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Fagna-Type Hydrological Unit for Runoff Measurement and Sampling in Experimental Plot Trials

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Abstract

The Fagna-type unit is a new device for the measurement and sampling of runoff in plot experiments. Its name derives from the Experimental Centre of Fagna where the Istituto Sperimentale per lo Studio e la Difesa del Suolo of Florence set up an experiment on 12 plots for monitoring soil erosion and chemical losses.

The working principle is based on a revolving pot which concentrates the runoff and, when filled, discharges it into a structure for conveying the water to a water meter. At every pot discharge the same quantity of runoff is sampled so that, at the end of the runoff event, an integrated sample is collected. Coarse materials that creep and hop at the bottom of the conveying flume are forced to settle in a siltation hopper before reaching the pot.

With respect to instruments which use multislot dividers, calibrated weirs and water level recorders , the new equipment directly and totally measures the volume of runoff , avoiding the risks linked to the indirect estimate which sometimes presents errors; especially when runoff is very feeble or in the presence of high peaks.

The Fagna-type unit has been successfully tested over four years. On the basis of the experimental results we consider the new equipment suitable for clayey soils and probably applicable in a wider range of conditions.

1 Introduction

In plot research, aimed at the study of hydrology and soil erosion, different types of measurement units, for superficial and deep runoff, are used. They are generally formed of a calibrated mouth coupled with a water level meter (mechanical or electric) for obtaining the runoff volume. After this, the total runoff is parcelled through one or several dividers in order to obtain a sample of turbid runoff to be analyzed for chemical and physical properties. The meter-sampler described here has been produced with the aim of improving the precision of the measurements, while keeping costs low and, at the same time, reducing the necessary labour for the maintenance of the equipment.

The new instrument has been named "Fagna-type hydrological unit" after the place (Fagna, in the province of Florence) where one of the experimental centres of the Istituto Sperimentale per

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lo Studio e la Difesa del Suolo is situated. In this centre 12 such units have been successfully working since 1988 on twelve experimental plots (10 meters × 20 meters) organized in four randomized blocks for surface runoff monitoring (fig. 1).

The new units have never stopped working even when a great quantity of sediment and organic residues from the surface of the soil was carried by a high peak of runoff. The soil, on which the plots are set up, is classified by the U.S.D.A. Soil Taxonomy as Typic Udortenths (Jannone et al. 1984). The grain size distribution of the topmost layer is: Clay = 49.8%, Silt = 32.7%, Sand = 17.5%, with pH = 7.8, $CaCO_3$ = 14% and OM = 2%. The soil erodibility factor is 0.024 t·ha·h/ha·MJ·mm and the yearly rainfall erosivity factor (average from 1976 to 1982) is 2038.6 MJ·mm/ha·h·a (Zanchi 1983a; Zanchi 1983b; Wischmeier & Smith 1978).

2 Components

The new device is very simple and composed of the following parts:

1. Flume for runoff adduction from the plot to the Fagna-type unit.
2. Hopper for sediment-creeping collection.
3. Discharge collector.
4. Revolving pot for discharge concentration, held by a frame.
5. Device for turbid-runoff sampling.
6. Runoff conveyance device to the water meter.
7. Water meter for measuring the total volume of runoff.
8. Cement box for sustaining and protecting the entire device.

The Fagna-unit is shown in photos 1, 2, and 3. The drawings of the various mechanical parts are reported in fig. 1 and refer to the type of device actually in use at the Fagna centre.

3 Working principles

Waters from superficial or deep runoff to be measured are conveyed through pipes or flumes in a siltation hopper, where the coarse materials, that creep and hop at the bottom of the flume, are forced to settle. The dimensions of the hopper must be adequate to maintain a water level flush with the base of the flume, otherwise settling rates of the sediment will vary with the depth of water in the hopper.

Runoff waters, thus cleaned of the coarser materials, come out of the hopper and continue their way to the measuring apparatus. The last part of the adduction flume is closed at the terminal end so that water must exit through a hole at the bottom of the flume. The water, passed through this hole and conveyed through a small piece of tube welded vertically onto the external wall of the flume, then falls on a revolving pot (2.8 litres). The support frame has two U-shaped forks (A, in fig. 1) with two coaxial pivots at the sides of the pot, therefore enabling it to turn completely upside down. In such a way the pot is simply supported and easily removable. When empty, the mouth of the pot is turned up, and its stable equilibrium is determined by a small weight externally applied to the bottom. As the water falls into it the pot reaches neutral equilibrium followed by unstable equilib-

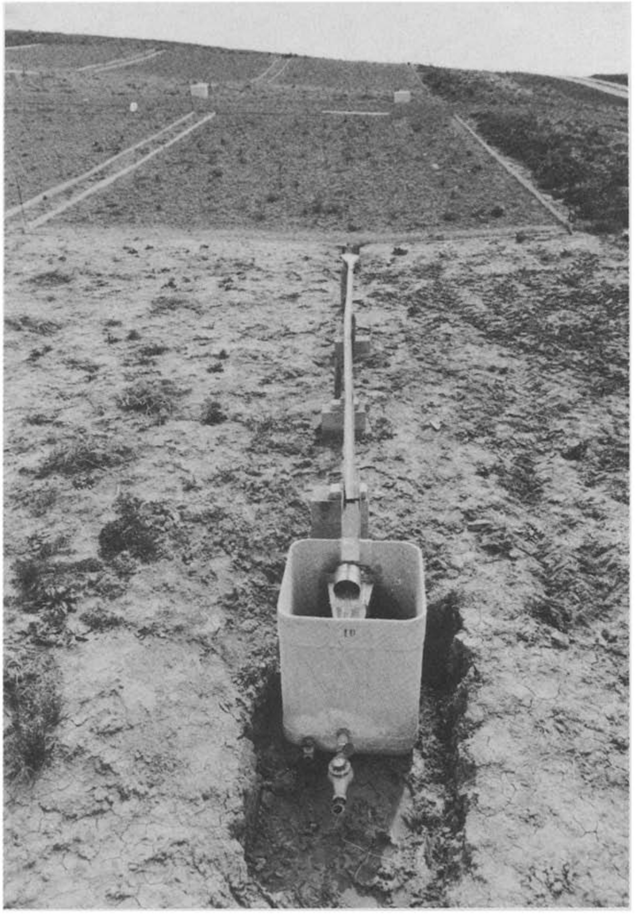

Photo 1: *Experimental plot at Fagna monitored with the new equipment.*

rium with the upsetting and discharge of the water and the immediate return to the vertical position. The upsetting always occurs forwards; this is done in two ways:

1. by unbalancing the pot, adding one or more nuts to the bolt which presses the pivot-holding belt to the pot.

2. by aiming the flux at a slightly forward position with respect to the bottom of the pot, to set it in front-direction rotating motion.

The discharged flux is then intercepted by a tray below, purposely inclined and shaped to increase the water speed and to convey it to the water-meter. This velocity is necessary for increasing the accuracy of the measurement.

On the bottom of the collecting tray a small hole is made in such a position as to enable a few cubic centimeters of runoff to enter when the water violently falls on it. This sample is then conveyed,

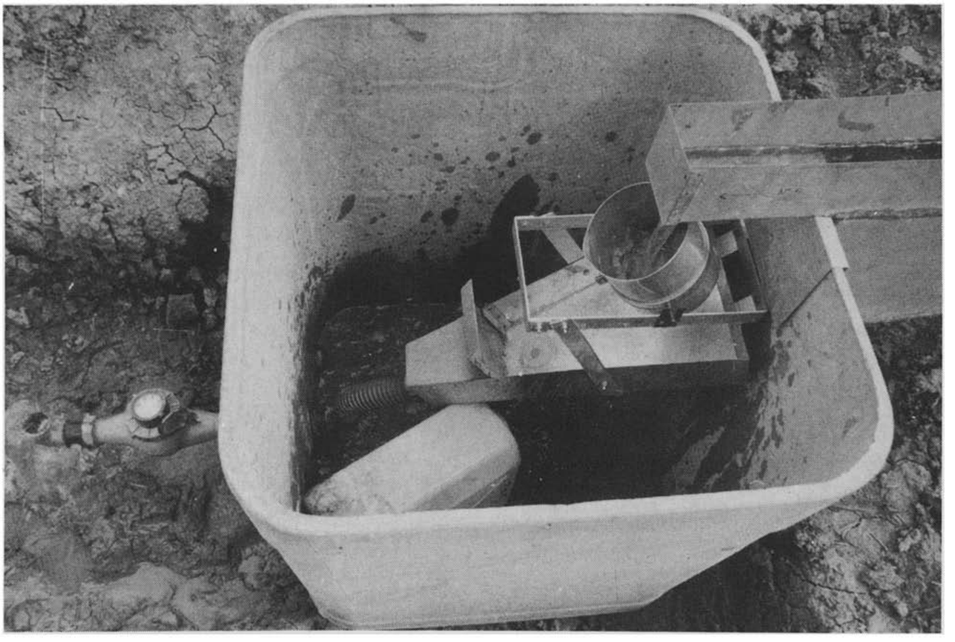

Photo 2: *Close-up view of the Fagna-unit with the pot in the charging phase. Note the previous discharge still flushing through the meter counter.*

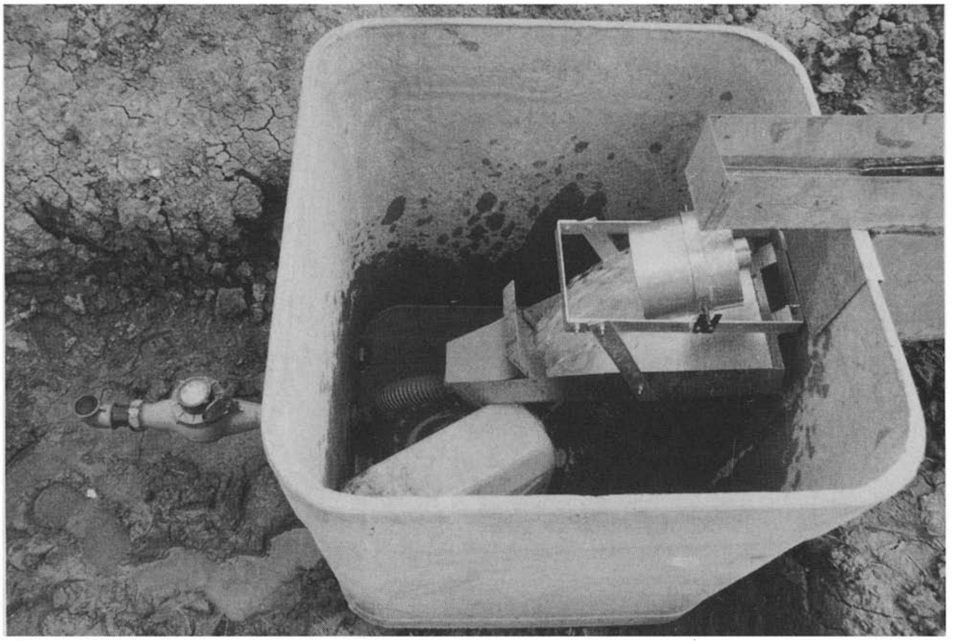

Photo 3: *Pot revolution with consequent discharge and turbid-runoff sampling.*

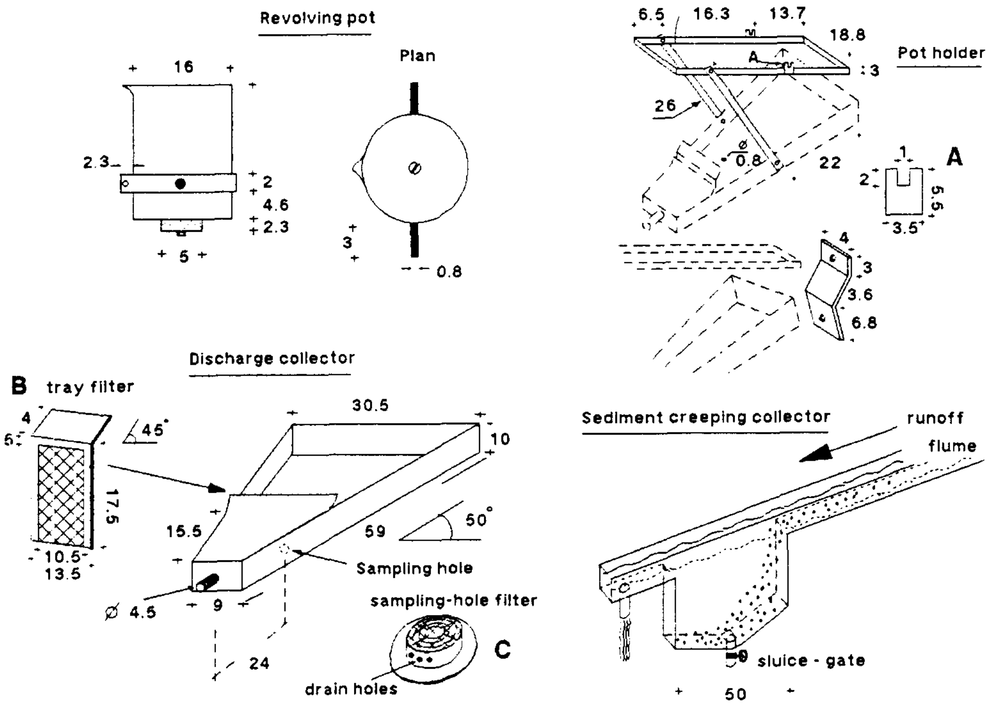

Fig. 1: *Construction details of the Fagna-type unit (measurements in cm).*

through a small plastic tube, to a tank. Since every pot discharge is sampled the same way, at the end of the runoff event the tank will contain an integrated and representative sample of the total turbid runoff.

The small sampling hole is protected from sealing by a very common plastic bath filter onto which a circle of mosquito-net has been pasted with a silicon glue. The filter, which is applied as depicted in fig. 1 (C), also means that the quantity of turbid runoff to be sampled may be chosen. When the water enters, the filter acts as a cage, allowing the sample to enter inside the hole on the bottom of the tray. By choosing the number and dimension of some small drain holes on the drum of the filter, the time the water remains inside the cage is varied and consequently so is the volume of the sample (only representative of suspended sediment).

The measurement of the material deposited in the settling-hopper before the mechanism, is carried out through the following operations:

1. energetic agitation of the sediment putting it in suspension inside the hopper, using a small broom;
2. immersion, during the agitation, of a large-mouthed bottle (capacity of one liter) without lid;
3. just after the filling, rapid extraction of the bottle from the hopper.

For correct sampling two operators are needed. The dimension of the sampling bottle depends upon the width of the flume (11 cm, in the devices placed at Fagna).

After drawing off the sample, the cleaning of the hopper is carried out by slowly opening the sluice-gate and at the same time using the broom for facilitating the exit of the material. From the total volume of the hopper (which is always the same) and from the concentration of sediment content in the bottle the total amount settled is easily calculated. If the sediment is too much to be resuspended the operator will take the measurement of the depth of the surface of the sediment inside the hopper (using a simple sounding-rod with a small disk at the end). From a previously-made calibration curve the quantity of material is achieved. The water, discharged by the oscillating pot, falls onto the tray from where it is conveyed to be measured by a turbine water meter. A sliding removable filter before the water meter prevents obstruction (B, in fig. 1).

The counter used at Fagna is the ASTRA MT-D model which has the following characteristics:

1. size: 3.81 cm;
2. cold water and multiple jet operating system;
3. magnetic joint and watch movement under vacuum;
4. volume range 10-0.16 m^3/h;
5. minimum readable quantity 0.1 liters.

From calibration we found that the measurement error of the water volume is about 1.5%. At Fagna, the counter is cleaned twice a year, using the special fluid CERFOX (main components: hydrochloric acid 9%, silicone defoamer emulsion, ammine derivatives for corrosion inhibition, detergent) which is easily found on the repair centres.

4 Innovations

With respect to multislot dividers (U.S.D.A. 1974, Cavazza & Linsalata, 1982) and generally to the devices which use calibrated weirs and water meter recorders, the new system enables the exact measurement and sampling of both small and protracted runoff events and very high runoff peaks. The Fagna unit is a conceptually new "total measurement station"; in fact the volume of runoff is directly and totally measured. On the contrary, in the existing systems the runoff is generally divided and then measured by means of a calibration curve. Such an indirect estimate sometimes presents errors; in fact, when runoff is very feeble and protracted it is very difficult to achieve its division into equal parts, and also the sensitivity of the water level recorder is too low for a measurement. On the contrary, with the same equipment, in the presence of a high peak of runoff, a small error in the reading on the time scale or in the level scale produces great errors in the estimate of the quantity. Especially when important events occur together with organic residues on the plot surface, the multislot-divider box may result partially obstructed and the flux not uniformly conveyed to the slots. This not rare disadvantage produces incontrollable, bad results of measurement and sampling. In comparison with the "Coshocton" wheel (Parson 1954, U.S.D.A. 1974) the new system does not present initial inertia and is able to record very small runoff fluxes. It is easier to construct and cheaper. Another advantage of the Fagna unit is the facility of installation and maintenance. In the field, it is generally not necessary to prepare a supporting platform in concrete, in fact the revolving pot always equilibrates in the vertical position and works even if not perfectly centered under the water flow; furthermore the mechanism also runs perfectly after long periods of inactivity, due to drought. The hopper that precedes the revolving pot carries out two important functions:

1. it separates the transported sediment in two parts: the creeping and the suspended ones. The knowledge of the quantity of creeping sediment is important. In fact, the attempt to maintain the eroded soil in the field, using conservation measures, is specially applied to this component. This coarse part of the sediment is also more subject to settling inside the watershed when the slope steepness decreases.

2. The sedimentation in the hopper avoids the plugging of the sampling system and loss of the measurement. This suggests that the Fagna unit would be suitable for different types of soils, and not only for clays.

Although we do not have direct experience it seems that the revolving-pot principle could be applied in hydrologic research on small watersheds. If requested, it is possible to replace the water meter with a recorder of the frequency of the pot discharges. This would also give the runoff-time relationship.

5 Calibration and testing

The calibration of the system of determination of the material deposited inside the hopper has been carried out in the following manner: in every trial a known quantity of sediment has been put inside the hopper. We used two types of sediment (clay and sandy loam) and for every one we ran three tests using 1, 2, and 3 Kg of material respectively, repeating the operation twice. The sediment was kept immersed under water inside the hopper for 15 days. After this period we filled the hopper with water to the maximum level and then we sampled as described before. The statistical computation gave this regression equation between the observed (OBSE) and the estimated (ESTSE) sediment (in Kg) (fig. 2):

$$OBSE = 0.105 + 0.901 * ESTSE \quad (1)$$

The determination coefficient resulted R^2=0.99 and the equation resulted highly significant. The calibration of the turbid sampler below the pot has been done by means of the sampling of 15 simulated runoffs. Each turbid runoff was done by putting in the upper flume 40 liters of water of variable solid charge, for very variable times (2 to 15 minutes). The measured turbidities of the integrated samples were practically the same as the respective total-runoff turbidity.

The simple regression obtained between the solid charge of the sample (SCS) and that of the runoff (RSC) (fig. 3) resulted as follows:

$$RSC = -0.35 + 1.068 * CSC \quad (2)$$

This equation too is highly significant, with R^2=0.98. During 4 years of continuous work without interruptions, the

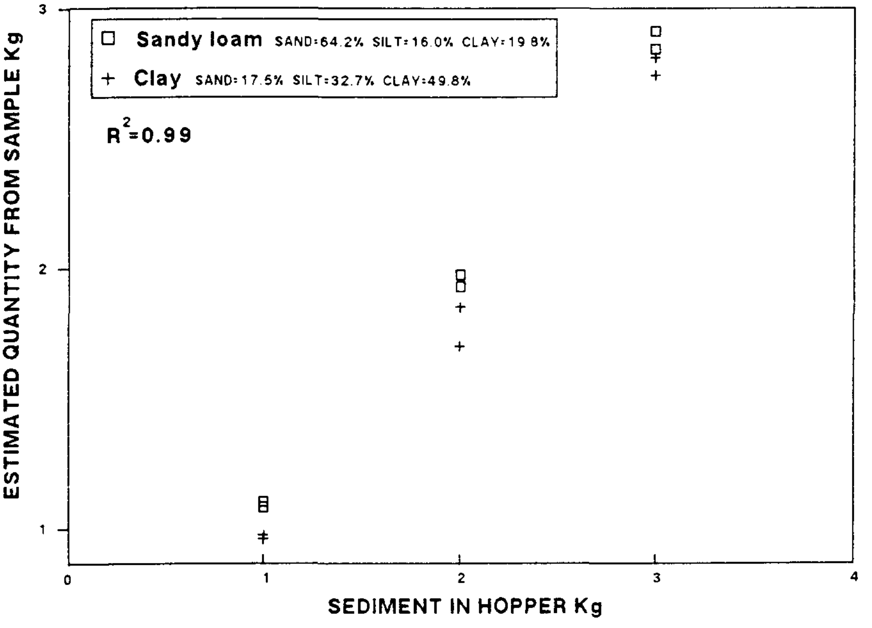

Fig. 2: *Calibration of the procedure for determining the quantity of sediment settled in the hopper.*

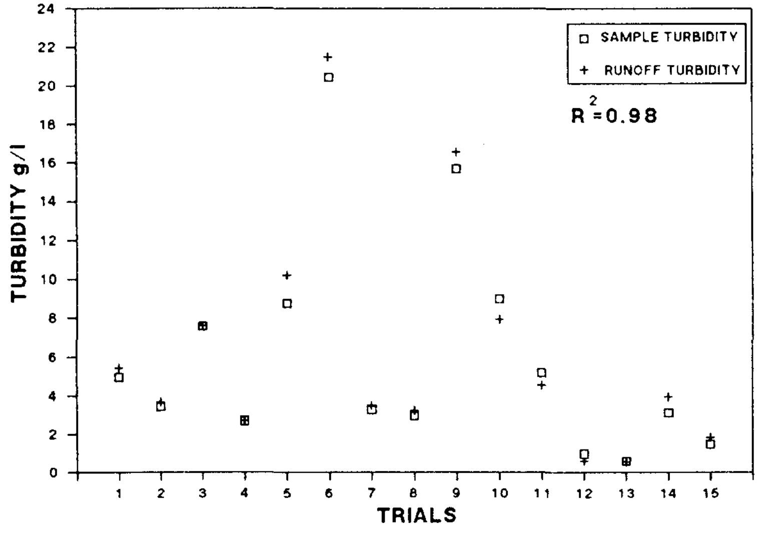

Fig. 3: *Calibration of the suspended-sediment sampling system.*

maximum quantity of soil loss detected in one runoff event has been 160.7 Kg per plot (corresponding to 8.03 t/ha).

The average time needed for every down-up pot tipping is 0.54 secs.; this determines the loss of sampling between tips which reches the maximum volume of 0.17 liters when runoff is very intense. To decrease the importance of this amount on the total quantity of runoff to be sampled it is sufficient to increase the pot capacity.

On the basis of these results we consider the new equipment suitable for soils that are not highly subjected to erosion and probably applicable in a wider range of conditions.

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