Technical approach for the measurement of surface runoff

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Abstract: *In this paper we describe practical application, design and installation of an in-field runoff collector exploitable for monitoring nutrients, pesticides and sediments loadings in runoff, improved with a home made level reading system able to measure with high temporal resolution, the runoff rate variation.
This configuration simplifies and lower the cost of conventional instruments used for measuring runoff. A multislot divisor was used to reduce the volume of runoff and plastic tank were use to collect it. An electro-mechanic type, floating level transducer was proposed. The homemade level reading system is composed of three parts: floating level transducer, signal conditioning system and data storage. The total cost for entire system is approximately € 642.*
Keywords: *runoff, multislot, floating level system.*

Riassunto: *In questo articolo viene descritta l'applicazione pratica, lo schema e l'installazione di un collettore per acque di ruscellamento, per il monitoraggio, a livello di campo, della perdita di nutrienti pesticidi e sedimenti. Il sistema è stato equipaggiato con un misuratore di livello costruito ad hoc, in grado di registrare con alta risoluzione temporale il tasso di variazione del ruscellato. Questa configurazione risulta semplice ed economica rispetto ai normali strumenti utilizzati per lo studio del runoff. È stato utilizzato un partitore per ridurre il volume di ruscellato raccolto in bidoni di plastica. E' stato proposto un trasduttore di livello a galleggiante di tipo elettromeccanico. Il sistema di lettura del livello è compost da tre parti: un trasduttore, un sistema di controllo del segnale e un data logger. Il costo totale dell'intero sistema si attesta sui 642 euro.*
Parole chiave: *ruscellamento, partitore, misuratore di livello.*

INTRODUCTION

A better understanding about nutrients, pesticides and sediments loadings in runoff and in surface water, at field scale, is of fundamental importance in many environmental studies, especially to evaluate different management practices and its role in soil and water degradation.

Many instruments have been developed to measure runoff and sediment transport (PAP/RAC, 1997), using different approaches (Hudson, 1993). Direct measurements are normally carried out in medium size plots (Hudson, 1993) (<100m²) where runoff is collected using tanks (Hudson, 1993; Bonilla *et al.*, 2006). To avoid big tank, necessary to collect all the runoff derived from the plots, and reduce costs, the plots are frequently characterized by small size (2-5m²) and therefore can become not much representative of the field condition (Toy *et al.*, 2002). Moreover total collection tanks are often unsuitable also for medium plots because the runoff can be excessive (Brakensiek *et al.*, 1979). Other commons instruments used in several runoff studies consists in sophisticated instrumentation able to measure and sample runoff at field scale (Bonilla *et al.*, 2006). These instruments continuously measure and record the runoff rate in a control section, and an automatic pumping sampler is used to draw samples. These instruments returned more detailed information about runoff and its rate evolution, through a mechanism to measure the depth of water and the velocity or the flow rates in a known section; but they are often too expensive and such system assume that samples extracted non-continuously could be representative of the entire phenomenon (Pinson *et al.*, 2004; Bonilla *et al.*, 2006).

To avoid problems in measuring, tools were introduced to collect runoff water. Slot-type sampler, using multislot divisors, collect a representative portion of runoff allowing to increase the plot size to better represent the field condition (Sombatpanit *et al.*, 1990; Reyes *et al.*, 1999; Franklin *et al.*, 2001; Pinson *et al.*, 2004; Bonilla *et al.*, 2006), reducing the amount of runoff that must be stored. Multislot dividers also know as slot dividers, slot samplers or multislot samplers; were firstly introduced by Geib (1933). In general a slot divisor consists in a box were the entire flow pass throughout a multiple outlet slot. The output of one of these slot was collected, between collection port or channel, to a tank and this single sample represent a known portion of the entire runoff volume (Pinson *et al.*, 2004).

For studies that do not required a time variation data

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of the runoff but only total event information, the slot dividers represent a low cost method. To be representative, not only for the volume but also for the sediment and contaminant concentration, the divisor should not permit the deposition of the solid part of the runoff during the splitting.

The goal of this paper is to describe practical application, design and installation of an in field runoff collector for measuring runoff, sediment and chemical losses, enhanced with a level reading system able to measure the runoff rate.

MATERIALS AND METHODS

Study area and site

The study area is located in the *Oltrepò Pavese*, part of the Province of Pavia, in the southwest Italian region of Lombardy. The area has an appennine mesoclimate (Mariani L., 2008) with an annual average temperature of about 12°C and an annual rainfall of about 680 mm, mainly concentrated in spring (May) and autumn (November) (Ottone and Rossetti, 1980; Mariani L., 2008).
The study was carried out in a 9-year-old vineyard at the "Centro Vitivinicolo Riccagioia" located in Torrazza Coste (latitude 44°58'40"44 N, longitude 09°5'4"56 E, 159 m a.s.l.). The plantation consists of single Guyot trained vines, at 2.5 m x 1.0 m pattern, which run along the maximum slope degree direction. The plot of about 686 m^2 includes four rows (three in-row), 88 meters long. The slope of the plot is about 17%. Each plot is delimited by a longitudinal, approximately 15 cm high earth embankment.
The grass cover in the inter-row is cut four or five

Fig. 1 - Multislot divisor with tanks.
Fig. 1 - Partitore e bidoni di raccolta.

times from April to August, chemical weeding in row is renewed in March and July.

Multislot divisor

The multislot divisor used in this work (Fig. 1) is the same proposed in Franklin *et al.* (2001).The only difference was in the use of a more thick stainless steel sheet for the collector floor, to avoid the risk of warping, indicated as a possible cause of the percent capture of runoff double than expected recorded by Franklin *et al.* (2001). We used a 2 mm thickness stainless sheet respect to the original 16 gauge (approx. 1.59 mm) sheet. The height of the side wall and of the dividers, that it was not specified in the original paper, was set to 15 cm.

Collection tanks

The two collection tanks (Fig.1) have been sized on the base of the maximum volume of water potentially collectible by the multislot on 1/100 partition. In this way the 1/10 partition tank is useful to measure runoff in small events and for the initial part of bigger events. To calculate the size of the tank were necessary to estimate the probability distribution of extreme runoff events and the corresponding peak runoff rates, applying the Curve Number method (United States Department of Agriculture, 1986). The volume was calculated on the base of the years when the weather data were available, period 1992-1996. A 125 dm^3 (516 mm Ø ´568 mm height) PPE tank, with vertical walls, was used for the application in reason of the entrance of the 25 cm high collector from the multislot. At the bottom side of both tanks a water taps were installed to evacuate the liquid after the sampling. Each 125 dm^3 tank was allocated on a supplementary buried 380 dm^3 PPE tank (638 mm Ø x 1200 mm height) to simplify the operation of cleaning and to place the level measuring device. The external tanks were equipped with drainpipes, to permit the evacuation of the liquid, and with caps.

Level reading system

Three parts compose level reading system proposed: i) a transducer, ii) a signal conditioning system, iii) and a data storage.
The chosen of the transducer was done considering the power consumption, the accuracy, the spatial encumbrance and the minimum of liquid height requested by some sensors to make a significant measure.
An electro-mechanic type, floating level transducer was selected for both tanks as best meets the requirements described above. This device (Fig. 2) is composed by a floating part, a 250 mm diameter circle

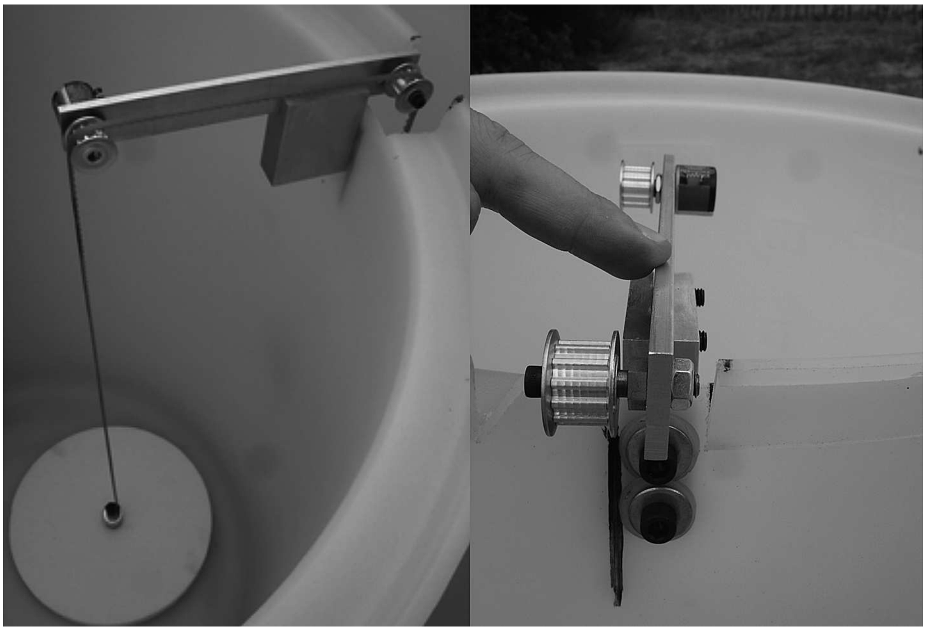


Fig. 2 - Floating level system.
Fig. 2 - Sistema di livello a galleggiante.

of 20 mm high made by polystyrene in adherence with the liquid, linked to the transducer organ through a timing belt (T5 type) connected in the centre of the floating with a screw. The transducer is a 10 turn, metric, 10 kΩ precision wire wound potentiometer 5% accuracy (Vishay Intertecnology Inc. mod. (http://www.vishay.com/ docs/57065/533534.pdf) and was chosen for the reliability and the low friction on the starting movement. This device is able to convert the rotary movement of the knob in a variation of resistance and a consequent voltage change when powered. The movement of the knob is allowed by a 18.25 mm Ø pulley (type 21 T5 12) mounted directly above the knob, that allows a measure of 573 mm in 10 turns of potentiometer. Major diameters allow covering more length but in the same time decrease the measurement sensibility. A timing belt runs up two pulleys, one connected to the potentiometer and one idle. The timing belt is connected with polystyrene floating in one side, and to a 150 g counterbalance in the other side.

The potentiometer is powered by the signal conditioning system. This system is a simple board (Fig. 3) which permit the power alimentation of the transducer and it receive back the voltage signal to sends to the data storage. Specifically the board contains a 12 V to 2.5 V DC voltage regulators (model LM 78L05) to supply the transducer, a unity gain buffer amplifier (model LM 358) to improve the impedance of the entrance signal and the basic electronics to operate these components.

The transducer receives tension from the regulator and provides a signal from 0 to 2.5 V DC in function of the rotary movement of the pulley linked to the floating. The power supply board is conducted by a 12 V 7 Ah battery connected to a solar panel of about 1W (12 V and 75 mA). The signal overcoming to the board goes directly to the data storage, a 12-bit HOBO U12-006 data logger (*http://www.onsetcomp.com/products/data-loggers/u12-006*).

This device is battery powered, with four input channels and permits the storage of 0 to 2500 mV voltage signals at a frequency from 1 second to 18 hours, with a resolution of 0.6 mV. For our purpose we use a 1 minute time step acquisition with permit a 15 days data storage.

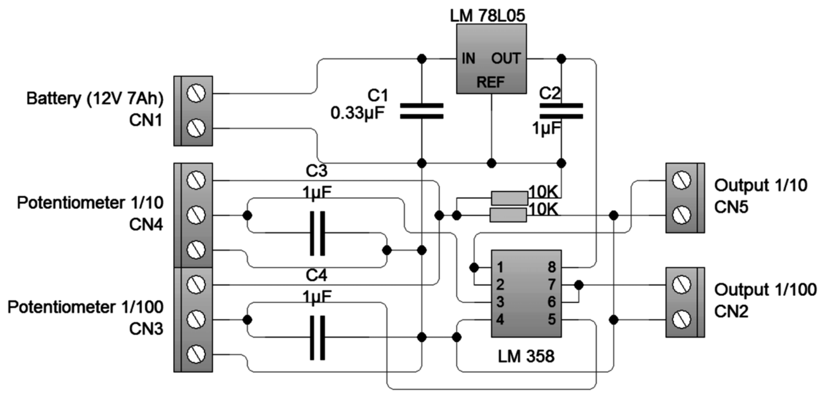
Field arrangement

Divider system and tanks are located over the field headland and the water is conveyed to the multislot through earth embankment (Fig. 4).It is planned to protect the embankments with plastic sheets. The field headland is considered part of the experimental field and its contribute in generate runoff is taken into account. The divider is placed at the end of the headland, where the slope is about 2%.

Field installation

Field installation was initiated using a multislot divisor template to identify holding tanks and divisor position. After the excavation, levelling was done for the bottom of the holes and a 10 cm of sand bed was created to ensure the stability of the tanks. The external tanks were embedded until the collection port enters in a tank as high as possible.

Threaded rods were cemented into earth for levelling



Component	Quantity
0.33µF Capacitor	1
1µF Capacitor	3
10K Resistor (1% 1/4W)	2
2 pin Terminal Block	3
3 pin Terminal Block	2
7805 (5V, 1A) Voltage Regulator	1
LM 358 Low Power Dual Operational Amplifier	1

Fig. 3 - Scheme of the signal condition system and component list.
Fig. 3 - Schema del circuito di condizionamento del segnale.

and fixing the multislot. Nuts are places above and below the eyelet to level the multislot.

Operation

After every runoff event, the data logger is downloaded, water sample are taken for analysis making sure to mix very well, tanks are emptied opening the tap, and cleaned. Also the floating systems are rearranged to the bottom of the tanks.

Calibration

Calibration of every tank is necessary to convert, in post processing, the volts value in litres of runoff. For every 125 dm^3 tank a known increment in litres were applied. First we put in the tanks 5 litres of water in 10 steps of 0.5 litres, then we put, in steps of 5 litres, the volume of water necessary to fill the tanks. Moreover, the percentage water of recovery was assessed with the instrument installed in the field, using a tank of 0.5 m^3 of water. 2 flow rates of 0.11 and 0.65 l s^{-1} with 2 replication was used. The flow rate was obtained discharging 400 l of water in 10 and 60 minutes, respectively. Due to the long distance between the source of water and the field equipped with the sampler, was not possible to perform more replication and to test the device for other flow rates.

Fig. 4 - Field arrangement.
Fig. 4 - Disposizione del campo sperimentale.

Franklin *et al.* (2001) did not test the accuracy of division for transported sediment, however precedent studies using very similar designs (Sheridan *et al.*, 1996) used also in Sheridan *et al.*, 1999 and modified by Franklin *et al.*, (2001) for use in water quality studies, indicated good sediment division. Also recent studies (Butler *et al.*, 2010; Matos *et al.*, 2008; Ortega *et al.*, 2007; Sistani *et al.*, 2008; Sotomayor-Ramírez *et al.*, 2008; White *et al.*, 2003) use the Franklin *et al.*(2001) splitter with good results.

Rayan (1981) attributes the accuracy of systems similar to that discussed in this paper, in the use of a sludge tank so that the divisor only handles water and suspended sediment in a smooth flow and the reliability of the divisor system because there are no moving parts (Rayan, 1981).

RESULTS

Calibration

Calibration lines for both tanks are shown in Figure 5.

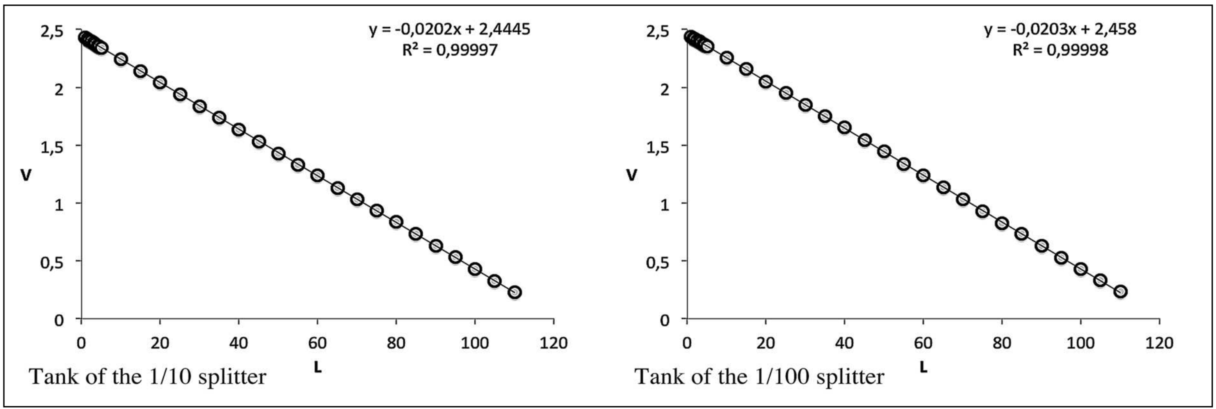


Fig. 5 - Calibration curve of the two tanks. 5 litres of water was added in 10 steps of 0.5 litres than the volume of water necessary to fill the tanks was added in steps of 5 litres.
Fig. 5 - Curve di calibrazione per i due bidoni di raccolta. I primi 5 litri d'acqua sono stati aggiunti in steps da 0,5 litri, i restanti necessari a reimpire i bidoni sono stati aggiunti in step da 5 litri.

The determination coefficients are close to 1 and linearity is excellent. Moreover, the slope and the intercept of the linear regression are very similar for the two tanks.
Calibration of the tanks and of the automatic level meter also shows that the material used is not subject to deformation due to the weight of the water.
Table 1 showed the percentage of water recovery with its coefficient of variation for the trials carried out. All the values are close to the expected ones, for both flow rates, with little variations between the two replications. The issue of a relevant overestimate of runoff from the 100x divider highlighted by Franklin *et al.* (2001) was not present in our prototype. Moreover, the divider was tested for flow rates up to 5 times greater of which was used by Franklin *et al.* (2001), demonstrating the ability of the instrument to be used also for the evaluation of the discharge of a whole plot, and not only for the width of the instrument as in the Gerlach type sampler.

Cost

The total cost for the instrument is about 642 € per installation. Detailed coasts are resumed in Table 1. A considerable amount of labour is required for installation, but no additional cost for mechanical means are necessary and low maintenance is required. The cost is comparable to the system proposed by Pinson (Pinson *et al.*, 2004) but in addiction, our system is able to register the runoff rate during an event. Other systems able to register runoff data variation are often more expensive (up to 5000 $) (Bonilla *et al.*, 2006).

CONCLUSIONS

The main object of this work was to present a practical application for the study of runoff. The configuration proposed in this article is an efficient and inexpensive method for measuring and study sediment and chemical losses under rainfall event. Measurement can be made at field scale, for different size plot and

	10x Divider		100x Divider	
Flow rate	0.11$_1$l s$^-$	0.65$_1$l s$^-$	0.11$_1$l s$^-$	0.65$_1$l s$^-$
Mean	9.88	10.50	0.98	1.01
CV %	3.58	3.37	7.25	8.73

Tab. 1 - Field calibration results. Mean recovery rate (%).
Tab. 1 - Prove di calibrazione del sistema di partizione.

Quantity	Component	Unit price	Amount
2	Tank dm^3 125	39,00	78,00
2	Tank dm3 380	89,00	178,00
1	Multislot	150,00	150,00
4	Pulley	5,5	22 ,00
2	Alluminium parts	5,00	10,00
2	Potent iomet er	11,50	23,00
1	Solar panel	32,00	32,00
1	Battery	12,00	12,00
1	Regulator board	5,00	5,00
2	Cables 5 m	5,00	10,00
1	HOBO 12 -bit	72,00	72,00
2	HOBO stereo cable	8,00	16,00
2	Float	10,00	20,00
2	Timing belt	7,00	14,00
Total			642 ,00

Tab. 2 - Detailed cost for components.
Tab. 2 - Costi dei vari componenti.

also where external power sources are not available. This instrument has been successfully used for over two years in farm field providing several data about runoff process in vineyard. Instrument's low price permits the use of this equipment in several replicates reducing the potential errors of singles observations.

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