EJP SOIL
European Joint Programme

Towards climate-smart sustainable management of agricultural soils

SCALE

Managing Sediment Connectivity in Agricultural Landscapes for reducing water Erosion impacts

Deliverable WP3-D1

Final report on the comparative analysis of accuracy and costs of the different soil erosion measurement and observation techniques, based on partner experience.

Due date of deliverable: M33

Actual submission date: 15.02.2024

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

GENERAL DATA

Grant Agreement: 862695
Project acronym: EJP SOIL SCALE
Project title: Managing Sediment Connectivity in Agricultural Landscapes for reducing water Erosion impacts
Project website: www.scale-ejpsoil.eu

Start date of the project: February 1st, 2021
Project duration: 42 months
Project coordinator: Elmar M. Schmaltz (BAW)

Funding source: H2020-SFS-2018-2020 / H2020-SFS-2019-1
Type of action: European Joint Project COFUND

DELIVERABLE NUMBER:	WP3-D1
DELIVERABLE TITLE:	Final report on the comparative analysis of accuracy and costs of the different soil erosion measurement and observation techniques, based on partner experience.
DELIVERABLE TYPE:	Report
WORK PACKAGE N:	WP3
WORK PACKAGE TITLE:	Standardization of up- and downscaling techniques of data from field to catchment
DELIVERABLE LEADER:	M. Fantappiè, CREA
AUTHORS:	M. Fantappiè[1], S. Pellegrini[1], N. Vignozzi[1], P. Deproost[2], S. Callewaert[2], P. Strauss[3], L.L. Johannsen[3]
DISSEMINATION LEVEL:	PU

Affiliations

No	Abbreviation	Name	linked third party to
1	CREA	Council for Agricultural Research and Economics / Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria	
2	VPO	Flemish Planning Bureau for the Environment and Spatial Development / Vlaams Planbureau voor Omgeving	EV-ILVO
3	BAW	Federal Agency for Water Management	BIOS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Table of Contents

1 Introduction

Calibration and validation of soil erosion models is essential to have reliable results, to be used in soil erosion monitoring programs, especially when fixed target values are set be achieved by soil protection measures. According to Borrelli et al. (2016), who reviewed 3030 erosion modelling records from 126 countries, in the early period (1994–2000) of soil-erosion modelling the percentage of studies accompanied by validation/evaluation was higher, than in the following period 2000 to 2015. They reported that, of the most applied models, those with the highest share of validation/evaluation (>85%) were ANSWERS, PERFECT, USLE-M, DSESYM, and EUROSEM. SWAT and WaTEM/SEDEM both had values around 80%, while LISEM, WEPP, and MMF total 72, 66, and 63.3%, respectively. Applications of USLE and RUSLE models showed reasonably high (63–69%) validation/evaluation values when applied to simulate sediment yield. However, these values drop when validating/evaluating hillslope gross erosion estimates (RUSLE: 41%; USLE: 34%). An extensive set of techniques were included in the validation/evaluation group, ranging from volumetric loss measurement (e.g., pins, cross-sections, contour gauge, and terrestrial laser scanning) to qualitative observations performed through field observations and remote sensing. About one-third of the entries reported model calibration. The models with the highest shares of calibration were SWAT, LISEM, WaTEM/SEDEM, and MMF.

An analysis of the different costs related to the implementation of the different techniques to measure and/or qualitatively evaluate soil erosion is missing. The aim of the present deliverable is to report the partners' experience on the accuracy and costs of the different techniques.

2 Partners experience

2. 1 CREA

2.1.1 At subfield-scale

Rainfall simulation

CREA carried out a field rain simulation campaign aimed to investigate the cause-effect relationship between rainfall kinetic energy and soil surface crusting, allowing some physico-mathematical description of the sealing mechanisms (Panini et al., 1997). This approach contributed to filling the gap between seal-causing processes and seal-induced effects. This study also contributed to the mathematical formalization of the effect of raindrop impact on soil macroporosity.
CREA also used simulated rainfall to assess the effect of different rates of organic amendment addition on topsoil structural properties (Pellegrini et al., 2013).

2.1.2 At field scale

1) Drone image analysis

CREA has experience in photogrammetry from aerial images acquired via Unmanned Aerial Vehicles (UAVs). This methodology has been developed for three main purposes: i) to obtain a quick measurement of rill erosion at field scale combining the simplicity of field survey to reliability of results

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

at an affordable cost; ii) to calibrate the RUSLE model to make it suitable for the purposes of CAP indicator assessment; iii) to provide a tool to technical regional services and independent evaluators responsible for the evaluation or rural development plans and soil conservation measures implemented within the framework of the CAP.

To determine the effectiveness and reliability of the new methodology a comparison between rill depth measured manually on 51 points and depth measured by UAV method was made. The obtained linear regression equation was highly significant (R^2=0.87). The UAV methodology has proven useful in terms of speed of data acquisition, degree of automation of data processing and economic efficiency (Bazzoffi, 2015). The main advantage of micro drone UAV photogrammetry is the possibility of obtaining, at affordable costs, high-resolution Digital Elevation Models (DEMs) from stereo images taken near the soil surface by a high-resolution camera. Furthermore, since the equipment is easy to acquire and manage, the user can schedule the flight plan when sunlight, weather and soil surface condition are favorable to obtain pictures suitable to generate a high-quality DEM. On contrary, the major limitation for obtaining good quality aerial images are: i) the presence of vegetation and crop residues that cover the soil surface, and ii) the shadow shifting between consecutive photo capture on adjacent areas (Bazzoffi, 2015).

Using soil loss data from 9 Italian experimental sites, a comparison was also made between erosion values estimated by RUSLE model and the ones measured by UAV method. The statistical analysis did not highlight any significant difference between the measured values and those estimated by the RUSLE model (Bazzoffi et al., 2015). Despite the limited number of observations, it can be stated that the correspondence between RUSLE estimated erosion values and the ones obtained by the UAV methodology is quite satisfactory.

The method was accurate, but it was not maintained by CREA, due to lack of staff.

<u>2) Visual inspection of erosion features</u>

CREA developed a software (ISUM*mate*) (Andrenelli et al., in press) based on the Improved Stock Unearthing Method (ISUM) (Brenot et al., 2008), able to estimate the erosion rate based on the difference of soil volumes, calculated considering the actual level of soil surface and that at vineyard plantation time, identified by the position of the grafting point (Casalì et al., 2009; Rodrigo-Comino et al., 2016). The tool requires as input, soil surface measurements and user's specifications related to vineyard design, tractor and soil characteristics, and returns, for each couple of consecutive surveyed transects, the erosion and deposition rate. The application has an intuitive design and includes instructions for users.

The application of the tool to a 16-year-old vineyard managed with continuous tillage and permanent grass provides coherent data, particularly for permanent grass.

ISUM*mate* application will be downloadable at https://github.com/SUVISA-project/ISUMmate, where further program versions will be continuously updated, and tutorials and handbooks added.

<u>3) Observations in field of presence or absence of evidence of soil erosion</u>

CREA stores in the national soil database 21,650 georeferenced observations in field on the presence or absence of evidence of soil erosion (table 1), collected during soil sampling campaigns in a period of time from 1952 to 2020. Both the observation of presence and absence of evidence of soil erosion has proven to be very useful in the qualitative validation of soil erosion mapping (Fantappiè et al., 2014).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

These qualitative observations are at no cost, apart from the time to record and store the information taken in field.

Table 1. Numbers of recorded field observations on the presence or absence of evidence of soil erosion extracted from the CREA national soil database.

Erosion type	from	to	N° of observations
absent	01/03/1952	05/11/2019	8572
water sheet erosion	01/06/1955	30/09/2020	9144
water rill erosion	01/06/1953	24/10/2019	2002
water gully erosion	01/06/1955	25/11/2014	582
water tunnel erosion	17/03/2007	17/03/2007	2
debris avalanches	01/06/1958	08/10/2012	26
earthflows	06/12/1983	16/06/2016	107
creeping and solifluction	01/01/1980	27/06/2012	106
wind erosion	10/07/1968	02/03/2017	1087
karst erosion	09/10/1991	08/10/2008	14
water bank erosion	16/04/1999	14/07/2016	5
anthropic erosion	10/05/1992	12/12/2008	3
total	01/03/1952	30/09/2020	21650

2.1.3 At catchment scale

CREA has compiled a data set with sediment deposition rates for reservoirs constructed in the 1950's and 1960's throughout Italy (Van Rompaey et al., 2003). Sediment deposition rates were assessed by direct sonar sub-bottom profiler measurements or derived from estimates and measures made by

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

ENEL (Italian Electricity Power Company) during dredging or from direct surveys. Only lakes and reservoirs with a likely sediment trapping efficiency of 100% were considered. Nevertheless, there is never a 100% guarantee that sediment trapped in a reservoir represents the total sediment yield from the watershed in the lapse of time from dam building to survey time. For this reason, only 44 watershed-reservoir systems were selected from the database, retaining only the better-known ones respect to management history. The sediment volumes were converted to mass volumes using a mean bulk density of 0.865 t m^{-3} derived from the direct analysis of sedimentary profiles of 4 reservoirs of the data set. Further details can be found in the cited document. The method was accurate, and it was used to validate the soil erosion risk map of Italy produced in collaboration with JRC, but it was quite costly and therefore it was not maintained by CREA, due to lack of staff.

2.1.4 Conclusions for CREA

The conclusions which can be taken by analyzing the summary provided in Table 2 is that the requirement in staff efforts of higher accurate instruments make their maintenance in functions more difficult. Measured visual inspections in the field seems a good compromise between accuracy and cost. Qualitative observation in field has also its advantages for a qualitative evaluation of soil erosion maps.

Table 2. Summary table of the experience in measuring/estimating soil erosion at CREA

INSTRUMENT TYPE	APPLICABILITY SCALE FOR CALIBRATION/VALIDATION	ACCURACY	COST	AVAILABILITY AT PARTNERS
Rainfall simulation	SUB-FIELD	high	medium	YES
UAV image analysis	FIELD	high	Medium-High	NO
Measured visual inspection	FIELD	medium	Low-medium	YES
Qualitative observations in field	FIELD	low	low	YES
Sediment deposition in reservoirs	CATCHMENT	high	high	NO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

2.2 VPO

2.2.1 At field – sub-catchment scale

In certain instances, VPO has employed Unmanned Aerial Vehicle (UAV or drone) flight observations to quantify erosion at the parcel or sub-catchment scale. This approach offers the advantage of acquiring high-quality data within a relatively short timeframe and at relatively low, that is, at a medium cost. The utilized drone at VPO is equipped with a visible light sensor, serving the purpose of photogrammetry. This capability facilitates the creation of an accurate 3D model of the landscape, providing valuable insights into features such as rill and gully formation. The drone has a flight duration of 15 to 18 minutes, covering an area of approximately 14 hectares. The resolution and accuracy of the photogrammetric output range from a few millimetres to 1 centimetre; however, several factors may influence accuracy, including flight height, vegetation cover density, and the presence of direct sunlight. To address some of these challenges, LiDAR apparatuses could be mounted onto drones, resulting in higher resolution and improved vegetation penetration for imagery. Nevertheless, this enhancement comes with a significantly higher economic cost, both in terms of technological devices and image processing capacity.

Moreover, addressing challenges related to drone flights is imperative. Firstly, navigating through diverse legislative laws is essential, often established at varying governmental levels, including European, national, or even regional. Restricted airspaces around airports and military bases impose limitations on flight altitudes and may even prohibit drone operations in specific locations or during certain times. This necessitates thorough planning and certification procedures before conducting drone measurements, hindering the spontaneity of assessments during sudden erosion events.

Secondly, in accordance with privacy and safety legislation, conducting drone flights over individuals and residences is prohibited without proper licensing and explicit consent. Obtaining permission for aerial photogrammetry measurements, especially in densely populated areas like most of Flanders, poses a considerable challenge.

Lastly, favourable weather conditions are crucial for optimal drone flights, requiring minimal wind, humidity, ample direct sunlight, and cloud-free skies. Unfortunately, these conditions are not always present during erosion events, making real-time measurements challenging. Consequently, resorting to before-and-after comparisons becomes necessary to estimate erosion totals. Nevertheless, executing these comparisons on a (sub-)catchment scale proves to be an expensive and time-consuming endeavour, whereas preforming them on a parcel scale could be more feasible. This is, however, currently not done by VPO or collaborating entities in Flanders for erosion monitoring purposes.

2.2.2 At catchment scale

1) On land observations

In Flanders, no long-term sediment and/or erosion observation measurements have been conducted by VPO. However, at the municipal level, records are available for locations where erosion or sediment problems have been identified. These observations primarily consist of qualitative information rather than precise measurement data that could be used to quantify erosion streams and denudation rates. Nonetheless, these observations contribute to understanding the patterns of sediment distribution in the landscape and can be utilized to validate modelled sediment streams at the catchment level. It is

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

crucial to recognize that the way and the purpose behind these observations have inherent social and economic biases. Since these observations are primarily carried out for civil erosion mitigation planning, documentation focuses only on erosion and sedimentation problems that pose social or economic threats, overlooking some of the more concealed or less acknowledged environmental consequences. Additionally, there are no standardized procedures for these observations, as most erosion mitigation plans are executed only at the municipal or sub-regional level. This lack of standardization poses challenges in comparing different datasets with each other.

2) Sediment monitoring in watercourses and sediment retention ponds

Since 2000, the Flemish Environment Agency (VMM) manages several sediment monitoring stations in Flanders. The oldest stations are situated in the erosion-prone areas of the Upper Scheldt Basin, later different sediment monitoring stations were installed in the Demer Basin (VMM, 2008), Dyle basin and other locations in Flanders. Some monitoring stations are temporary, other stations will remain operational to evaluate the temporal variations. At each monitoring station, turbidity, sediment concentration and flow rate are measured.

The (water) turbidity is measured using turbidity sensors. These operate via an optical light beam sent into the water, the degree of reflection on suspended material (sediment) in the water column is a measure of water turbidity. Since turbidity is highly correlated with suspended sediment concentration in the watercourse, a calibration curve can be established between the sediment concentration and turbidity.

The sediment concentration refers to the total fraction of suspended matter in the water column. This concentration is determined in the laboratory by the dry residual analysis. The samples are taking during rainfall events throughout the year.

The sediment load or sediment export (SE, tonnes/yr) through a watercourse for a given time period is the sum of the sediment flow rates of the watercourse over this period. The sediment flow rate (kg/s) of a watercourse is determined by multiplying water flow and sediment concentration. The sediment export per unit area of catchment is called 'specific sediment export' (SSE, unit tonnes/ha/yr).

The monitoring stations generate continuous measurement data with a measurement frequency of 15 minutes. The stations operate as autonomously as possible, with data being automatically transmitted 4 times a day to a central database. The data from the sediment measuring stations (flows and sediment concentrations) are publicly available via waterinfo.be.

These measurements are combined with sediment accumulation data of retention ponds to calibrate the WaTEM/SEDEM model for Flanders.

2.2.3 Conclusions for VPO

Unmanned Aerial Vehicle (UAV or drone) flight observations are promising techniques to monitor erosion processes, but equipping these UAV with LiDAR apparatuses has several advantages compared to visible light sensors. Restricted airspaces, privacy and safely legislations in densely populated areas and bad weather conditions may hamper drone flights. On land observations at catchment scale can be used to qualitatively validate modelled erosion and sedimentation processes but are to be improved by standardizing observation procedures. Monitoring of sediment loads in watercourses provides essential data to calibrate and validate models like WaTEM/SEDEM.

Table 3. Summary table of the experience in measuring/estimating soil erosion at VPO

INSTRUMENT TYPE	APPLICABILITY SCALE FOR CALIBRATION/VALIDATION	ACCURACY	COST	AVAILABILITY AT PARTNERS
UAV image analysis	FIELD/SUB-CATCHMENT	high	medium-high	YES/NO (possibility to expand, but no real monitoring history)
Observation records of sedimentation and erosion	CATCHMENT (especially populated areas)	low	low	YES
Sediment monitoring in watercourses and retention ponds	CATCHMENT	high	high	YES

2.3 BAW

2.3.1 At sub-field scale

Rainfall simulation

A second tool that we use quite often is rainfall simulation (Strauss et al., 2000; Davidova et al., 2015). It is not possible to provide a general error because of the impossibility of providing true values. A typical coefficient of uniformity is in the range of 0.8 – 0.9 (Christiansen uniformity coefficient) but this does not provide sufficient detail yet to estimate a general error of an application. Typical costs of using a rainfall simulator are in the middle range between 500 – 5000 €. This depends to a large extent on the size of a rainfall simulator and the side equipment that is used when applying it.

2.3.2 At field scale

1) Image analysis

We use close-range photogrammetry and image analyses to measure various soil surface properties: proportion of dead/living soil cover (Riegler-Nuerscher et al., 2018, Bauer and Strauss, 2014) and soil surface roughness/bulk density (Bauer et al., 2015, Bauer et al., 2014, Laburda et al., 2021). Some details about the accuracy of measurements are provided in the respective papers. As a general rule the accuracy of close-range photogrammetry is in the range of few mm – 1 cm. The error of image analysis for automatic detection is about 5%. The advantage of both methods is their low costs and

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

easiness of measurement. Low cost in this context means costs of less than 500 € to establish measurements.

2) Tipping bucket and disdrometer measurement for rainfall

Tipping bucket equipment can both be used for the collection of rainfall and runoff water from erosion plots. The typical size of rain gauges that use tipping buckets is in the volume range of between 100 cm^2 and 500 cm^2. Today they do not represent the last evolutionary step in rainfall data technology. They have been replaced by rain gauges that work on a balance principle. The typical costs of tipping buckets rain measurements are about 1000 €, while the cost for balance-based equipment is about 4000 €. Another way of measuring rainfall is with disdrometers, which measure raindrop size and velocity and thus can be used for improved rainfall erosivity estimation. However, the accuracy of disdrometers vary among the available types (Johannsen et al., 2020a, 2020b). The cost of disdrometers starts at around 3000 € upwards.

3) Tipping bucket measurement for runoff

Another way of tipping bucket implementation for erosion studies is to use them for the measurement of runoff volumes on erosion plots (Konzett et al., 2024). Typical sizes for their implementation vary between a few m^2 to 100 m^2. The advantage of using tipping bucket systems is to record the total runoff volume dynamically via the number of tips per unit of time. Together with a system to collect a small share of the total volume it is also possible to obtain information about the total sediment load that is occurring during single events. The costs of such a system would be in the middle range for one plot (about 3000 €).

4) Visual inspection of erosion features

A common method to establish erosion rates of typical field to small catchment scales is the visual inspection of visible erosion features. This can be accomplished either manually using measuring tapes to record the length, width, and depth of single erosion rills or gullies. There is an increasing effort to monitor these features automatically using drones, also from our side. The costs for implementing such a method are medium when using drones but not cheaper when using visual inspection because of a relatively high cost of manpower.

2.3.3 At catchment scale

Flumes

Flumes are typically used for relatively small but continuous flow conditions to monitor headwater catchments. Various types exist; one commonly used type is the so-called H-flume, a device that enables flow measurements for a particularly wide range of flow conditions (Blöschl et al., 2016). In addition to the flume itself, for every flume, there is a need to measure flow depth. This can be accomplished with different systems ranging from pressure transducers to radar sensors. Our experience suggests using radar sensors because of their precision (a few mm) and ease of use. In contrast, pressure transducers may exhibit a different behavior for the rising and falling limb of a flow curve. Costs for a complete implementation of a flume (plus measurement device) are typically in the range of several thousands of Euro.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

2.3.4 Conclusions for BAW

Costs of equipment in general are independent of the scale of observation. They depend largely on the quality of the data sets obtained in terms of temporal and spatial resolution of data collection. Also, costs in Table 4 refer only to costs for purchasing and setting up the instruments. Thus, costs for person power to maintain equipment and analyze data obtained have not been included. However, these costs are usually much higher compared to purchasing costs, independent of the equipment of interest.

Table 4. Summary table of the experience in measuring/estimating soil erosion at BAW

INSTRUMENT TYPE	APPLICABILITY SCALE FOR CALIBRATION/VALIDATION	ACCURACY	COST	AVAILABILITY AT PARTNERS
Rainfall simulation	SUB-FIELD	high	medium	YES
Tipping bucket	FIELD	high	medium	YES
Image analysis	FIELD/CATCHMENT	high	Medium-High	YES
Measured visual inspection	FIELD	medium	Low-Medium	YES
Flume and sediment concentrations	CATCHMENT	high	medium	YES

3. Conclusions

The main conclusions which can be derived by the comparative analysis of partners experience (Table 5) is that the costs of equipment in general are independent of the scale of observation and that the costs for person power to maintain equipment and analyze data obtained are usually much higher compared to purchasing costs, independent of the equipment of interest. Measured visual inspections in the field seems a good compromise between accuracy and cost, in case that there is shortage in staff availability.

Qualitative observation in field and at catchment scale are used both by CREA and by VPO to qualitatively validate modelled erosion and sedimentation processes but are to be improved by standardizing observation procedures.

A promising technique, applied by all partners, is the photogrammetry which can be applied using Unmanned Aerial Vehicle (UAV or drone). The drawbacks of this technique to be considered, us

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

underlined by the colleagues of VPO, are restricted airspaces, privacy and safely legislations in densely populated areas and bad weather conditions may hamper drone flights.

Flume and sediment concentration monitoring and monitoring of waterflow and sediment concentration in watercourses, retention ponds and in reservoirs provides essential data to calibrate and validate erosion models at catchment scale and have been used both by Belgium and by Italy to calibrate and validate soil erosion maps at national scale.

Table 5. Summary table of the experience in measuring/estimating soil erosion for all partners

INSTRUMENT TYPE	APPLICABILITY SCALE FOR CALIBRATION/VALIDATION	ACCURACY	COST	AVAILABILITY AT PARTNERS
Rainfall simulation	SUB-FIELD	high	medium	CREA & BAW
Tipping bucket	FIELD	high	medium	BAW
Measured visual inspection	FIELD	medium	Low-Medium	BAW and CREA
Qualitative observations in field	FIELD	low	low	CREA
Observation records of sedimentation and erosion	CATCHMENT	low	low	VPO
UAV and Image Analysis	FIELD-CATCHMENT	high	Medium-High	ALL PARTNERS
Sediment monitoring in watercourses, retention ponds and in reservoirs	CATCHMENT	high	high	CREA and VPO
Flume and sediment concentrations	CATCHMENT	high	medium	BAW

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

References

Andrenelli M.C., Fila G., Vignozzi N, Pellegrini S., Quick and friendly procedure set up to quantify soil erosion in vineyard. In Press on: BIO Web of Conferences

Anton J.J. Van Rompaey, Paolo Bazzoffi, Robert J.A. Jones, Luca Montanarella, Gerard Govers, Validation of Soil Erosion Risk Assessments in Italy. European Soil Bureau Research Report No.12, EUR 20676 EN, (2003), 25pp. Office for Official Publications of the European Communities, Luxembourg.

Bauer, T., P. Strauss, 2014: A rule-based image analysis approach for calculating residues and vegetation cover under field conditions. Catena 113, 363-369. https://doi.org/10.1016/j.catena.2013.08.022

Bauer, T., P. Strauss and E. Murer, 2014: A photogrammetric method for calculation soil bulk density. J. Plant Nutr. Soil Sci., 177, 496-499, https://doi.org/10.1002/jpln.201400010

Bauer, T., P. Strauss, M. Grims, E. Kamptner, R. Mansberger, H. Spiegel, 2015: Long-term agricultural management effects on surface roughness and consolidation of soils. Soil & Tillage Research 151, 28-38, https://doi.org/10.1016/j.still.2015.01.017

Bazzoffi P., 2015. Measurement of rill erosion through a new UAV-GIS methodology. Ital. J. Agron. 10(s1):708

Bazzoffi P., Francaviglia R., Neri U., Napoli R., Marchetti A., Falcucci M., Pennelli B., Simonetti G., Barchetti A., Migliore M., Fedrizzi M., Guerrieri M., Pagano M., Puri D., Sperandio G., Ventrella D., 2015. Environmental effectiveness of GAEC cross-compliance standard1.1a 'temporary ditches' and 1.2g (permanent grass cover of set-aside) in reducing soil erosion and economic evaluation of the competitiveness gap for farmers. Ital. J. Agron. 10(s1):710

Blöschl, G., Blaschke, A. P., Broer, M., Bucher, C., Carr, G., Chen, X., Eder, A., Exner-Kittridge, M., Farnleitner, A., Flores-Orozco, A., Haas, P., Hogan, P., Kazemi Amiri, A., Oismüller, M., Parajka, J., Silasari, R., Stadler, P., Strauss, P., Vreugdenhil, M., … Zessner, M. (2016). The Hydrological Open Air Laboratory (HOAL) in Petzenkirchen: A hypothesis-driven observatory. Hydrology and Earth System Sciences, 20(1), 227–255. https://doi.org/10.5194/hess-20-227-2016

Borrelli, P., Alewell, C., Alvarez, P., Ayach Anache, J.A., Baartman, J., Ballabio, C., Bezak, N., Biddoccu, M., Cerdà, A., Chalise, D.,Chen, S., Chen, W., De Girolamo, A.M., Gessesse, G.D., Deumlich, D.,Diodato, D., Efthimiou, N., Erpul, G., Fiener, P., Freppaz, M., Gentile, F.,Gericke, A., Haregeweyn, N., Hu, B., Jeanneau, A., Kaffas, K.,Kiani-Harchegani, M., Lizaga Villuendas, I., Li, C., Lombardo, L.,López-Vicente, M., Lucas-Borja, M. E., Märker, M., Matthews, F., Miao, C.,Mikoš, M., Modugno, S., Möller, M., Naipal, V., Nearing, M., Owusu, S.,Panday, D., Patault, E., Patriche, C. V., Poggio, L., Portes, R.,Quijano, L., Reza Rahdari, M., Renima, M., Ricci, G. F.,Rodrigo-Comino, J., Saia, S., Nazari Samani, A., Schillaci, C., Syrris, V.,Soo Kimc, H. S., Noses Spinola, D., Tarso Oliveira, P., Teng, H., Thapa, R.,Vantas, K., Vieira, D., Yang, J. E., Yin, S., Zema, D.A.,Zhao, G., Panagos, P., 2021. Soil erosion modelling: A global review and statistical analysis. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2021.146494

Brenot J., Quiquerez A., Petit C., Garcia J.-P., 2008. Erosion rates and sediment budgets in vineyards at 1-m resolution based on stock unearthing (Burgundy, France). Geomorphology, 100, 345-355.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Casalí J., Gimenez R., De Santisteban L., Alvarez-Mozos J., Mena J., de Lersundi J.D.V., 2009. Determination of long-term erosion rates in vineyards of Navarre (Spain) using botanical benchmarks. Catena 78, 12-19. https://doi.org/10.1016/j. catena.2009.02.015.

Davidova, T., T. Dostal, V. David, P. Strauss, 2015: Determining the protective effect of agricultural crops on the soil erosion process using a field rainfall simulator. Plant Soil Environ. 61, 3, 109-115, DOI: 10.17221/903/2014-PSE

Fantappiè, M., Priori, S., Costantini, E.A.C., 2014. Soil erosion risk, Sicilian Region (1:250,000 scale), Journal of Maps, DOI: 10.1080/17445647.2014.956349

Johannsen, L.L., Zambon, N., Strauss, P., Dostal, T., Neumann, M., Zumr, D., Cochrane, T.A., Blöschl, G., Klik, A., 2020a: Comparison of three types of laser optical disdrometers under natural rainfall conditions. Hydrological Sciences Journal, 65(4), 524–535. https://doi.org/10.1080/02626667.2019.1709641

Johannsen, L.L., Zambon, N., Strauss, P., Dostal, T., Neumann, M., Zumr, D., Cochrane, T.A., Klik, A., 2020b: Impact of disdrometer types on rainfall erosivity estimation. Water, 12(4), 963. https://doi.org/10.3390/w12040963

Konzett, M., Strauss, P., Schmaltz, E., 2024: The not-so-micro effects of in-furrow micro-dams and cover crops on water and sediment retention in potato fields. Soil & Tillage Research, 235, 105911, 1-12. https://doi.org/10.1016/j.still.2023.105911

Laburda T., Krása J., Zumr D., Devátý, J., Vrána, M., Zambon, N., Johannsen, L.L., Klik, A., Strauss, P., Dostál, T., 2021: SfM-MVS Photogrammetry for Splash Erosion Monitoring under Natural Rainfall. Earth Surf. Process. Landforms. 1–16. https://doi.org/10.1002/esp.5087

Panini T., Torri D., Pellegrini S., Pagliai M., Salvador Sanchis M.P., 1997. A theoretical approach to soil porosity and sealing development using simulated rainstorms. Catena, 31, 199-218.

Pellegrini S., Andrenelli M.C., Simoncini S., Vignozzi N., 2013. Assessment of topsoil structure degradation in a compost-amended silty clay loam soil under simulated rainfall. Soil Degradation, Advances in GeoEcology 42, 199-213, Catena Verlag, Reiskirchen, Germany.

Rodrigo-Comino J., Quiquerez A., Follain S., Raclot D., Le Bissonnais Y., Casalí J., Giménez R., Cerdà A., Keesstra S.D., Brevik E.C., Pereira P., Senciales J.M., Seeger M., Ruiz Sinoga J.D., Ries J.B., 2016. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. Agric. Ecosyst. Environ., 233, 158-170. https://doi.org/10.1016/j.agee.2016.09.009.

Riegler-Nurscher, P., Prankl, J., Bauer, T., Strauss, P., & Prankl, H., 2018. A machine learning approach for pixel wise classification of residue and vegetation cover under field conditions. *Biosystems Engineering*, *169*, 188–198. https://doi.org/doi.org/10.1016/j.biosystemseng.2018.02.011.

Strauss P., J. Pitty, M. Pfeffer, A. Mentler, 2000: Rainfall Simulation for Outdoor Experiments. Jamet, P., J. Cornejo (Eds.): Current research methods to assess the environmental fate of pesticides. INRA Editions, 329-333.