Analysis of suspended solids and Glyphosate and efficacy of the cross-compliance Standard 5.2 'buffer strips' in the protection of superficial water from suspended solids in runoff conveyed through a vineyard

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Abstract

Several studies have described the effectiveness of vegetated buffer strips, interposed between the cultivated areas and water bodies, in removal of suspended solids and other pollutants such as Glyphosate conveyed through surface runoff. This monitoring study has quantified the effects of a 5-metre wide herbaceous buffer zone, adjacent to a vineyard, built according to the Standard 5.2 of Cross-compliance (M.D. 27417). The amount of runoff generated was 3.9% of the total annual rainfall, with negligible differences in terms of volume after flowing through the buffer zone. The effectiveness of the buffer zone in suspended solids removal was, in terms of mass balance, of 45.5%. The glyphosate outputs from the vineyard, unlike in other experiences, were negligible and therefore it was not possible to evaluate the efficiency of the buffer zone in removing it. This is due to the low rainfall occurred in the period following distribution that has favoured in situ degradation of Glyphosate.

Introduction

The fine particles of soil and any pesticides adsorbed by them are transported to the water bodies mainly by surface runoff (Warnemuende *et al.,* 2007), although in some contexts process of vertical infiltration toward the water table could occur. The superficial runoff can generate for several reasons (Uusi-Kämppä *et al*., 1997); for example in soils with reduced permeability when the intensity of precipitation exceeds the infiltration capacity of soil (Muscutt *et al.,* 1993).

Among the pesticides with high adsorption capacity in the soil particles, which are carried in runoff, especially important is Glyphosate (Warnemuende *et al.,* 2007), a non-selective herbicide widely applied in the vineyards (Borggaard anf Gimsing, 2008; Landry *et al.,* 2005). Despite several investigations (Busse *et al.,* 2001; Vereecken, 2005), highlighted the low polluting capacity of Glyphosate due to short residence times in soils, other experiences (Veiga *et al.,* 2001; Landry *et al.*, 2005; Siimes *et al.,* 2006; Shipitalo *et al.,* 2008) pointed out toxicity problems related to its use. These studies have shown strong variability in the processes of absorption and degradation strictly dependent on the composition and properties of soil. Other researches (Dillaha and Inamdar, 1997; Syversen and Bechmann, 2004; Borin *et al.,* 2005; Carluer *et al.,* 2011) have pointed out a significant role of vegetated buffer strips in reducing suspended solids and pesticides adsorbed by them and transported by runoff. The removal processes are mainly related to entrapment/deposition of sediments conveyed in the buffer zone and subsequent transformation processes of the accumulated substances.

The field studies of these processes have been addressed mainly by two approaches: i) simulating controlled runoff events (Syversen and Bechmann, 2004) ii) monitoring over time of removal capacity during natural precipitation events (Screpanti *et al.,* 2005). In this study, the results of a yearly long monitoring about the amount of suspended soil and Glyphosate generated in a vineyard and the efficiency in removing such substances by a 5-metre wide herbaceous buffer strip, and realized according to the Standard 5.2 of Cross-compliance (M.D. 27417), are discussed.

Materials and methods

Experimental site

The monitoring was carried out from June 2013 to June 2014, in a 12-year vineyard, located in the municipality of Ponte di Piave (TV) (45° 42 '27.65' 'N, 12 ° 27' 50.37''E, 5 m asl), planted with *Vitis vinifera* L. cv. Pinot grey and grafted on SO_4, with a density of 5,000 vines per hectare (2.5 m spacing). The vineyard is located in a floodplain of the Piave River, on the left bank, in the production area of DOC Piave; it has a system of drip fertigation with hose underground. During the experimental period three treatments (April, June and July) with Glyphosate (for a total of 2.3 kg ai^{-1}, see Table 1) have been performed. The harvest was performed in the second week of September.

The main soil characteristics are reported in Table 2.

Monitoring plan

The monitoring scheme has been designed in line with the model proposed in the 'Standard 5.2 of buffer strips' M.D. 27417.

Two plots (experimental thesis) 2.5 m wide, called VIG (counterfactual: the output from the vineyard) and FT (factual: the output from herbaceous buffer strip) with a catchment area, defined by the ground level, of 268.93 m^2 and 281.43 m^2 respectively (Figure 1) have been set for the experimental activities. In the herbaceous buffer zone two mowing per year are performed (June and August) with removal of vegetation and managed in accordance with the Standard 5.2 (M.D. 27417). The two plots are separated by a gap of 5 m to avoid interference; the slope gradient was 0.56% in the vineyard and 0.53% in the buffer zone.

At the exit of each thesis, a tool for collecting and measuring runoff volumes (Figure 1) specifically designed and made by Borgatti and Peruch adapting the instructions given in Hudson (1993) was placed. The tool was made of a covered PVC gutter 2.5 m long, placed just below the ground level and connected to a PVC pit of 128 L capacity. Any volumes exceeding this capacity flowed out through a separator system (adjusted to a ratio of 1: 500) that collected an additional representative sample in a PVC tank. The samples were first stirred and then collected from the two systems and analysed separately. The sampling was performed just after each significant rain event. The gutter collecting water was placed perpendicular to the slope of soil, defined with a properly relief realized by means of a GPS system Leica 1200+ composed of two geodetic receivers GPS / GNSS Leica AS10.

The experimental design also provides the installation of a in situ gauge rain (WatchDog 1120 Data-Logging Rain Gauge, Spectrum) and three FDR probes (WaterScout SM 100) connected to a data logger (WatchDog 1400 Micro Station - w / 4 External Ports) for the measurement of precipitation and volumetric soil humidity at different (0, 15 and 30 cm) depths.

Chemical analysis

The total suspended solids (SS) were measured gravimetrically as provided by the method APAT CNR IRSA 2090 B, 2003. The analyses of Glyphosate content were realized in samples of 1 L by analytical techniques of liquid-chromatography coupled to mass spectrometry (LC-MS / MS) (Rubinson and Rubinson, 2002).

Results

Hydrological dynamics

Despite the low slope (0.56% and 0.53£%, respectively) the vineyard and the buffer strip are able to generate, during some rain events, significant quantities of runoff. During the annual monitoring, the measured runoff flowing out of vineyard and the FT was 45.5 and 43.5 mm respectively, that corresponds to the 3.94% and 3.76% of the annual rain volume (1156.4 mm).

The relative proportion between the volumes of runoff and precipita-

Table 1. Amount of glyphosate applied, concentrations measured in the water conveyed through runoff and main hydrological parameters during the monitoring period.

Date	Glyphosate application (kg ai ha^{-1})
22/04/13	1
14/06/13	0.8
10/07/13	0.5

Date	Period (days)	Period after previous Glyphosate application (dd)	Rainfall Amount	Rainfall Max intensity (mm h^{-1})	Runoff VIG (mm)	Runoff FT (mm)	[Glifosate_ runoff VIG] (µg L^{-1})	[Glifosate_ runoff FT] (µg L^{-1})
02/06/13								
10/06/13	8	49	6	2.2	0.02	0.01	< 0.08	< 0.08
09/07/13	29	25	7.4	3.0	0.00	0.00	nd	nd
17/07/13	8	7	8.2	4.6	0.00	0.00	nd	nd
30/07/13	13	20	17.8	7.6	0.01	0.00	< 0.08	< 0.08
21/08/13	22	42	22.4	4.2	0.01	0.00	< 0.08	< 0.08
29/08/13	8	50	38.1	16.4	0.01	0.02	< 0.08	< 0.08
Total	80	93.9	16.4	0.03	0.02			

tion is highly variable in time, with values calculated between two consecutive samples ranging from 0 to 9.19%, the latter recorded between 29/11/2013 and 16/01/2014. It is well known that the amount of runoff depends on the interaction of several factors (Uusi-Kämppä *et al.*, 1997); in this study we have recorded (Figure 2) the highest values in autumn-winter period (from 10/09/2013 to 07/03/2014), characterized by soil water content values close to saturation in the first layers of soil and frequent and significant precipitation both in overall (892.2 mm), and intensity terms (26.9 mm, 15.6 mm and 12.2 mm in 30 minutes interval during 10/30/2013, 11/19/2013 and 19/01/2014 respectively).

In spring and summer the amount of runoff is rather close to zero, even during high intensity events (16.4 mm in 30 minutes the 25/08/2013) because, as highlighted by the trend of humidity values (Figure 2), the processes of evapotranspiration and vertical percolation of the water flow are prevalent. Finally, it is important to point out the negligible differences in runoff volume (Table 3) coming out of both the vineyard and the buffer strip.

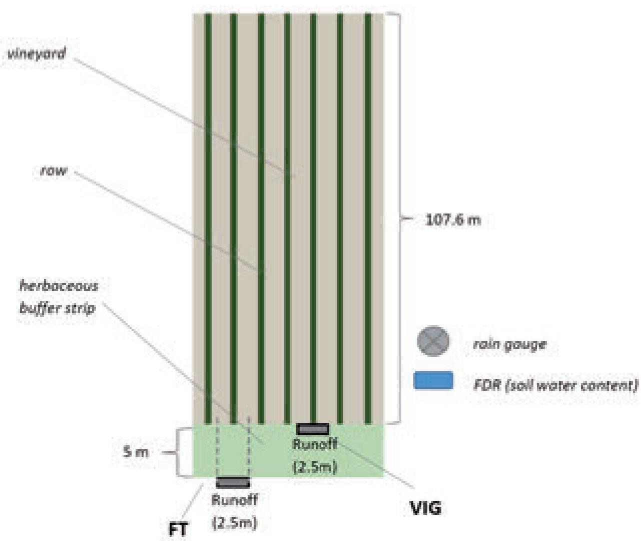

Figure 1. General monitoring scheme, including indications on field instruments and sampling points.

Table 2. Main physical and chemical soil characteristics.

Parameter Layer	Units cm	0-30	Values 30- 60	60-90
Sand	%	40	43	20
Silt	%	42	39	70
Clay	%	18	18	10
Texture	USDA	Loam	Loam	Silt Loam
Organic matter	%	1.3	1.2	0.6
Total N	% N	0.1	0.1	0.1
Available phosphorus	mg/Kg P	13.6	10,0	4.4
Exchangeable K	mg/Kg K	231	199	92
Exchangeable Mg	mg/Kg Mg	169	174	110
Exchangeable Ca	mg/Kg Ca	2480	2320	1606
Total carbonate	% $CaCO_3$	48	37	31
Active carbonate	% $CaCO_3$	12.4	7.2	8.0

Table 3. Rainfall and runoff data recorded during the monitoring period.

Date	Period (days)	Rainfall Amount (mm)	Rainfall Max intensity (mm h^{-1})*	Runoff VIG (mm)	Runoff FT (mm)	Runoff/ rainfall VIG (%)	Runoff/ rainfall FT (%)
31/05/13							
10/06/13	10	6	2.2	0.02	0.01	0.27	0.12
09/07/13	29	7.4	3.0	0.00	0.00	0.00	0.00
17/07/13	8	8.2	4.6	0.00	0.00	0.00	0.00
30/07/13	13	17.8	7.6	0.01	0.00	0.07	0.01
21/08/13	22	22.4	4.2	0.01	0.00	0.02	0.01
29/08/13	8	38.1	16.4	0.01	0.02	0.03	0.04
12/09/13	14	14.3	4.8	0.00	0.00	0.01	0.01
09/10/13	27	42	7.2	0.00	0.00	0.01	0.01
31/10/13	22	60.9	26.9	1.98	1.89	3.25	3.11
18/11/13	18	75.8	5.0	5.98	5.71	7.88	7.53
28/11/13	10	90.8	12.2	7.89	7.54	8.69	8.31
16/01/14	49	137.6	7.6	13.23	12.64	9.61	9.19
21/01/14	5	69.4	15.6	2.52	2.41	3.63	3.47
27/01/14	6	14-2	2.4	0.00	0.00	0.00	0.00
25/02/14	29	365.8	8.6	11.68	11.16	3.19	3.05
07/03/14	10	35.7	6.2	2.14	2.05	6.00	5.74
31/05/14	85	150	7.5	0.05	0.04	0.03	0.02
	365	1156.4	26.9	45.52	43.47	3.94	3.76

* Maximum 30-minute rainfall intensity.

Effects on suspended solids transport

The differences in terms of suspended solids transport conveyed by runoff coming out from the vineyard and the buffer zone are shown in Table 3. In terms of mass balance, there is a significant difference between input and output (17.77 mg/m^2 and 9.68 mg/m^2, respectively) due to the herbaceous buffer strip action, with a reduction rate of 45.5%. Analysing each period (Table 4) it can be observed very heterogeneous values, with removal rates even negative but negligible to the overall contribution, and others in which the filter action shows high efficiencies of over 60%.

The graph in Figure 3 shows how during the summer/early fall (from 01/06/2013 to 10/09/2013) a suspended solids transport by runoff close to zero has been registered; while in the next period, up to 16/01/14, a sharp increase was recorded, this trend becomes until irregular then reaching very low levels at the end of the monitoring period.

Glyphosate output

Glyphosate concentrations were measured in the samples of runoff collected (when available) starting from 10/06/2013 until 29/08/2013. In no sample concentrations above the threshold of the detection instrument, that is equal to 0.08 micrograms L^{-1}, have been detected. The first sampling, corresponding to the runoff stored between 2 to 10 of June 2013, would have recorded the presence of glyphosate distributed 49 days before. After the following distributions of Glyphosate, 14/06/2013 and 10/07/2013, there were weak precipitations unable to generate releases via runoff. The last sampling was collected 20 days after the last distribution (Figure 4). Therefore it was not possible to evaluate the effect of the buffer zone of this specific pollutant.

Quantitative indicator

The indicator of basic level chosen to define the suitability of the standard 5.2 relatively to its environmental target consists in the effi-

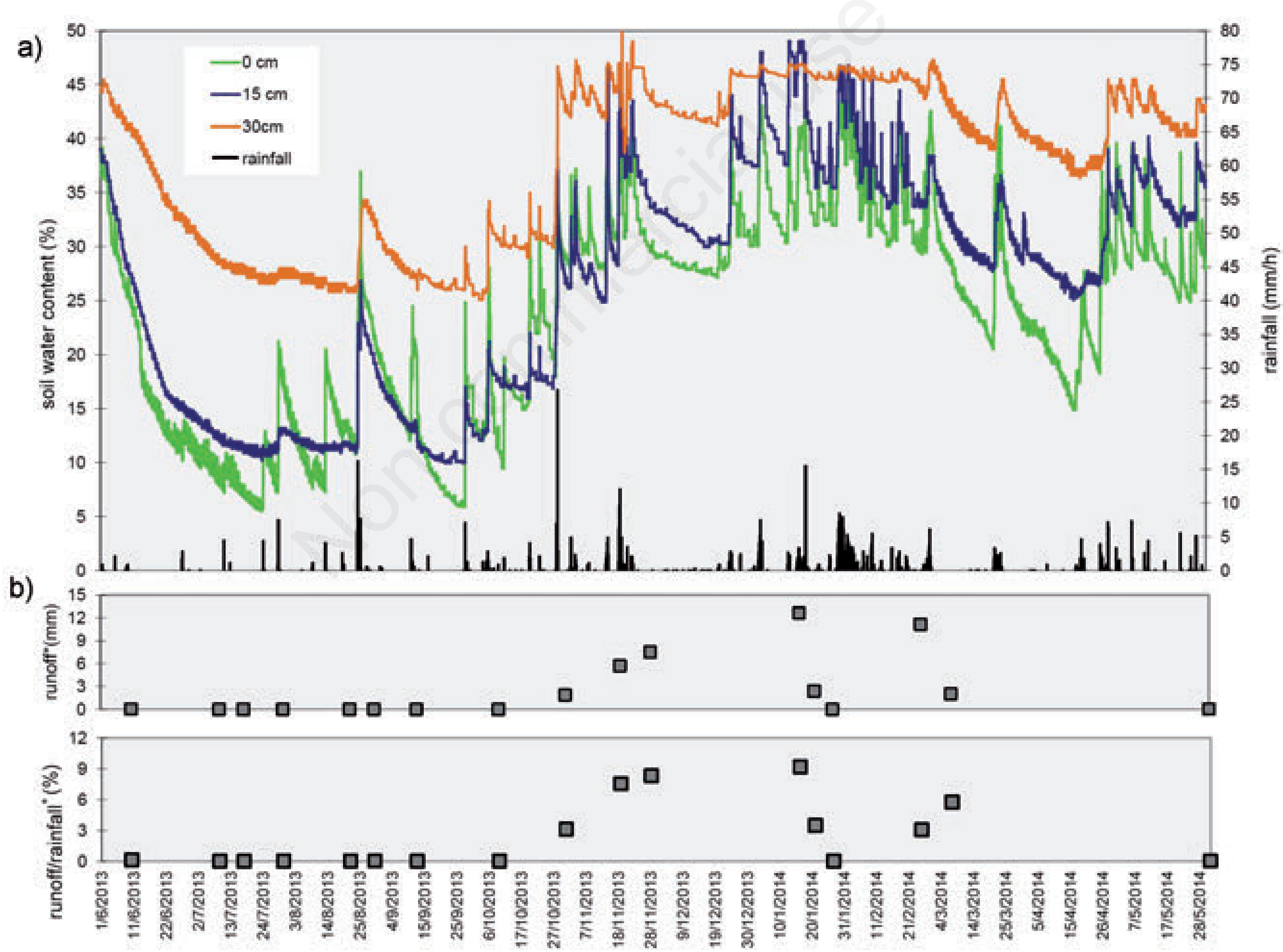

Figure 2. a) Comparison between the volumetric water content in three soil layers and rainfall (hourly data obtained from data recorded every 30 min); and b) the volume and percentage of runoff. The showed runoff data are those recorded as output from FT, but they are very similar to those coming out from the vineyard (VIG), as shown in Table 3. *Each square is placed next to the sampling dates and represents the total runoff produced in the period before sampling.

ciency of total suspended solids removal, calculated by the mass balance:

% of removal*	Judgment of indicator efficiency
<=30	Poor
>30; <=60	Medium
>60	High

The results are shown in Table 5.

Efficiency judgment

The studied site was part of the buffer strip monitoring relatively to the Cross-compliance Standard 5.2, whose further results are discussed in the Technical Report by Gumiero *et al*..

Discussion and conclusions

The experiment carried out in the vineyard of Ponte di Piave, showed that in autumn and winter significant quantities of surface runoff are produced (3.94% of the total annual rainfall), even if the slope is very low (0.56%) and the top layer of soil is loamy. Generally higher values were found with steeper slopes and more impermeable soils (Screpanti *et al.,* 2005; Borin *et al.,* 2005). Probably the soil permeability was significantly reduced by the soil compaction.

The measured runoff volumes showed negligible differences between input and output from the buffer strip. In this case the buffer system, in contrast with other experiences (Patty *et al.,* 1997; Syversen and Bechmann, 2004; Borin *et al.,* 2005), is not able to enhance infiltration processes or water retention. This result can be explained by some characteristics of the buffer system: very regular soil surface between the vineyards and the buffer system, the absence of physical obstacles generated by trees and their residues (occurring in more complex wooded buffer systems), low level of soil cracking in the FT due both to the soil texture, and lack of root systems causing significant physical action on soils; and finally to the good coverage of herbaceous vegetation.

Despite the negligible reduction in the runoff volume, the removal of suspended solids, due mainly to sedimentation process, was quite significant and comparable to the results obtained in other experiments (Dillaha and Inamdar, 1997; Carluer *et al.,* 2011). This monitoring con-

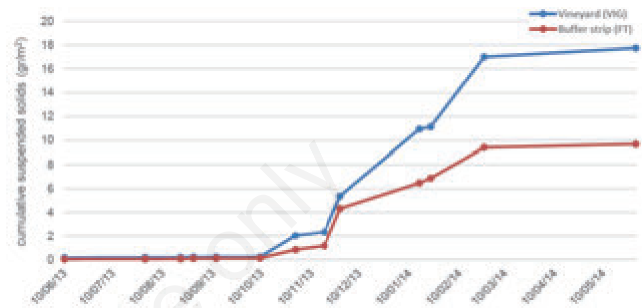

Figure 3. Cumulative amount of suspended solids in runoff conveyed through the two control points during the monitoring period.

Table 4. Amount of suspended solids conveyed through runoff from the vineyard, through the buffer zone and efficiency of removal.

Date	SS_VIG (mg/m^2)	SS_FT (mg/m^2)	SS removal efficiency (%)
31/05/10			
10/06/13	0.15	0.03	77.3%
30/07/13	0.03	0.00	83.3%
21/08/13	0.01	0.01	-45.9%
29/08/13	0.03	0.05	-83.5%
12/09/13	0.00	0.01	0.0%
09/10/13	0.02	0.02	0.7%
31/10/13	1.80	0.71	60.4%
18/11/13	0.31	0.31	-1.8%
28/11/13	3.03	3.17	-4.6%
16/01/14	5.57	2.14	61.6%
23/01/14	0.18	0.40	-123.1%
25/02/14	5.90	2.54	57.0%
30/05/14	0.75	0.28	62.6%
Total	17.77	9.68	45.5%

Table 5. Efficiency judgement.

Experimental site	Parameter	Removal efficiency (%)	Efficiency level
Vineyard Ponte di Piave CREA-VIT (Conegliano)	Suspended solids (runoff)	45.5	Medium
	Glyphosate (runoff)	n.d.	n.d.

n.d., not detected.

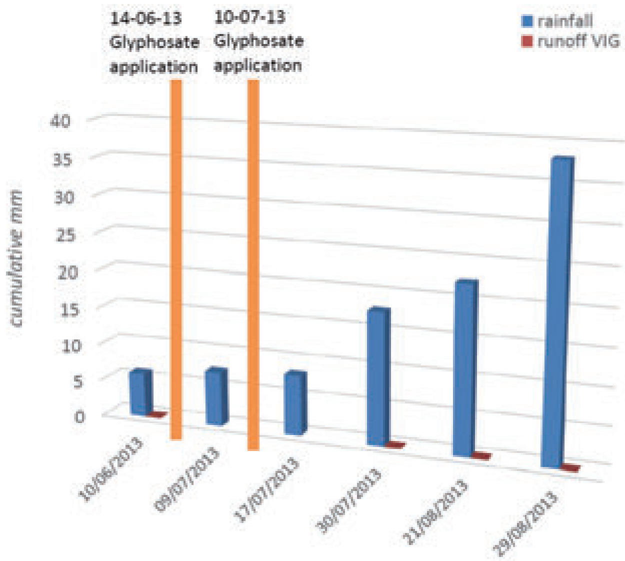

Figure 4. Precipitation and runoff in the thesis VIG (the data of the thesis FT are of the same order of magnitude) generated during the period covered by the distribution of Glyphosate.

solidates the effectiveness of only herbaceous buffer zones in retaining pollutants conveyed through runoff even in 5 m-wide buffer strip as required by Standard 5.2 of cross-compliance.

Concentrations below detection threshold recorded for Glyphosate are explainable considering the time elapsed (respectively 49, 25 and 20 days) among the three distributions and very low generation of surface runoff due to very sporadic rainfall occurred after the distribution. This has favoured the possibility of Glyphosate degradation, which has the half-life generally not exceeding the threshold of 20 days (Screpanti *et al.,* 2005; Borggaard and Gimsing, 2008). However it is likely that in case there are heavy rainfalls on the days immediately following the distribution the results could be significantly different.

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