minimize environmental interference on measured precipitation and to protect against in-splash by a metal or plastic grid.

The design of the pit took into account dimensions of the gauges and a method of installation of the respective gauge. The sides of the pit are formed of bricks and concrete and they are supported to prevent collapse. As a result, a large pit of 170 cm depth was built and divided in four parts for installing the reference rain gauges as shown in figure 5.6.

Supporting walls were built around the edges and four galvanized steel grating of 187,5 x 187,5 x 12,0 cm (LxWxH) were rested on pit walls. The base of the pit is deep enough to allow the correct installation of the rain gauge and its levelling. The base of the pit has a recess (extra pit) to allow water to be drained by an electric pumping system. The grating is strong enough to walk on, to maintain its shape without distortion and it was made in two sections to allow part of it to be lifted, to give access to the rain gauge. The grating was made of galvanised sheet steel. The grating has a central open square for the correct and levelled installation of the rain gauge. To prevent in-splash from the top surface of the grating, the strips of the grating are 0.3 cm thick and the distance between the edge of this central square and the ground is greater than 60 cm.

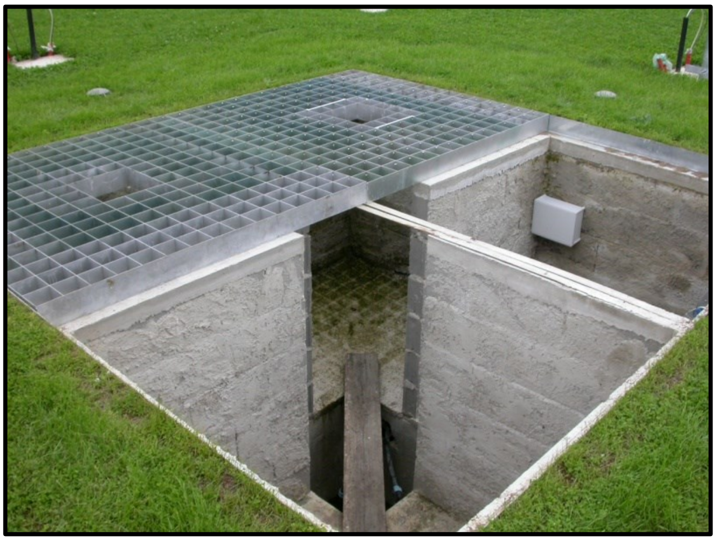


Fig. 5.6 The gratings, the pit internal walls and the pit recess for drainage (Vigna di Valle, Italy, 2007).

Gauges are typically mounted at some distance above the ground to reduce debris (dust, needles and leaves) being blown into the orifice. A standing gauge acts as a disturbance to the air flow. This wind-induced effect has been known from more than one century and it is described as JEVONS effect (1861) (see *Koschmieder, 1934*). The effect of flow deflection and the associated eddies and turbulence around the gauge cause some of the rain drops (particularly smaller ones) to miss the orifice area. The resulting rainfall catch error depends on the ambient wind speed, the rainfall drop size distribution (DSD) and the gauge design. The buried or "sunken" gauge (e.g. *Koschmider, 1934 and Sieck et al., 2007*) is expected to show a higher rainfall reading than the gauge above the ground, with differences potentially 10% or more, when both instruments work perfectly and accurately. The effect is enhanced in snowfall.

In the case of a RRGP, this influence is minimized. Moreover, the influence of the turbulent vertical movements is likewise reduced to a minimum, since these disappear at the earth's surface.

The *Lead Centre "B. Castelli"* selected as "working references gauges" and installed in the field site the following instruments:

- No.2 Weighing Gauges (WG): OTT-Pluvio^2 and GEONOR-T200B equipped with 3VWs (vibrating wires), both with a collecting area of 200 cm^2 and respectively located in CP1 and CP4 positions in Fig. 5.5;
- No.1 Tipping Bucket Rain Gauge (TBG): CAE-PMB25 equipped with an "intertip-time algorithm" correction, with a collecting area of 1000 cm^2 and located in CP2 position in Fig. 5.5;

- N.1 Drop Counting Rain Gauge (DropC): Quantum Detectors High Precision Drop Counting Raingauge (briefly DropC-QD), with a collecting area of 150 cm^2 and located in CP3 position in Fig. 5.5;

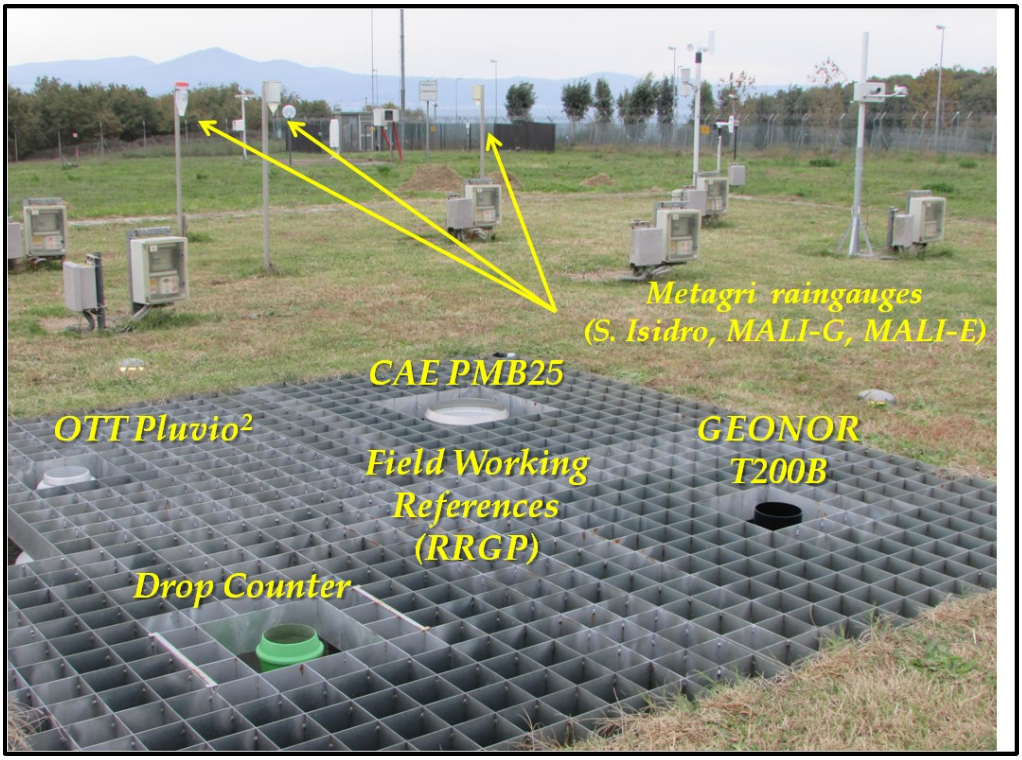


Fig. 5.5 Lead Centre "B. Castelli" on Precipitation Intensity – Working References (Standard Group).

5.4 Method and procedures

5.4.1 Data acquisition and Quality Assurance (QA)/Quality Checks (QC)

During the laboratory tests in Genova (Italy) and before the start of the field tests, qualified personnel of the *Lead Centre "B. Castelli"* field site participated in several meetings with the experts of the laboratory in charge of performing tests for sharing results and other relevant information for the field phase. Both experts agreed on the following procedures and methods to be adopted during the field intercomparison of METAGRI gauges:

- before field installation, each gauge should be checked, calibrated and cleaned by qualified meteorological personnel;
- data acquisition, specifically "the reading of graduated scales" of METAGRI simple plastic rain gauges, or simply the "readings[2]", should be preferably performed by a qualified personnel (meteorological observer or an even higher qualification);

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[2] The readings of simple plastic gauges (totalizing gauges) consist in the value of the **precipitation amount** collected by the raingauge over the sampling time and expressed in millimeters (mm).

- an electronic dataset of METAGRI gauges field measurements should be established and backed-up regularly with the followings data as minimum: date, local time of observation, precipitation amount in millimeters [mm] for all 5 METAGRI gauges, precipitation amount in millimeters [mm] for all field working references;
- the data sampling (readings) of plastic gauges should be performed in two different ways in order to take into account possible operational procedures when such instruments are operated by farmers. The first mode of sampling is performed at 10:00 local time of the day after a precipitation event occurred (daily events); the second mode of sampling is performed at variable intervals multiple of 24 hours after a precipitation event occurred (multiple daily events);
- following the previous procedure, two separated datasets are updated on regular basis and analyzed: “24hrs dataset” and “>24hrs dataset”;
- ancillary data should be also reported and stored in a separated dataset, specifically: temperature, relative humidity, wind speed and direction, present weather conditions;
- evaporation should be investigated and possibly quantified[3] for data analysis and recommended procedures in operational cases;
- met-observers in charge of data acquisition and maintenance should collect and record observations or notes on the activity in order to provide the data analysis with additional metadata and to permit the recommendation of good practices on the operational use of farmer simple plastic rain gauges.

Quality Control (QC) of data is a basic component of quality management systems and is important for the examination of data to detect errors and take follow-up actions. The general guidelines are described in the CIMO Guide (*WMO, 2010*). The aim of a QC system is to verify the data and to prevent the recurrence of errors. These procedures can be applied both, in real time and in non-real time as a delayed action for data quality assurance. The *Lead Centre “B. Castelli”* also agreed on the Quality Assurance (QA) activities during the field intercomparison of METAGRI rain gauges as follows:

- weekly inspection of plastic gauges leveling;
- to clean/wash plastic rain gauges containers when necessary;
- to accurately empty out rain gauges after readings and to quantify their water mass content by a calibrated weighing device (scale) after each reading for consistency check on readings;
- real-time and non-real-time quality checks on field working references data before the determination and validation of the field reference value;
- periodic field tests and laboratory calibration of working reference gauges.

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[3] NOTE: climatic conditions may be very different from Italy to Sahelian and Guinean regions where simple plastic raingauges have distributed and installed. Such differences play a fundamental role in the evaporation rate that influences field measurements, especially when the Metagri gauges are sampled several hours after the end of a precipitation event.

5.5 Data analysis and results

5.5.1 Data processing and availability

The QC procedures described in section 5.4.1 have been implemented before the intercomparison and the data analysis so as only Quality Checked data ("QC-ed") or validated data were provided to the data manager for the derivation of results. Those data that were erroneous or doubtful according to QC procedures have been filtered out and excluded from the derivation of results. Not validated reference data are also excluded from the determination of the field reference value (see sec. 5.5.3.1).

The Metagri field intercomparison has been continuously managed for 13 months in all weather conditions, from May 2015 to May 2016. Considering the extraordinary lack of precipitation during the intercomparison period, the scheduled and maintenance service of the *Lead Centre* data acquisition system and its field energy and data cabling (implying no availability of reference data), the total availability of precipitation data was 71% of the 30-years average data availability of Vigna di Valle[4]. The number of valid precipitation samples was 43 out of 49 total samples, corresponding to 87.8% of collected data and to 675 mm of total accumulated precipitation over the intercomparison period. The plot in figure 5.6 shows the monthly distribution of the total accumulated precipitation (only valid data).

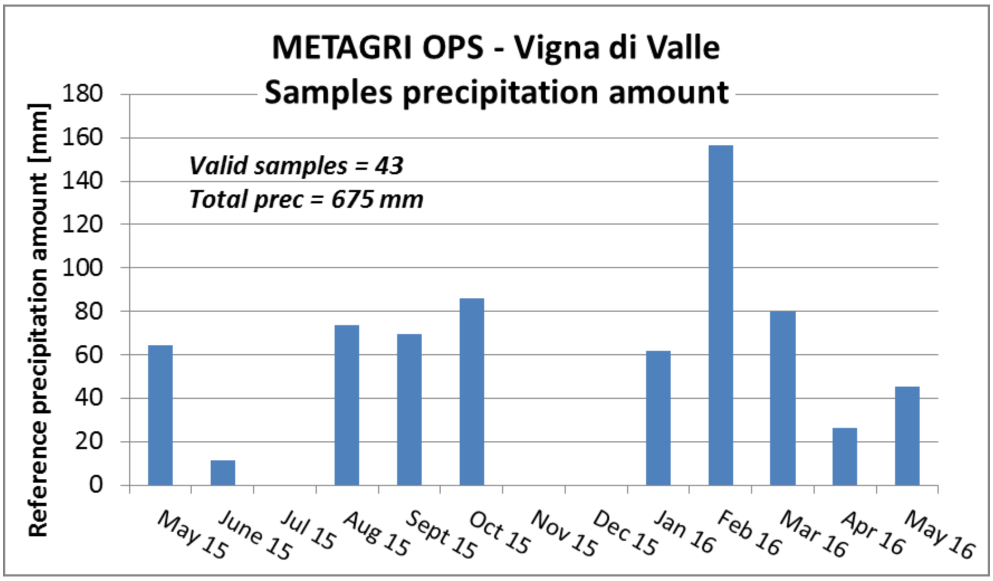

Fig. 5.6: Monthly distribution of METAGRI OPS total accumulated precipitation in Vigna di Valle (only valid data for data analysis).

5.5.2 Data analysis

In order to perform the best intercomparison of Metagri simple plastic rain gauges in the field conditions, it was necessary to select the appropriate methodology, to compare different instrumental responses during the examined seasonal range of rainfall events. Therefore it was necessary to find a specific approach, taking

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[4] The 30-years annual average precipitation amount is 948.6 mm

into account the nature of the observed phenomenon. The analysis of the precipitation data was done through three different steps:

1. First, a reliable working reference made up from the four reference rain gauges installed in the pit (OTT-Pluvio^2, GEONOR-T200B, CAE-PMB25, DropC-QD) was determined.
2. Second, each rain gauge data were analysed in comparison with the calculated reference and its performance was evaluated.
3. Third, evaporation effects were evaluated too.

5.5.2.1 Reference value and uncertainty

The field reference is the best estimation of the true value that can be obtained from the appropriate combination of working reference gauges inside the RRGP, The determination of a reference value is fundamental for defining the baseline for the intercomparison. Since there are four instruments that were available as reference gauges, it was necessary to define how to convert their readings into a composite reference value. The best estimation of a composite working reference can be done using two different methods:

1. The combination of dynamic responses of the set of reference gauges;
2. The statistical evaluation of the experimental data.

The first method requires specific laboratory tests to determine experimentally the step response function and the time constant of each instrument, that should be suitably combined to derive the reference value for each precipitation sample. The laboratory dynamical calibration in steady and unsteady state conditions that the *Lead Centre "B. Castelli"* has recently finely tuned and optimized for all catching-type precipitation gauges permits the improvement of measurement performance in field conditions and therefore a more accurate estimation of the composite reference value for a set of pit gauges in any operational conditions.

The second method consists of a statistical evaluation for deriving the composite working reference. Such statistical evaluation is made by using a weighted average of the working reference gauges in the RRGP as follows:

$$\sigma = \sqrt{\frac{\sum_{j=1}^{N} (h^j - h_{ref}^j)^2}{N}}$$

where:

- h_{ref} is the reference precipitation height or amount expressed in mm;
- h_i is the precipitation height or amount measured by Metagri raingauges expressed in mm;
- μ_i is the weight of the reference raingauge i (i = OTT-Pluvio^2, GEONOR-T200B, CAE-PMB25, DropC-QD).

The weights are calculated taking into account both a global statistical parameter, obtained from the whole data set, and also the evaluation of each single event/sample from which the average is calculated:

$$\mu_i = \frac{S_i^{-1} \cdot F_i}{\sum_i S_i^{-1} \cdot F_i}$$

where $S_i = \sum_{k \neq i} \sigma_{ik}$ with k = OTT-Pluvio^2, GEONOR-T200B, CAE-PMB25, DropC-QD but $k \neq i$; σ_{ik} are 3 statistical parameters calculated for each reference gauge *i* compared to the other references raingauges in RRGP throughout the database of all precipitation events/samples as:

$$\sigma^2_{ik} = \frac{\sum_{j=1}^{N} (h_j^i - h_j^k)^2}{N}$$

where:

- *hji* the j^{th} accumulated precipitation measured by the reference raingauge *i* in the RRGP,
- *hjk* the j^{th} accumulated precipitation measured by the reference raingauge *k* in the RRGP,
- N the number of precipitation samples.

The evaluation of each single event/sample is introduced in the weights *μi* through the factor F_i, which is a "gross" parameter determined on the basis of a non-real-time examination of the precipitation data for that event/sample. This parameter can be 1 or 0, it is 1 if the reference raingauge under examination is not evidently affected by random gross causes not filtered by QC, otherwise it is 0, which means that pit gauge for that particular event/sample is excluded from the calculation of the reference value.

For the purposes of the Metagri instruments intercomparison, a combination of both methods has been applied: the reference value was calculated by applying the functions of the second method and using a combination of pit gauges dynamically calibrated and optimized by the *Lead Centre Laboratory* in Genova (Italy); however the tipping bucket and the drop counting gauges in the RRGP were specifically optimized for precipitation intensity measurements and its 1-minute variability, therefore it was agreed to exclude such gauges from the derivation of the reference precipitation amount value (so $F_3 = F_4 = 0$ and $\mu_3 = \mu_4 = 0$ for all events/samples). This approach simplifies the calculation of the weighted average to derive the composite reference value for each precipitation sample as follows. The calculation of the statistical parameters S_i, according to the above-mentioned procedures, gives the following values:

$\sigma_{12} = \sigma_{21}$	$S_1^{-1} = S_2^{-1}$
0.670	0.746

Tab. 5.1

being i=1 the OTT-Pluvio^2 and $i = 2$ the GEONOR-T200B. Moreover, in all events with $F_1 = F_2 = 1$ we have the following values for weights:

$\mu_1 = \mu_2$
0.5

Tab. 5.2

otherwise one of the two weights is null and the other is equal to 1.

The method described above permitted to calculate the composite working reference value as the best estimation of the field precipitation amount true value for each event/sample. In order to evaluate the uncertainty of this calculated composite working reference, it was decided to proceed as follows.

A Gaussian distribution of the deviations of the precipitation amount measurements of the pit gauges is assumed and the standard deviation of the distribution with respect to the reference value is calculated according to the formula:

$$\sigma = \sqrt{\sum_i \frac{1}{N} \sum_j^N (h_i^j - h_{ref}^j)^2}$$

where the sum is extended for all validated precipitation events/samples (*j*= 1,..,N) and for the two selected reference pit gauges (*i*=1,2). It is common practice in metrology to express the uncertainty as “expanded uncertainty” in relation to the “statistical coverage interval”, therefore the 95% confidence level, or k=2, is used for all measurements. Since the measurement uncertainty is assumed to be independent on precipitation height, the reference expanded uncertainty (95%) is calculated as $U(h_{ref})=2\sigma$ and the value obtained for the Metagri intercomparison is $U(h_{ref})= 0.94$ mm. The relative uncertainty (k=2) is thus $u_{rel}(h_{ref})= (U(h_{ref}) / h_{ref})\cdot 100$ and plotted in Fig.5.7. The 95% of all experimental points are inside the uncertainty limits and the formula to calculate the relative uncertainty of the reference precipitation height is a function of h. In Fig. 5.7 are also represented the relative differences of pit gauges with respect the reference values calculated as follows:

$$RD[\%] = 100 \cdot \frac{(h_i - h_{ref})}{h_{ref}}$$

and represented as a function of the reference precipitation height.

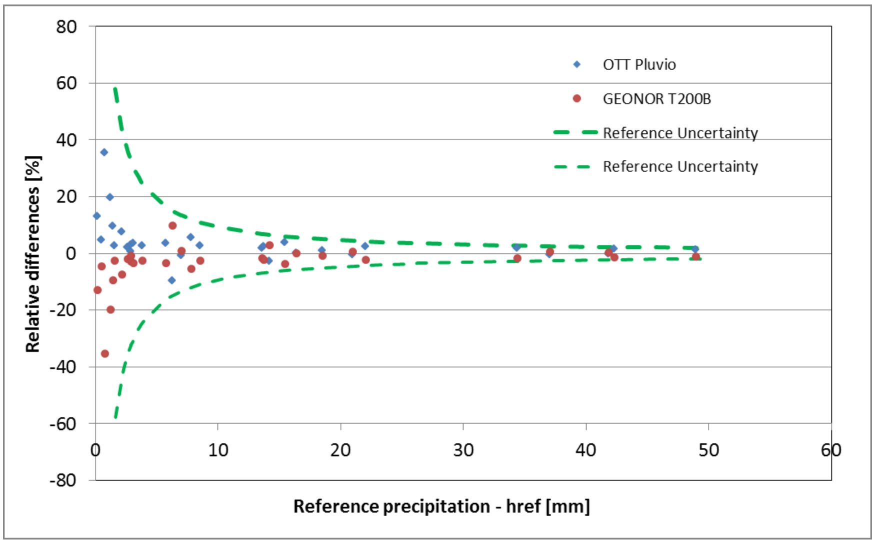

Fig. 5.7 Relative differences (RD) of pit gauges precipitation amount and the reference precipitation. Green lines delimit the region which includes the 95% of the experimental points according to $u(h_{ref})=(2\sigma/h_{ref})\cdot 100$

5.5.2.2 Results

The following section and is dedicated to the results of the comparison between the precipitation amount measured by the Metagri rain gauges and the composite working reference. Two different ways to show the behaviour of each instrument compared to the reference precipitation are described:

- Linear regression plots;
- Relative differences (%) of Metagri Gauges versus reference;
- Results table showing total, average relative differences of Metagri gauges and the calculated field relative achievable uncertainty.

The plots reported in Fig. 5.8 – 5.12 represent the trend of each instrument compared to the composite working reference, where the trend line is obtained from a linear law fitting of the experimental data:

$$h = a \cdot h_{ref} + b$$

where *a* and *b* are constants to be determined for each Metagri rain gauge. The corresponding best fit equations are reported on each plot. The best fit curves must be interpreted with their corresponding correlation coefficient (R^2). A low R^2 value greatly reduces the representativeness of the best-fit curve.

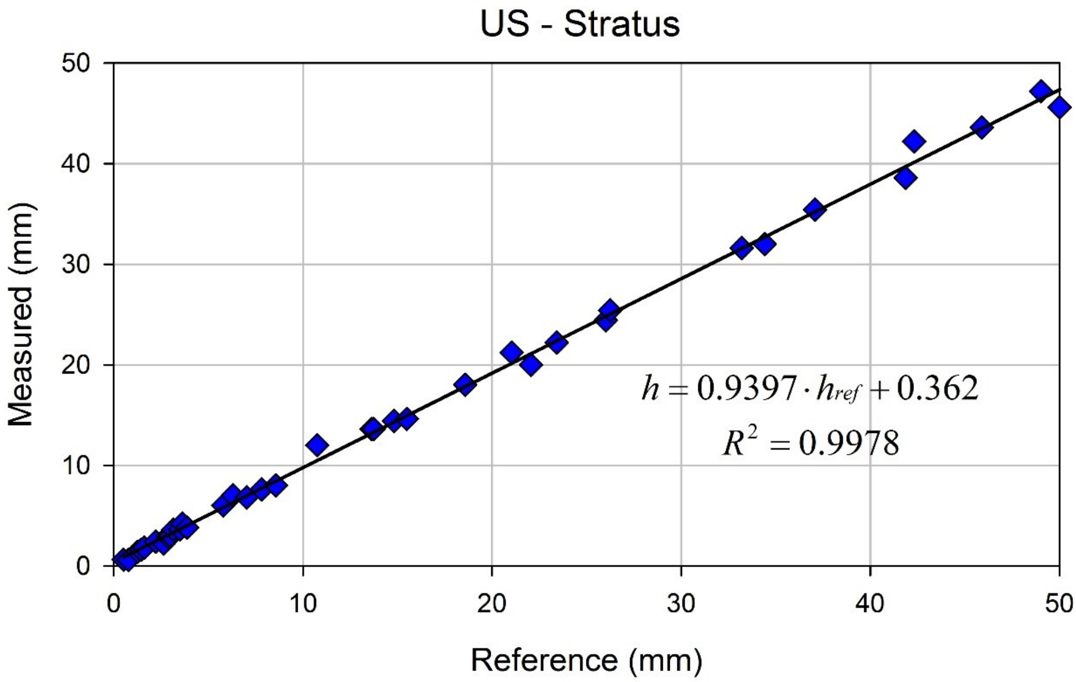

Fig. 5.8 Measured vs. reference cumulated precipitation measurements for the Stratus gauge.

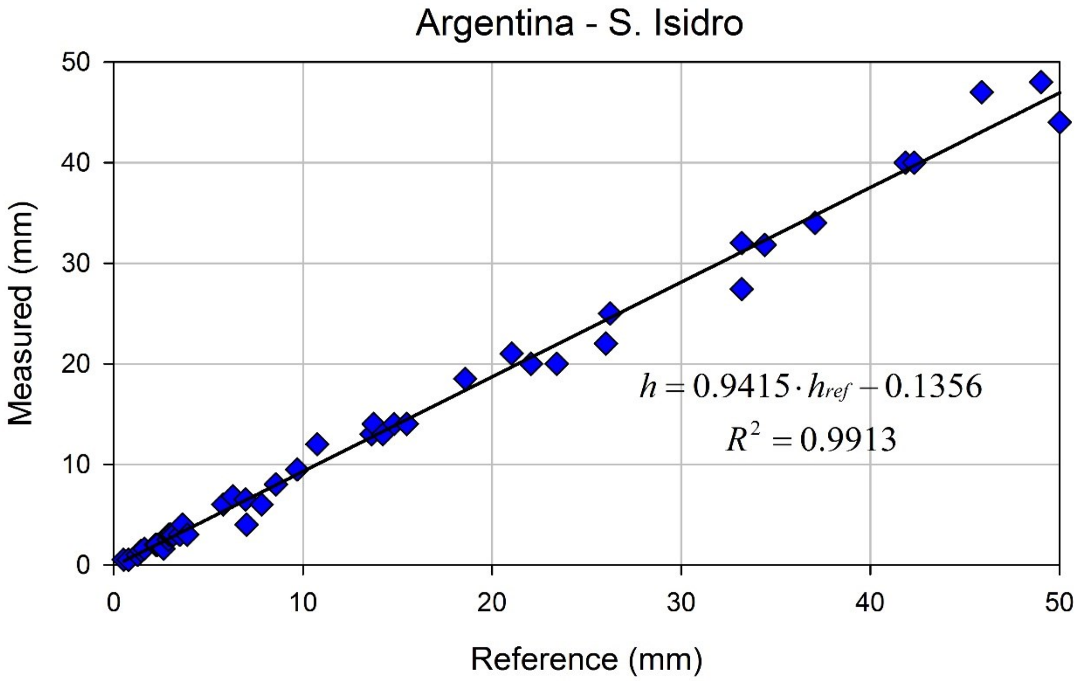

Fig. 5.9 Measured vs. reference cumulated precipitation measurements for the S. Isidro gauge.

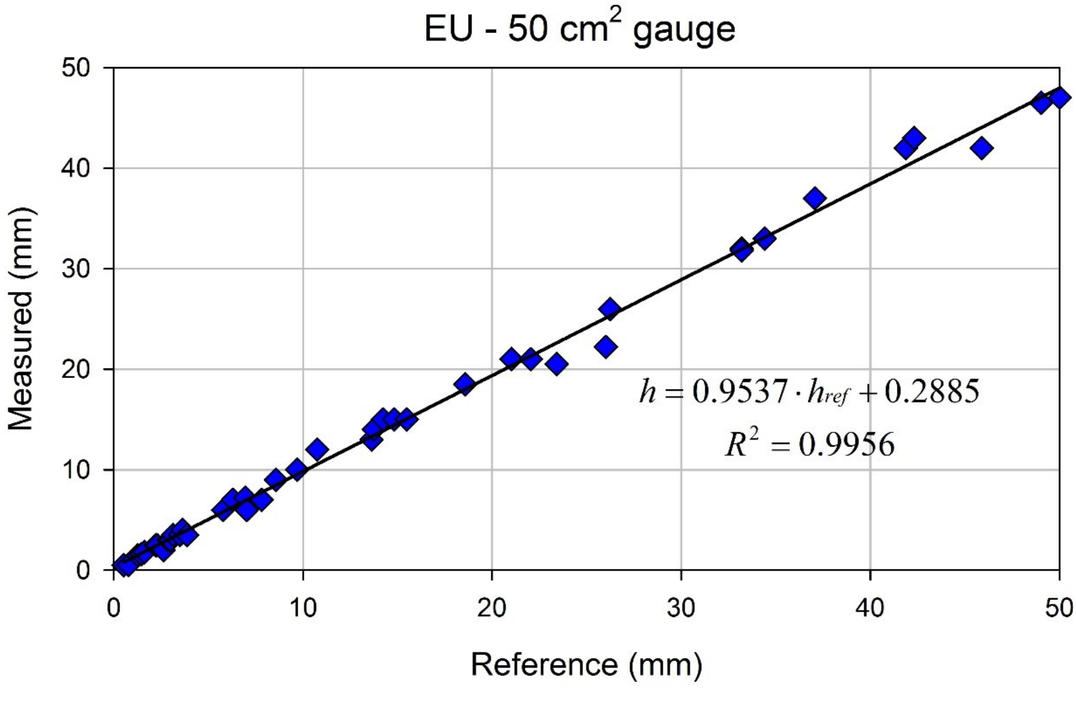

Fig. 5.10 Measured vs. reference cumulated precipitation measurements for the 50 cm^2 gauge.

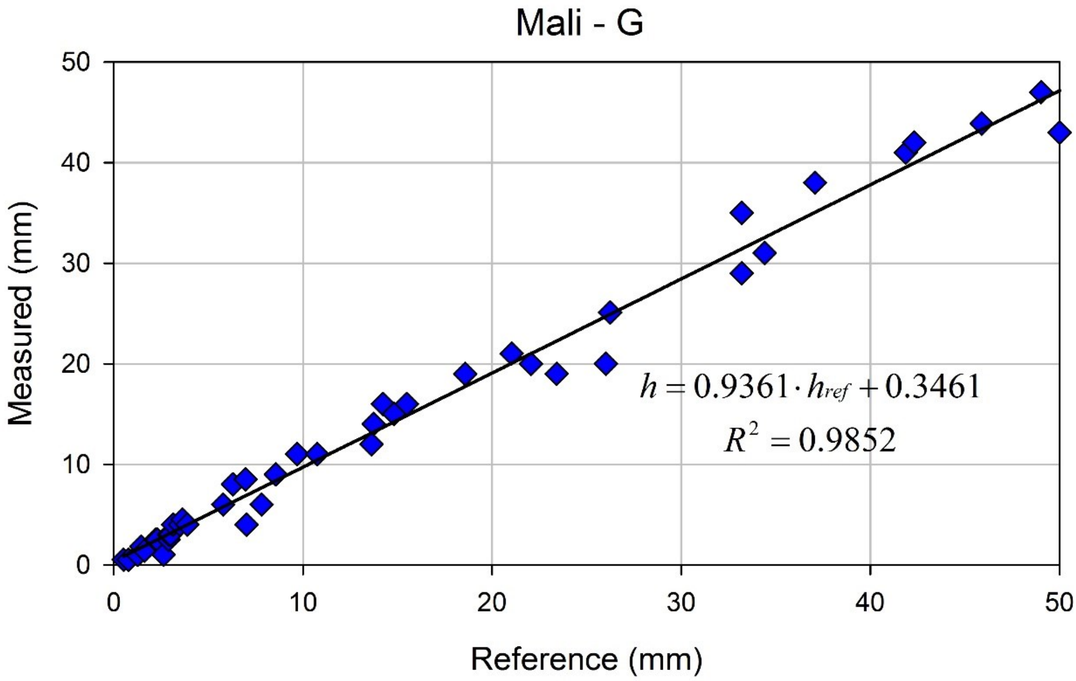

Fig. 5.11 Measured vs. reference cumulated precipitation measurements for the Mali-G gauge.

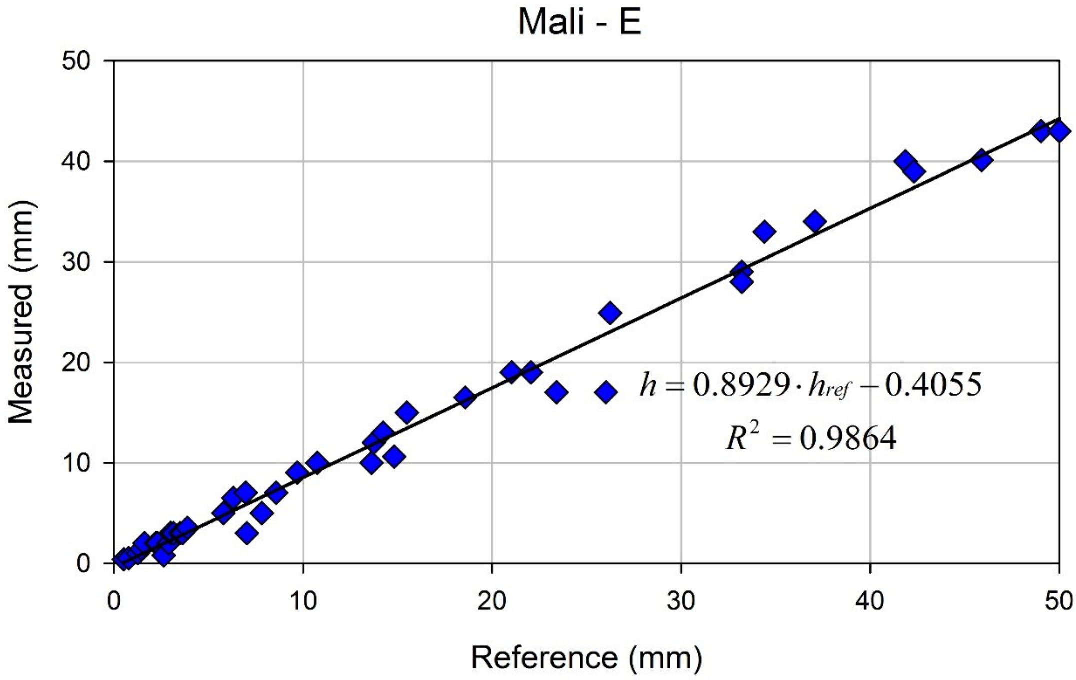

Fig. 5.12 Measured vs. reference cumulated precipitation measurements for the Mali-E gauge.

The plots reported in Fig. 5.13 – 5.17 represent the trend of the plastic rain gauges' relative differences with respect to the cumulated reference precipitation for all samples. The gray dashed lines are ±5% limits.

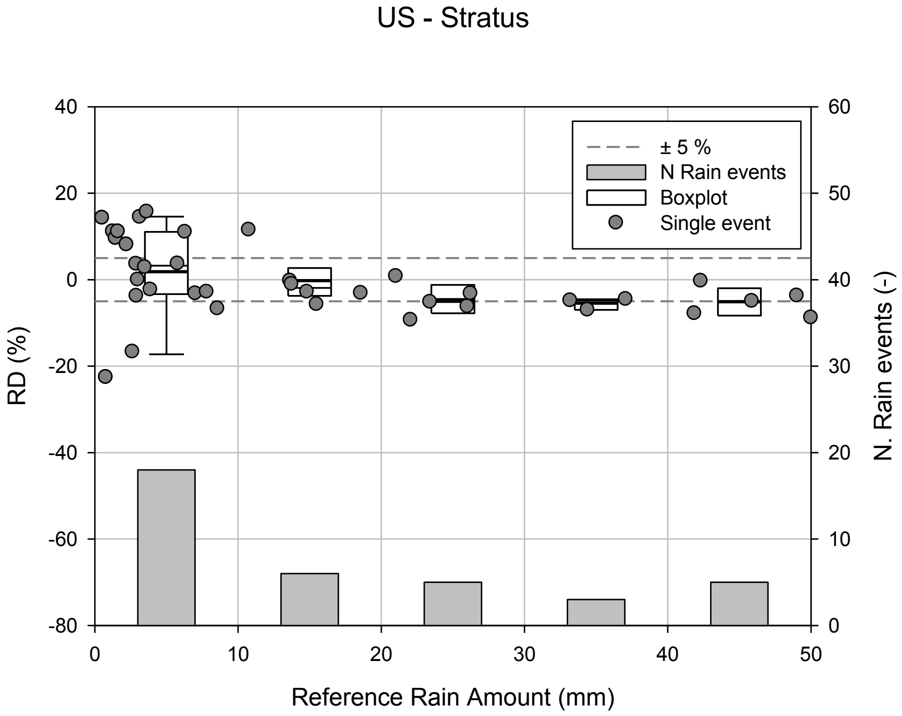

Fig. 5.13 Relative differences vs. the reference cumulated precipitation for the Stratus gauge.

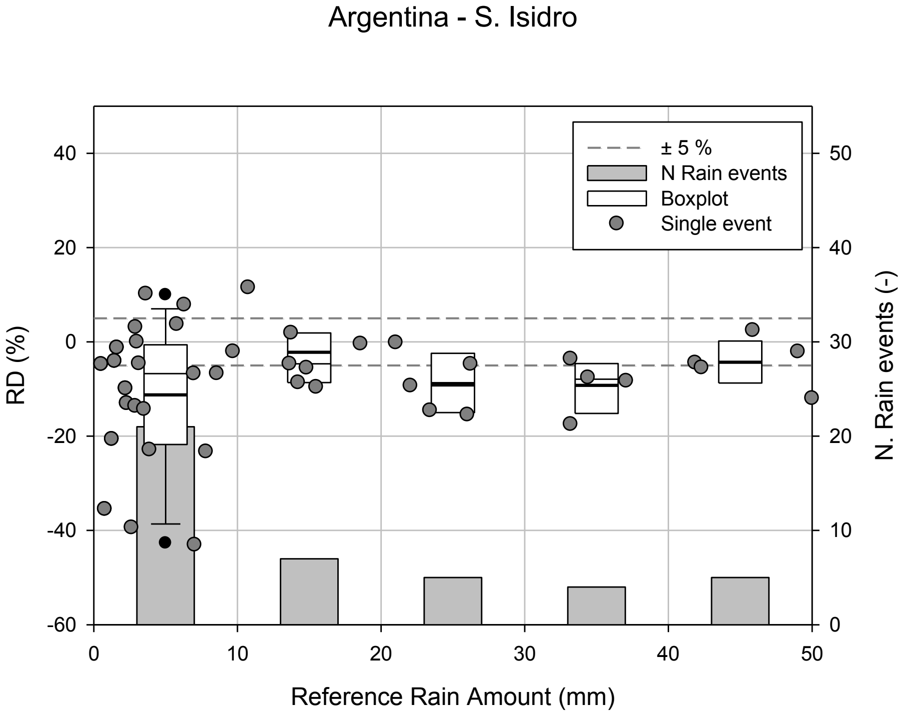

Fig. 5.14 Relative differences vs. the reference cumulated precipitation for the S. Isidro gauge.

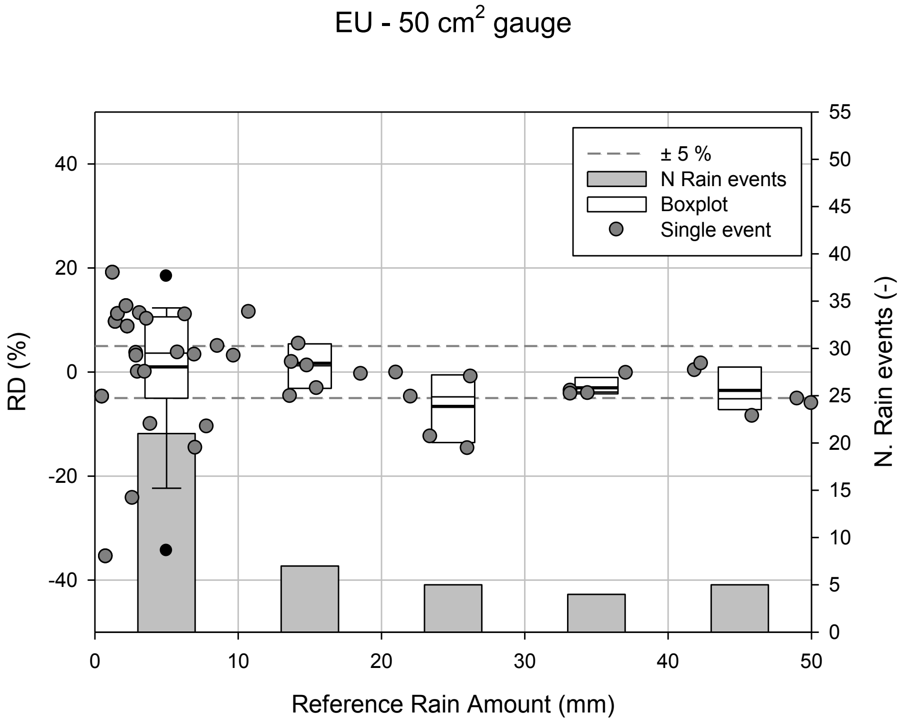

Fig. 5.15 Relative differences vs. the reference cumulated precipitation for the 50 cm^2 gauge.

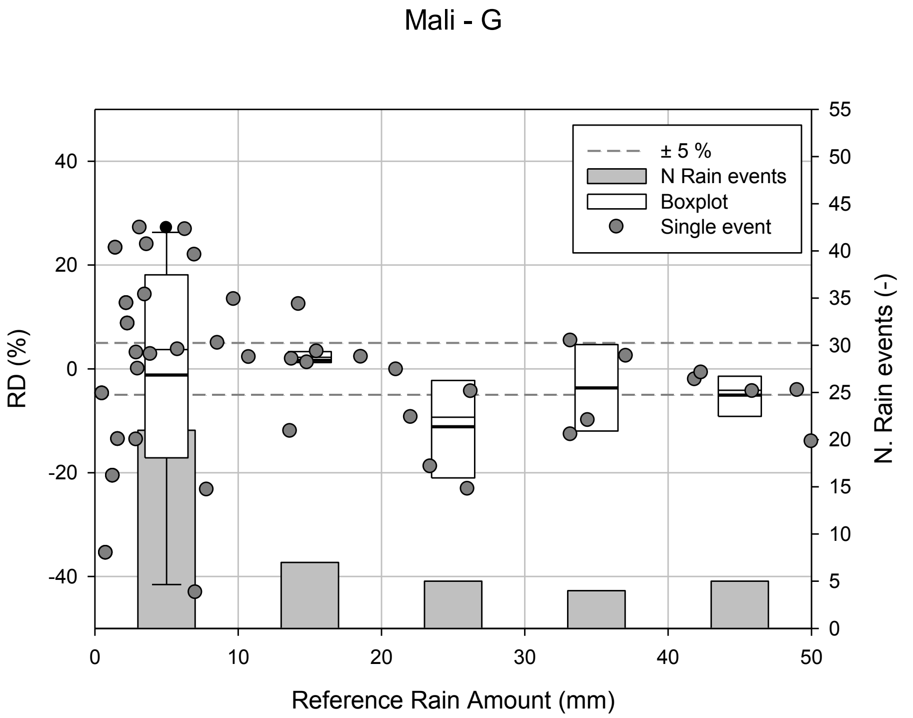

Fig. 5.16 Relative differences vs. the reference cumulated precipitation for the Mali-G gauge.

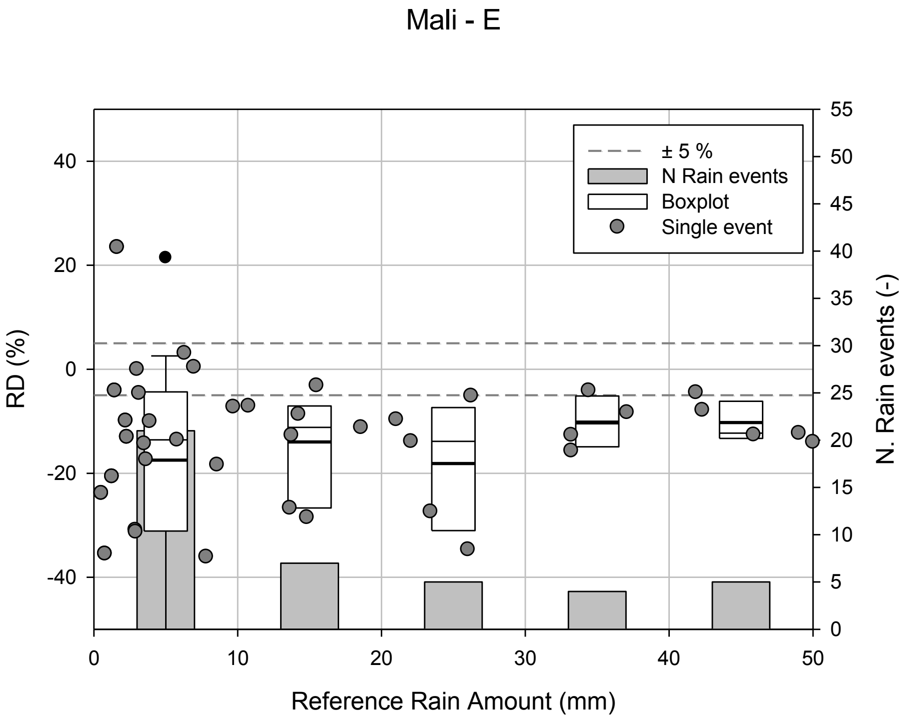

Fig. 5.17 Relative differences vs. the reference cumulated precipitation for the Mali-E gauge.

The performance of Mali-E gauge with respect to the other Metagri gauges can be mainly explained with the presence of an improperly tilted measuring strip on the plastic container which makes the reading difficult and inaccurate.

The table below reports few parameters for further analysis on the performance of simple plastic rain gauges field. In particular:

- the relative difference of the total accumulated precipitation ("Total RD"),
- the average relative difference of precipitation amount in all events ("Avg RD")
- the relative standard deviation σ, and
- the field achievable uncertainty

have all been calculated for each simple plastic rain gauges and shown in Table 5.3. The field achievable uncertainty has been represented as a relative uncertainty, namely u(80%), and calculated in terms of the interval where the 80% of all precipitation samples is found. This is a basic parameter characterizing the dispersion of the field precipitation measurements of plastic rain gauge under test.

		Ref	***Stratus***[5]	***S. Isidro***	***EU 50cm^2***	***Mali-G***	***Mali-E***
Tot acc	mm	**674,9**	585,6	629,6	656,1	646,7	585,2
Total RD	%		-3,8	-6,7	-2,8	-4,2	-13,3
Avg RD	%		-0,5	-8,4	-0,8	-2,7	-15,6
σ	%		8,5	11,7	10,1	18,0	15,8
2σ	%		17,1	23,4	20,2	36,0	31,6
u(80%)	%		*[-6,3÷9,6]*	*[-14,8÷ -0,1]*	*[-6,1÷9,5]*	*[-13,7÷12,6]*	*[-27,4÷ -4,6]*

Tab. 5.3 Synthesis of the performance parameters for all gauges.

For all gauges, a general underestimation of precipitation amount can be observed. Except for the Mali-E rain gauge, the uncertainty intervals are almost symmetric with respect to the average value (avg RD), indicating a normal distribution of deviations from the reference value. In conclusion, the Stratus and EU 50 cm^2 rain gauges show a smaller dispersion of precipitation measurements than S. Isidro and the two Mali gauges and a smaller underestimation of the reference precipitation amount (average relative differences close to 0).

5.5.2.3 Evaporation effects

Since the evaporation can represent a major issue for measurement accuracy in field conditions, especially in those regions where farmer simple plastic rain gauges are intended to be installed and sampled, a preliminary evaluation of such negative influence on measurements is provided below. The plots reported in Fig. 5.18 – 5.22 represent the trend of the Metagri rain gauges relative differences with respect to the cumulated reference precipitation for all samples, but making a clear separation between data sampling interval, basically 24 hours of sampling (daily events) and variable multiples of 24 hours (multiple daily events). Again, the gray dashed lines are ± 5% limits.

Except for Mali-E, whose performance is mainly affected by the improper attachment of the measuring strip, the plots of relative deviations actually show an increased underestimation of precipitation amount in those cases where the sampling time was larger than 24 hours, clearly indicating that the evaporation losses play an important role in measurement accuracy.

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[5] US – Status : no. of samples 38, field measurements started later (see sec.5.2 for additional explanation)

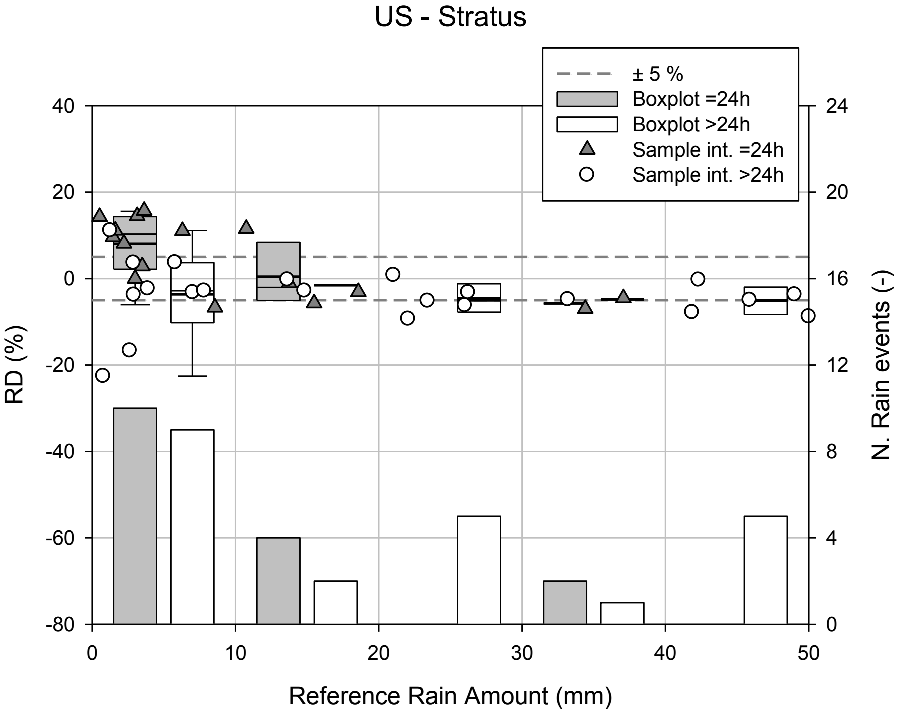

Fig. 5.18 Relative differences vs. the reference cumulated precipitation for the Stratus gauge.

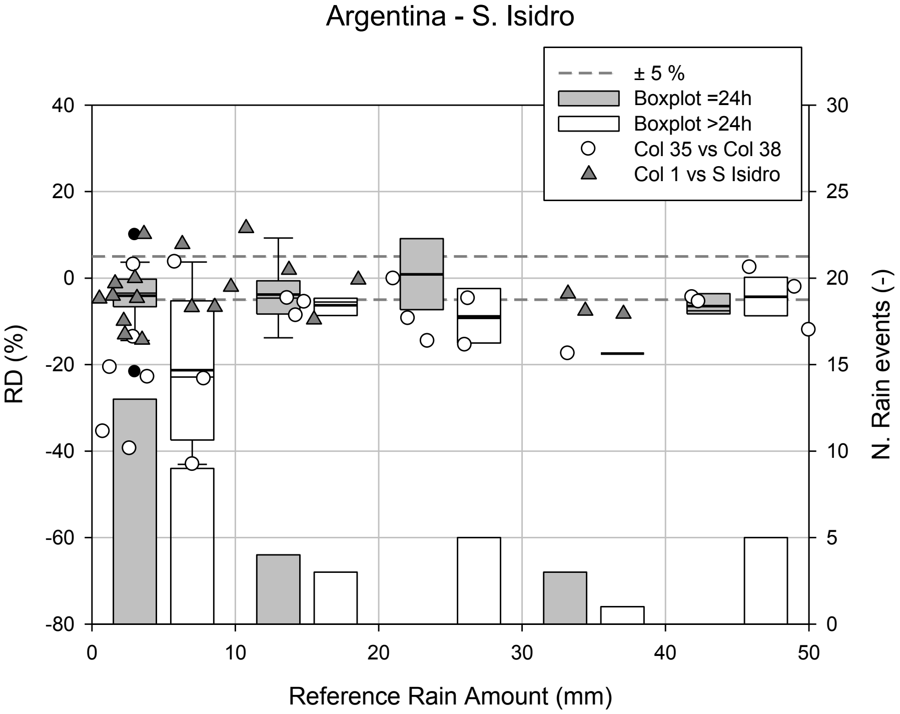

Fig. 5.19 Relative differences vs. the reference cumulated precipitation for the S. Isidro gauge.

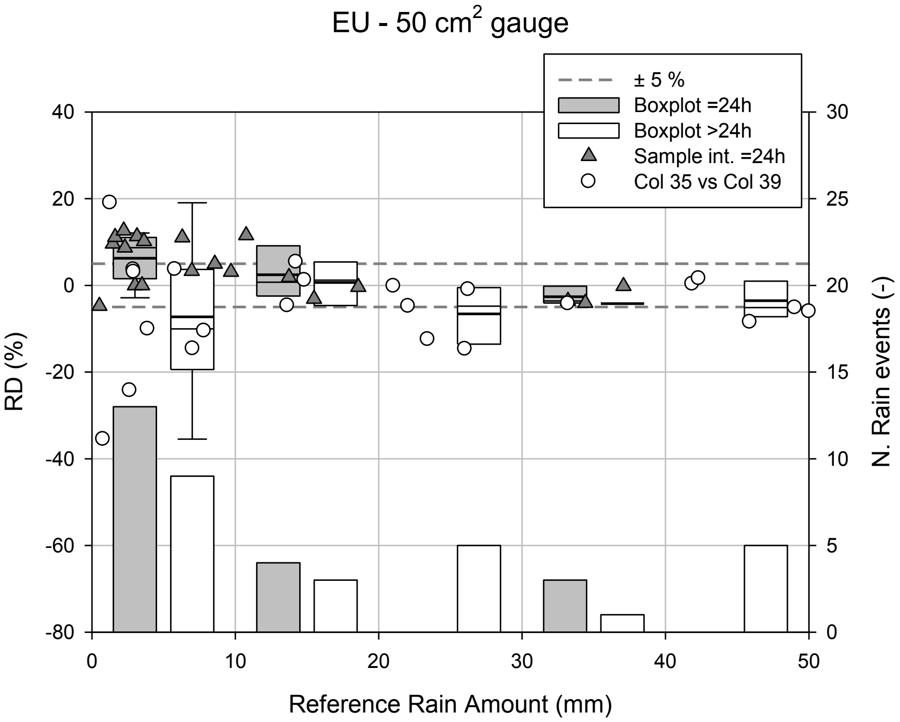

Fig. 5.20 Relative differences vs. the reference cumulated precipitation for the EU-50 cm^2 gauge.

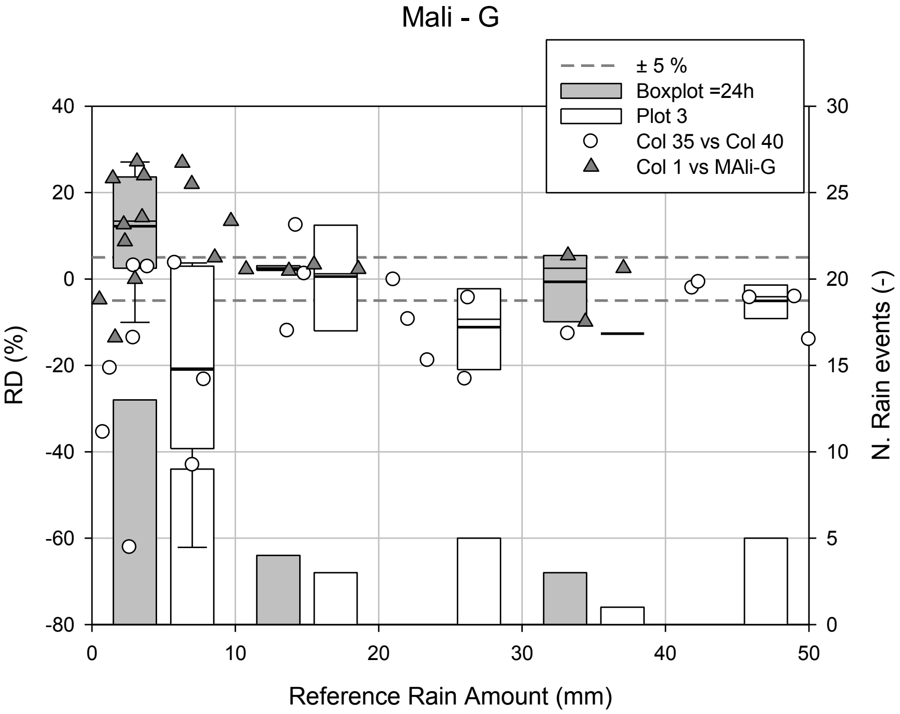

Fig. 5.21 Relative differences vs. the reference cumulated precipitation for the Mali-G gauge.

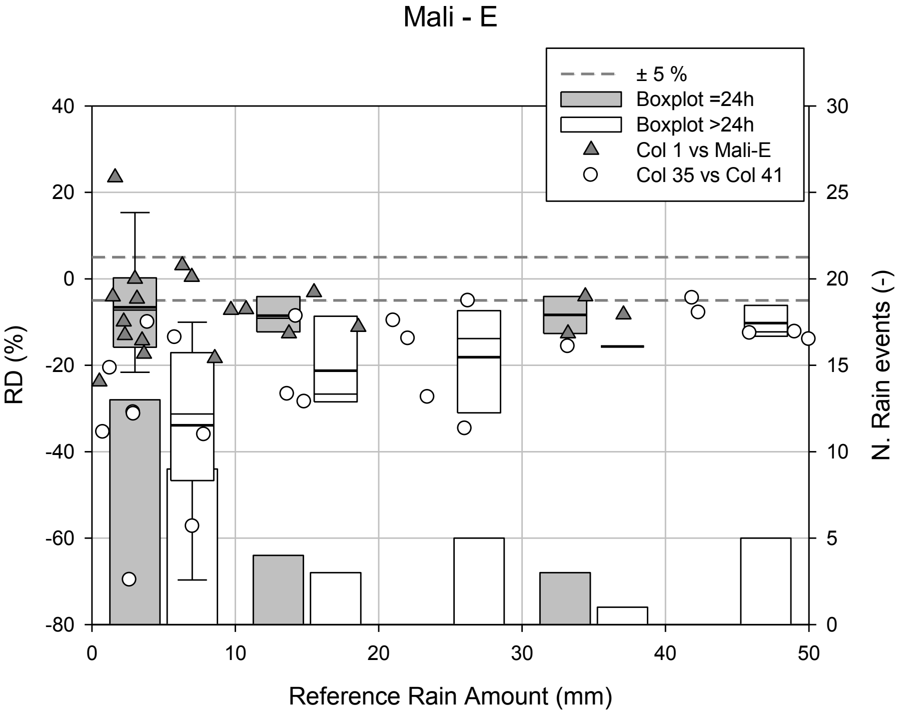

Fig. 5.22 Relative differences vs. the reference cumulated precipitation for the Mali-E gauge.

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6 – Overall assessment and recommendations

6.1 Overall assessment

The overall comments and recommendations follow the description of the laboratory and field experiment results reported in Chapter 4 and 5.

6.1.2 Laboratory tests

Model 1 - *SAN ISIDRO*

Model number 1 showed poor results due to reading difficulties related with the opaque material, the varying precision of the scale and a not clear marking of the numerical references. The laboratory analysis provided errors larger than +/- 5% with a reference precipitation amount smaller than 45 mm and larger than 116 mm with a poor WMO compliance index I_{WMO} = 5.0 (insufficient).

It is suggested to make thinner notches, clear and more defined references increasing the contrast, making immediate and understandable to which notch numerical values are related, increasing the length. Enlarge the scale between 0-20 mm to reduce the error at low precipitation and add circular references to reduce parallax errors.

Model 2 - STRATUS

Model 2 (STRATUS) showed the best performance in terms of measurement accuracy and material characteristics (declared UV resistant). This notwithstanding, readings may become difficult when the outer cylinder is involved (> 25.4 mm) and the operator reading tests highlighted the need of improving the chromatic contrast of the numerical references. In addition, the vertical section of the funnel should be increased to meet the specifications of WMO, point 4 and adding marks on the outer cylinder and circular references to reduce parallax errors is highly advisable. The error figures remain within +/- 5% in a when the reference precipitation ranges between 3 mm and 25.4 mm and for values larger 150 mm than with a WMO compliance index I_{WMO} = 8.7.

Model 3 - 100 cm^2 (MALI) gauge.

The measurements reading of Model 3 are based on a glued scale not engraved on the instrument. For this reason, the positioning of the scale may cause errors that are quantifiable only by checking each individual instrument. Similarly to the other models, circular references are recommended to reduce parallax errors and an increasing of the notches spacing would improve the reading. In particular, we suggest adopting a spacing that is larger than 2 mm in the 0-20 mm range. The WMO compliance index has an acceptable value equal to I_{WMO} = 6.7. Positive characteristics are the transparency of the material and the sharpness of the scale. With a few improvements, the error would remain within +/- 5%.

Model 4 . 50 cm^2 gauge.

The scale of model n. 4 is uniform between 0-50 mm resulting in a precision of +/-1 mm, while the WMO recommends a sensitivity at least equal to 0.2 mm for low precipitation amounts measurement. The collector orifice should be sharper to avoid precipitation catch errors due to the splashing of the raindrops that hit the rounded edge. The enlarged collector section before the measuring cylinder should be modified in order to meet the WMO requirements and avoid internal splashing. Circular references are recommended to reduce the parallax errors. The error is within +/- 5% and the overall score (I_{WMO} = 6.0) is sufficient for the transparency of the material and ease of reading, despite the low precision for light precipitation.

6.1.3 Field experimental campaign

Model 1 - SAN ISIDRO

A relevant underestimation (equal to -6.7% on the total accumulation with an average value of -8.4% on the single event) has been observed during the field campaign for model n. 1. This underestimation is combined with a significant dispersion of the measurements that can be related to the difficulties in reading, a problem highlighted also during the laboratory tests.

From the test performed to evaluate the evaporation impact, it emerges that evaporation has a significant effect on the measurements, exacerbating the underestimation of the rain accumulation, especially for low rain cumulated events.

Model 2 - STRATUS

Model 2 shows a relative low values of relative difference of total accumulation (-3.8%) and of single event average values (-0.5%). This fact, combined with a lower measurements dispersion, lead to evaluate this instrument as the more efficient with respect to the other gauges here considered.

Also, the evaporation tests highlights that a minimal effect has been observed in the range of low accumulation events, and this is lower if compared with the other gauges. The reason of this behavior can be ascribed to the presence of the upper funnel, which largely limit the evaporation.

Model 3 - 100 cm^2 (MALI) gauge.

Considering the remark on the glued scale for the reading and possible positioning effects, model n. 3 shows a large dispersion on the measurements relative distances. Moreover, we obtained values of the averaged relative distance of the precipitation amount of all the events which are significantly different between the two gauges under test (-2.7% for the MALI-G and -15.6% for the MALI-E). The same results is present if the total amount relative difference is considered (-4.2% for the MALI-G and -13.3% for the MALI-E). The requirement of a unique scale to read the precipitation amount is here evident.

The evaporation tests highlight the relevant influence of evaporation, which leads to an additional underestimation of the gauges measurements.

Model 4 - 50 cm^2 gauge.

The model n. 4 shows good performance in terms of relative difference of the total amount (-2.8%) and the average result of the precipitation amount relative difference in all events is comparable to the value obtained by the STRATUS gauge (-0.8%). Concerning the dispersion of the measurements, it exhibit good results, which is better than the other gauges except the STRATUS.

Evaporation tests point out a moderate influence especially in the events with low-mid accumulation.

6.2 Proposed improvements in materials or design of simple farmer rain gauges

The rain gauge should be designed according to the technical specifications and recommendations contained in the "Guide to Meteorological Instruments and Methods of observation", Guide N° 8 of the WMO/CIMO. The rain gauge should have at least the following characteristics:

- Material resistant to UV rays.
- The rim of the collector should have a sharp edge and fall away vertically inside and should be steeply bevelled outside.
- The area of the orifice should be known to the nearest 0.5 per cent.
- The construction of the orifice should be such That this area remains constant while the gauge is in use (plastic having a suitable coefficient of thermal expansion).
- The collector should be designed to prevent rain from splashing in and out. This can be done by having the vertical wall sufficiently deep and the slope of the funnel sufficiently steep (at least 45 per cent).
- The diameter should be less than 33 per cent of the rim of the gauge so as the container has a narrow entrance and is sufficiently protected to minimize the loss of water by evaporation.
- The graduations should be finely engraved, with marks at 0.2 mm intervals and be clearly figured with lines at each whole millimetre.
- Repetition of the main graduation lines on the back of the measure (helpful for reducing the errors of reading).

Thus the rain gauge that matches the characteristics required by WMO should be very similar to the rain gauge model n. 2 (Stratus), consisting of two cylindrical containers built with material resistant to UV rays and with a low coefficient of thermal expansion and a Collector designed to prevent rain from splashing in and out. The diameter of the outside cylinder must have a proper value with marks to bring the precision of at least +/- 0.5 mm. For small rainfall accuracy of 0.2mm the precision is maintained with the inner cylinder. Repetition of the main graduation lines on the back of the measure is helpful to reduce the reading errors. The most suitable dimensions of the collector (D 1), the diameters of the cylinders (internal D2 and external D3) and the maximum overall dimensions (H) can be defined only based on the expected daily maximum precipitation amount. A sketch of a suggest farmer rain gauge suitable to the Sahelian and Guinean climate is shown in Fig. 6.1.

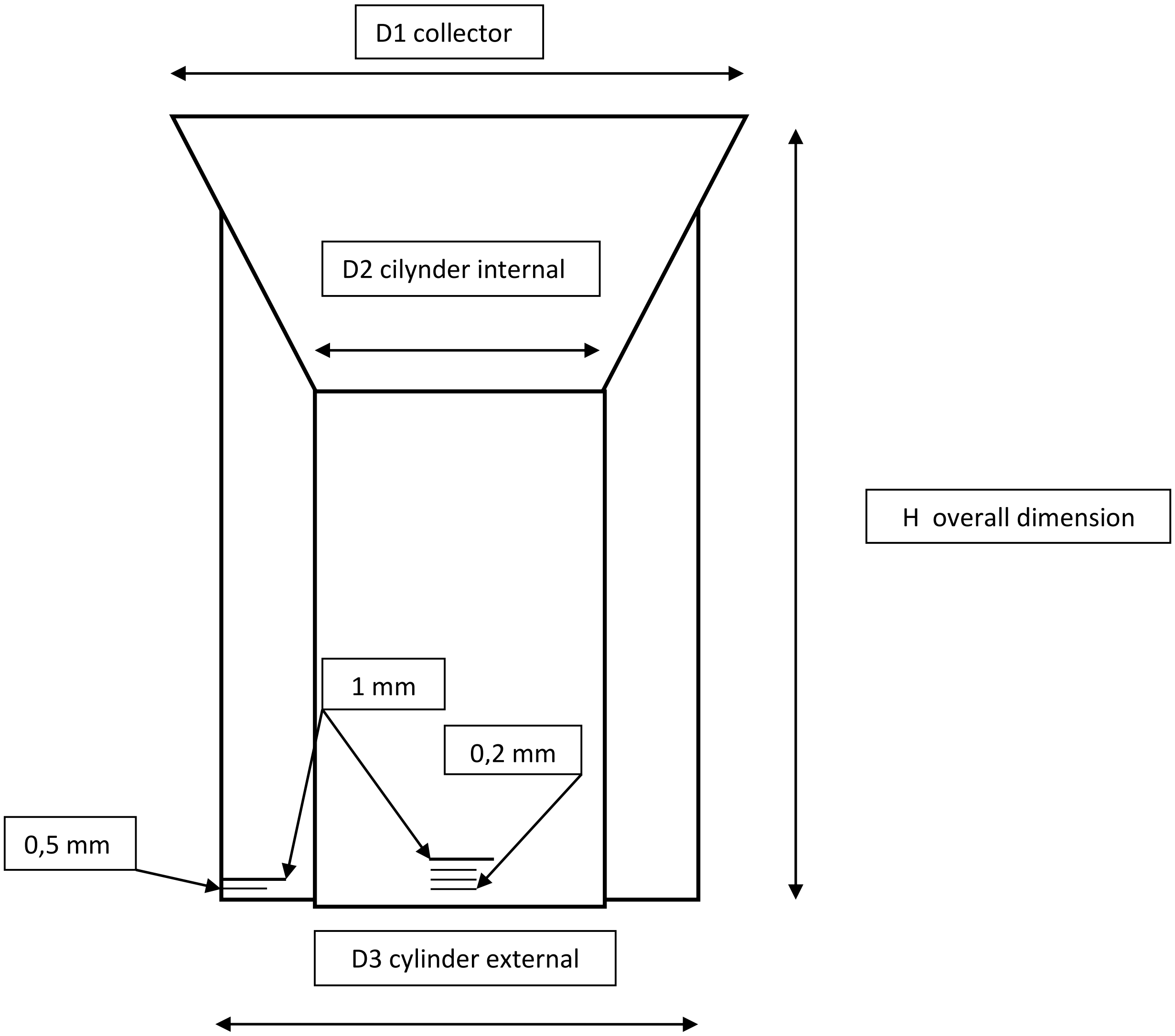

Figure 6.1 Sketch of a simple farmer manual gauge suitable to the Sahelian and Guinean climate.

6.3 Guidelines for instrument installation and reading for non-professional observers

The notebook data should include at least daily readings, if possible at the same time (or zero if there is no rainfall), the time of the observation, the observer's name and some notes. In particular, it is important to report whether the gauge is properly installed in a vertical position, the presence of any type of material (animals, leaves, sand, etc.) inside, any loss of transparency and whether the marker is yet defined and readable. This would allow proper maintenance or replacement. The installation in the vertical position is difficult with the current supports (see Figure 6.2), given the absence of stabilizer rods and a spirit level. We suggest using a stand with three rods, fixed to the ground to maintain a stable position, equipped with a spirit level to allow proper installation and control when the observer reads the instrument (see Figure 6.3).

Figure 6.2 Current support.

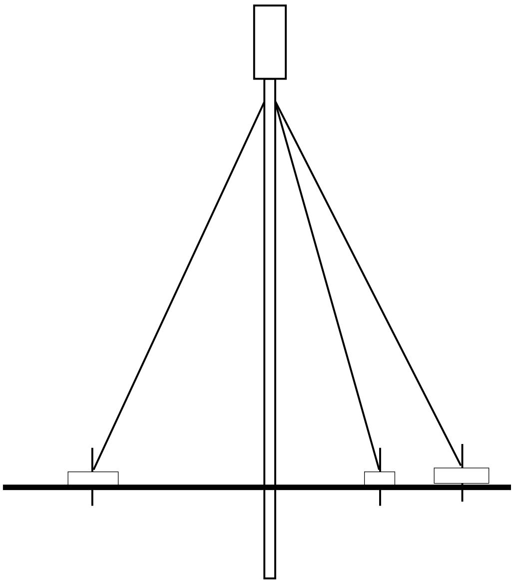

Figure 6.3 Proposed three rods solution

Given that the best procedure to reduce human errors is the awareness of the reason and the usefulness of the measurement performed, training with production of related material are essential to illustrate how the observations need to be made and how to fill the notebook of observations. During the practical exercises of reading, particular attention must be paid to the proper/correct positioning of the rain gauge and to perform the reading while avoiding the parallax error. In Figure 6.4 the positioning of the rain gauge is not correct; in Figure 6.5 the reading could result in a possible parallax error and in Figure 6.6 devices (e e.g. spirit levels) for proper setting are not shown.

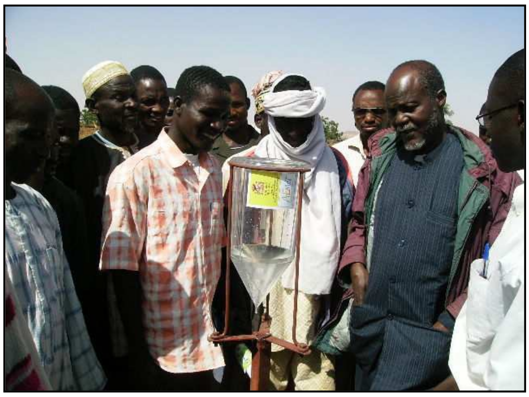

Figure 6.4 Incorrect positioning of the rain gauge (levelling).

Figure 6.5 Parallax error could affect the reading.

Figure 6.6 Spirit levels seem to be missing.

Therefore, measurements should be performed using the following procedure:

1. Fill in the notes of the book describing the state/condition of the instrument. To facilitate the observer's task, precompiled forms can be provided that need only be confirmed or not (spirit levelled/vertical position, presence of material inside, sand, proper transparency, mark / readable scale, etc.).
2. Read any data recorded by the instrument properly positioned, and write its value in the notebook.
3. The data have to be read, according to the WMO requirements, "for all measurements the bottom of the water meniscus level should define the water level".
4. Drain and dry the instrument.
5. Reposition the measuring station into operational conditions and fill any special notes.
6. In case of reading during a rain event, wait – if possible – a pause in rain in order to minimize the error. Otherwise, record the daily reading even with the rain.
7. Any judgment/opinion/valuation of the event, (heavy, medium or weak) ongoing or occurred between two periods of reading would be desirable.
8. An area should also be appointed (which includes more instruments) that periodically checks whether and how the observations are made.
9. Transmit to the data center the module compiled monthly by the area responsible, which shows the daily values of the various instruments and any comments.

10 – Conclusions

Some of the currently adopted solutions for simple farmer rain gauges show gross design errors affecting the measurement accuracy of rainfall accumulation. Gross errors appear in the form of misalignments of the graduation bar, insufficient refinement of graduation marks, poor quality of the construction material, etc.

When the basic system design is correct, laboratory tests suggest that the calibration and accuracy of simple farmer rain gauges are generally good and inaccuracies are mostly associated with random errors due to subjective operator influence and the reading modalities.

Field tests confirmed the results of the laboratory assessment and demonstrated that environmental factors such as evaporation and wind can lead to significant inaccuracies in 24-h rainfall accumulation measurements. In particular, evaporation is identified as the most relevant source of systematic inaccuracies, which are expected to assume an even larger role in a warm climate.

The importance of a standardized measurement procedure and dedicated training of the personnel who actually perform the measurement are highlighted as key factors to achieve accurate measurements.

Two indications to foster more reliable rainfall measurements for agricultural purposes seems to emerge, i.e. to improve the design of the gauge and continue with training and the dissemination of good practices in measurement procedures.

The overall results of the performed laboratory and field tests indicate that improved design of a new farmer rain gauge should aim at reducing the impact of evaporation and wind on the catching performance of the gauge. Evaporation is the most relevant issue for 24-h accumulation measurements, while wind plays a minor role unless very light rainfall is considered.

Any post-processing for the correction of recorded data would require further measurements of related variables (temperature, humidity, wind) and is generally unfeasible at most locations. Instead, the role of evaporation can be minimized e.g. by reducing the accumulation time interval (increasing the frequency of readings), or by employing a more specific design of the gauge.

It is worth underlying that standardization of both the instrument performance and measurement procedures at the international level is an essential requirement in order to ensure the homogeneity of rainfall measurements across various countries, and comparable accuracy of the derived information.

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