Effectiveness of the cross-compliance Standard 5.2 'buffer strips' on protecting freshwater against diffuse nitrogen pollution

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Key words: Cross-compliance; rural development; Standard 5.2; buffer strips; competitiveness.

Work done under the Project MO.NA.CO. (National network for monitoring the environmental effectiveness of cross compliance and the differential of competitiveness charged against agricultural enterprises) funded by the Ministry of Agricultural, Food and Forestry Policies (MiPAAF) in the context of Action 1.2.2 'Interregional Workshops for development' of the Operational Programme called 'National Rural Network 2007-2013', Coord. Paolo Bazzoffi.

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Acknowledgments: We thank Dr. Maria Carmen Beltrano, Research Unit for Climatology and Meteorology applied to Agriculture (CREA-CMA), for providing the hourly data of temperature and precipitation measured at the National Agro-meteorological station network of Monterotondo (Rome).

Italian Journal of Agronomy 2015;772
doi:10.4081/ija.2015.772

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Abstract

Seven buffer strips (BS) adjacent to fresh water bodies, realized according to the technical data contained in the Standard 5.2 of Cross-compliance, located in different areas and climate contexts, were monitored for a period of two years. It was done in order to quantify their effectiveness in removing dissolved inorganic nitrogen conveyed through sub- surface flow from field crops with different cultural practices. Except for two case studies (sites: Lodi and Metaponto) in all monitored systems has been confirmed an outflow, permanent or temporary, through the buffer systems, with flow rates ranging from 919 to 8590 $m^3 y^{-1}$ every 100 meters of buffer stip. The differences in flow rate were mainly due to different sizes of agricultural basins related to buffer systems, which in the case studies ranging from 3.6 to 33.3%. Based on the mass balance, was found percentages of applied inorganic nitrogen, flowing from cultivated fields to the buffer systems, varied between 1.6 and 29.4%. In most of the sites was estimated of BS nitrogen reduction between inlet and outlet of BS, with percentages ranging from 33 to 61.9%. The exceptions were the systems with groundwater that: or have no interaction with the rhizosphere (deep flow) or not crossing the buffer zone. Low percentages of removal shall be justified by the young stage of the monitored sites, being in many cases recently converted to buffer strip. This study confirms the extreme variability of these systems efficiency and the key role of hydrology drives its effectiveness.

Introduction

The point-source pollution has been reduced significantly in recent decades thanks to increasing of efficient sewage treatment plants, while is not the case for widespread source pollution. Researchers have recognized the importance of non-point source pollution starting from the 1980s when improvement in wastewater treatments failed to produce the expected enhancement of streams and rivers water quality (Campbell *et al.,* 2004). Diffuse pollution is difficult to measure and control because it is often intermittent and linked to seasonal agricultural activity or irregular events, such as heavy precipitation, and involve complex transport and transformation through several media like air, soil and water (Dhondt *et al.,* 2004; Zhang *et al.,* 2012; Cheng *et al.,* 2013).

In a watershed, the main sources of nitrates are: i) the microbial processes of organic matter (mineralization and nitrification); ii) the oxidation of organic matter due to human activities: agricultural (manure) or urban (civil waste); iii) chemical fertilizers. In rural environment, two critical contaminant from diffuse pollution are pesticides and nutrients, in particular phosphorus and nitrogen. Fertilizer inputs to crops are generally higher than the amount of nutrients required to maximize plant productivity, hence this surplus may accumulate in soils (Sebilo *et al.,* 2013) and in water bodies. Nutrient load is drained from the agricultural territory or livestock origin, through processes of runoff, leaching and percolation. Nitrogen stored in soils is moved by tillage and erosion and then by water flow from cultivated areas to waterways. Nitrogen can also be delivered to atmosphere through volatilization of NH_3 and microbial generation of N_2O (greenhouse gas) (Carpenter *et al.,* 1998; De Simone *et al.,* 2010; Audet *et al.,* 2014). Despite the increasing efforts at national and European levels (Nitrate Directive 91/976/EEC, currently included in the Water Framework Directive 2000/60/EC) to reduce NO_3 inputs from intensive agriculture, it is still one of the major contaminants of superficial freshwater and groundwater resources (http://isonitrate.brgm.fr). Confined systems like shallow lakes, lagoons and enclosed seas are very sensitive to the excess of nutrients and can have highly impacted consequences like eutrophication (Boesch *et al.,* 2002; Khan and Ansari, 2005; Ansari *et al.,* 2010; Gren and Destouni, 2011). Furthermore, nitrate because of its high solubility in water, tends to be accumulated in groundwater, often used for drinking water, causing problems for human health (Carpenter *et al.,* 1998; Weyer *et al.,* 2001).

Diffuse nitrate decreasing can be reached with two different strategies: by reducing fertilizers inputs following more sustainable agricultural management or by facilitating natural processes of water phytodepuration that are usually very efficient in Buffer Strip and Wetlands systems as were established in many studies (Clement, 2002; Coops and van Geest, 2007; Billy *et al.,* 2013; Gumiero *et al.,* 2011, 2013; Hefting *et al.,* 2013).

In all European legislation related to water resources is emphasized the need to integrate policies of water protection management with the management of production activities, particularly agriculture, in order to achieve the goal of sustainable development. The Directive 2000/60/EC establishes the principle that '*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*'. It requires Member States '*to achieve good status of surface and ground water*' by 2015 (Art. 4 WFD). Member States must draw up plans for the river basin management (RBMP) and the programs of measures. They may implement this policy by using part of the funds of other sectorial policies, such as those provided by Common Agricultural Policy (CAP). As in Europe about 50% of the total surface is an agricultural land, it shapes the landscape and plays a key role in the sustainable management of water resources both in quantity and quality. For this reason the EU Council has pointed out the need to protect water resources within the CAP (COM (2012) 673 of 14th November 2012, 'Blueprint to safeguard Europe's water resources'). To achieve the objectives of the EU policy on water resources, the CAP uses mainly two tools: Cross-compliance and the European Agricultural Funds for Rural Development (EAFRD) (in Italy they are called PSR). These tools help to promote sustainable agriculture by encouraging good agricultural practices and promoting the environmental goods and services. Within the Cross-compliance Standards there are several obligations that directly affect water quality, one of them is GAEC 5.2, concerns the obligation to introduce 'buffer strips' at the edge of the cropland and close to watercourses in order to protect them from diffuse pollution caused mainly by agricultural activities. This requirement in Italy was introduced in 2009 and implemented since 1st January of 2012. Buffer strip is a vegetated area, near watercourses, permanently covered with grass, shrubs, trees, spontaneous or not. The Standard requires a strip 5m wide excluding unvegetated roads or paths. The obligation of buffer strips covers all agricultural areas, with the exception of land under permanent pasture and olive groves. In the requirement of buffer strips the following watercourses are excluded: i) drains, ditches and other hydraulic artificial structures made for the collection and conveyance of storm water, with temporary discharge; ii) irrigation channels; iii) 'suspended' channel; iv) watercourses with consistent levees that cause a discontinuity between the field and the aquatic system (www.agricoltura24.com). Elsewhere in Europe the commitments of Standard 5.2 are almost the same for all member countries. What changes most is the wide of the buffer zone that can range from 2 to 10 meters. Ten meters usually makes reference to the prohibition of organic fertilization. This paper shows the results of diffuse nitrate removal efficiency of different buffer strips, setup according to the technical indications reported in the Standard 5.2, and highlight the major factors that improve or reduce buffer effectiveness.

Materials and methods

Experimental sites

Seven experimental sites, distributed in different Italian regions, were set in order to conduct the experimental activities. The main characteristics of each site are summarized in Table 1. In all sites the management was limited to mowing (1-2 times for year) and, when necessary, to the lateral pruning of trees and shrubs, including the removal of any branches or logs, to allow the passage of agricultural machinery. In accordance with the Cross-compliance Standard 5.2 (M.D. 27417), no distribution of fertilizers or other phytosanitary products has been done in the buffer strips.

In all afferent agricultural catchments, except for DIANA-FT2 (seeding), the usual operations of ploughing (up to 30-40 cm from ground level) and harrowing have been performed. Only in site CAMP7-(Metaponto) irrigation could be provide if necessary.

With the exception of the site TORMA, where the buffer strip was 8.5 m wide, in all sites they were 5 m wide. The experimental sites were well distributed both in term of different territorial context (hilly or lowland areas) and vegetation typology (3 only herbaceous and 4 herbaceous + tree and shrubs buffer strips).

The ratio between the buffer strips and the afferent crop catchment areas, was quite variable from a minimum of 3.6 % in FAGNA-FT2 to a maximum of 33.3% in DIANA-FT1. The catchment surface has not been defined in the sites of Baroncina (Lodi) and CAMP7 (Metaponto), where no hydrological connection between the crop fields and the buffers strips were found.

Experimental design

The experimental designs have been planned in coherence with the indications reported in the Cross-compliance Standard 5.2 (M.D. 27417) (Figure 1).

The monitoring points were choosen as following:

A) Counterfactual: located in the interface zone between the 'margin of the crop' and the beginning of buffer strip, where the flow of pollutants from the crop towards the inlet of the buffer zone was monitored. It was considered the reference without Standard application.

B) Factual: section located at the end or in an intermediate portion of the buffer zone to provide information about the effects of the Standard application.

Because of different types of buffer strips, the factual area was further specified according to the following definitions:

Factual I : herbaceous (only) buffer strip at least 5 meters wide;

Factual II: herbaceous buffer strip, at least 3 meters wide, and placed between the edge of the crop and the beginning of a woody buffer strip, in a buffer system given by the combination of the two.

Factual III: outlet point of a buffer zone composed by the combination of an herbaceous strip, at least 3 meters wide, plus a woody strip at least 2 meters wide.

The monitoring scheme for each experimental sites is reported in Figure 1.

In order to monitor both hydrological and chemical-physical parameters, each experimental site was set up as shown in the simplified scheme of Figure 2.

Even if some specific differences between sites existed, in all of them have been set:

a piezometric network, generally consisting in a 3x3 grid, with 3 wells (replicates) placed perpendicularly to the theoretical line of subsurface runoff from the field to the water body and placed respectively in the entry to the buffer zone (counterfactual), in an intermediate zone (generally the zone of transition between herbaceous and woody strips) and in correspondence of the output of buffer zone (factual). In addition a sampling point was also placed in the crop area. The fully screened piezometers had a diameter of 2 inches, and variable depth according to the depth of saturated zones. They were used both for water sampling (through a system of flasks placed inside the piezometer) and for instantaneous measurements of the groundwater level (by a manual freatimeter);

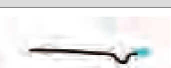
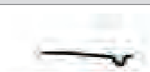
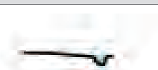
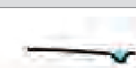
2 electric contact gauges to measure every 30 minutes the piezometric head, placed inside 2 dedicated piezometers: one at the input and the other at the output of the buffer zone;

FDR sensors registered the volumetric soil water content at different soil depths;

3 lysimeters collecting water at different depth (30, 60 and 90 cm), in the crop field.

The soil samples have been drawn at different depth both in the cultivated field and in the buffer strips by a manual drill.

Table 1. Main characteristics of the experimental sites.

Experimental sites	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Geographical coordinates	43°58' 49.90 N 12°18' 43.00 E	43°58' 57.30 N 11°20' 36.75 E	45°17' 24.24 N 9°29' 55.76 E	45°34' 27.88 N 12°19' 01.87 E	45°34' 47.65 N 12°18' 40.65 E	42° 05' 31.19"N 12° 38' 05.46"E	40°22' 12.78 N 16°48' 33.13 E
Geographical context	Hilly	Hilly	Lowland	Lowland	Lowland	Hilly	Lowland
Topography							
Slope° (%)	4.4 / 9.2	6.5 / 1.7	0.2 / 0.7	4.3 / 4.5	3.9 /4.3	7.4 / -2.3	0.52/0.63
Crop	Wheat	Sunflower/maize	Maize	Maize	Ryegrass/maize	Wheat	Vegetables
Waterbody typology	Natural stream	Natural stream	Irrigation ditch	Ditch	Ditch	Collector ditch	Collector ditch
BS cover	Herbaceous + arboreous and shrub	Herbaceous	Herbaceous + arboreous	Herbaceous	Herbaceous+ Harboreous and shrub	Herbaceous+ arboreous and shrub	Herbaceous
Total width of BS (m)	5	5	5	5	5	8.53	5
Upland slope length (m)	135	130	n.d.	10	13	176	n.d.
Area BS/area catchment (%)	3.70	3.57	n.d.	33.33	27.8	4.8	n.d.

°The first number refers to the average slope of the crop catchment, while the second to the average slope of the buffer strip; BS, Buffer strip; n.d., not detected.

Methods

Water balance

The subsurface flow discharge has been calculated by the Darcy's Law in the following form:

$$Q = ks\, S\, \vec{i}$$

where Q is the average inflow flux, i is the head gradient between the two considered piezometers set with the transducers and S is the saturated area perpendicular to the groundwater flow.

Parameters

For each site a series of chemical and physical parameters were detected. Some of them were defined as priority parameters (key parameters) some other as ancillary parameters (parameters which are not mandatory but useful as additional information to confirm whether certain interpretations of the results). The parameter type, the location of the sampling points, the frequency and the analytical method used are summarized in Table 2.

Results

Hydrological dynamics

Thanks to the surveys carried out it was possible to describe the main characteristics of the soil and of the hydrological dynamics in the experimental sites. A summary of the most significant characteristics for each site is shown in the Table 3. In most of the case studies, the rain or irrigation waters flow in the agricultural soils above the first impermeable layer of soil (placed at variable depths from a minimum of 90 to a maximum of 300 cm) and generate a saturated zone (suspended groundwater) which could be permanent or temporary (the saturated zone disappears during the warm season). With the exception of the Baroncina site (Lodi), where there was not a clear prevalent direction of the subsurface flows, and CAMP7 (Metaponto) site, where the groundwater flows almost parallel to the buffer strip toward a lateral draining ditch, in all the other cases investigated the groundwater flows perpendicularly from the crop to the buffer system. The groundwater slope varied between a minimum of 1% (DIANA-FT2 site) and a maximum of 13% (Fagna-FT1 site). The hydraulic conductivity meas-

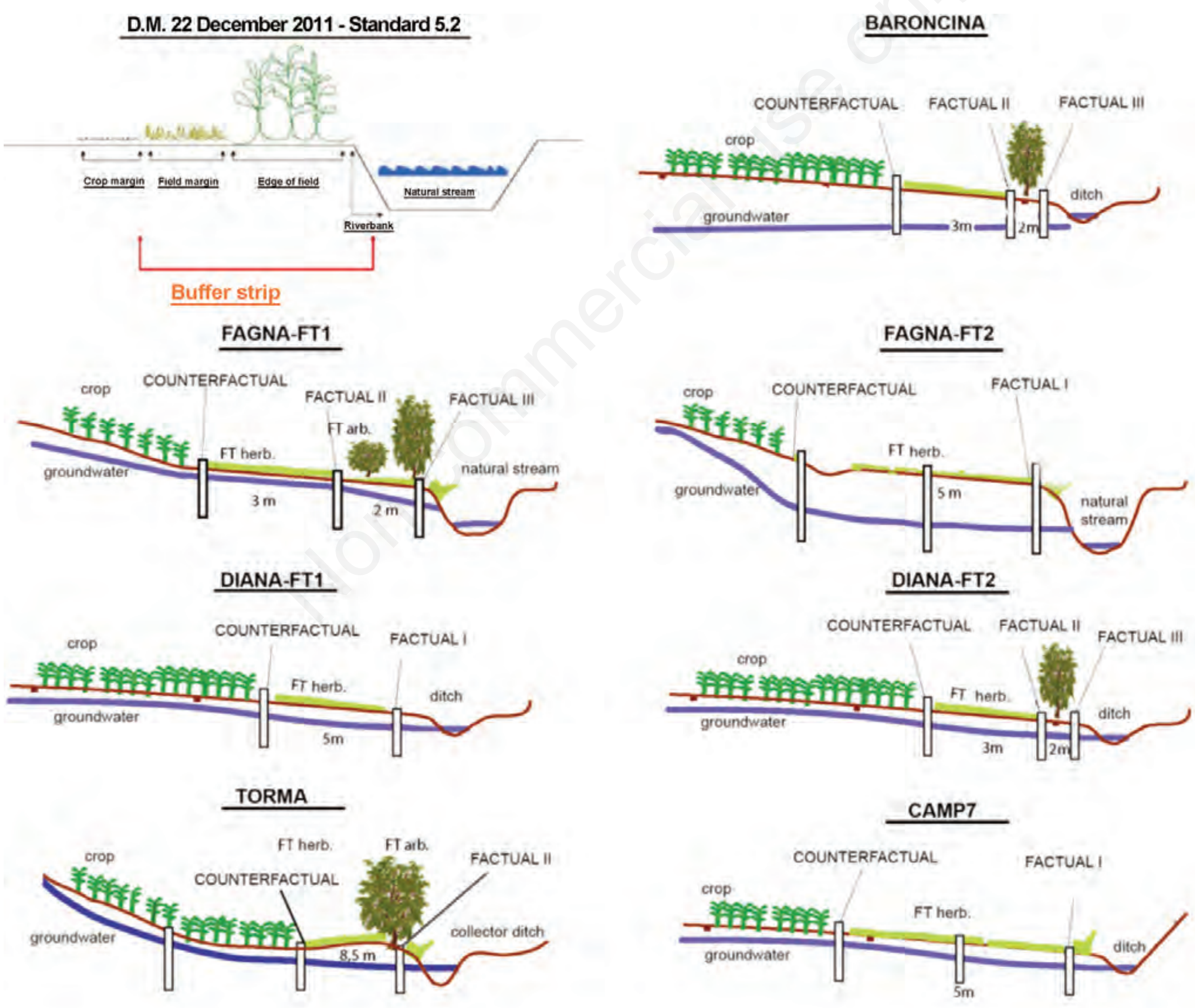


Figure 1. Experimental schemes of the experimental sites and their comparison with the general case contained in M.D. 27417.

ured by slug tests differed considerably (about one order of magnitude) from the theoretical one related to the soil texture. This was generally due to the presence of macro-cracks in the soil caused by the ploughing activities or alternatively by the effect of the vegetation roots (Mastrocicco *et al.,* 2013).

The trend of groundwater fluctuations in all monitored sites is shown in Figure 3. In the two sites located within the experimental farm Diana (DIANA-DIANA-FT1 and FT2) a temporary phase of saturation during the cold months (generally from November to May) has been observed. In the remaining months the soil was unsaturated except during high intensity rainfall events. The water table fluctuations were strongly related to the rainfall events and saturation conditions often reach the ground level. A similar trend has been observed in the experimental site CAMP7 (Metaponto). On the other hand in the site Fagna-FT2 was recorded a permanent water table (at least in the monitored period) laying on an impermeable layer about 3 meters deep; the fluctuations were rather small between 2-3 m from the soil surface. The sites Fagna-FT1 and TORMA have similar hydrological behaviour with an almost complete saturation of the first 2 m of soil for most of the year. This behaviour was favoured by particularly intense and persistent rainfall events during the two years of monitoring; thus it cannot be excluded than during years of drought the soil may result temporary unsaturated. The Baroncina site, in term of saturation, had strong fluctuations correlated with rainfall events.

The main items of the water balance for each of the monitored sites were listed in the Table 4. Since the absence of subsurface flows from crop to the buffer strip both Baroncina and CAMP7 sites were not included in Table 3, about the water balance, and in Table 5, about the nitrogen balance as they were equal to zero.

The discharge of the sub-surface flows which convey the pollutants from the crop to surface waterbodies through the buffer system, are strictly related to the size of the catchment area, the slope and soil characteristics. As an example in the Fagna-FT2 site the high permeability of the sandy soil in the surface layers (further enhanced by the agricultural processing) favoured the infiltration of the rainwater towards the deep (300 cm from the soil surface) impermeable layer of ancient clay. Above this layer, thanks to the slope, groundwater rapidly flows towards the buffer zone. Moreover due to the significant surface of the agricultural basin, the flow rate reached the high value of about 8590 m^3 / year (to 100 m on buffer strips) corresponding to 64% of the rainfall in the basin (the remaining part is subject to processes of evapotranspiration). On the other hand the low values of subsurface discharges in the two sites of DIANA farm were the consequence of small size of the afferent agricultural basin. Also in this case a significant portion of the water volumes tends to be lost through subsurface flows (55.4% and 64.0% of the total rainfall) due to the heavy ploughing operations of the crop field. Catchments basins with steep slope which decreases sharply just before the buffer strip, and a very low hydraulic conductivity of soils like in the Fagna-FT1 and TORMA sites, the subsurface flows discharge represent only a small portion of total rainfall volumes (17.8 and 31.8%, respectively), while the dominating phenomena are surface runoff and evapotranspiration.

Nitrogen dynamics

The comparison between the concentration values of dissolved inorganic nitrogen in different points of the groundwater is shown in Figure 4.

In most cases the concentration values were rather low; the lowest values were recorded in the site of TORMA, while in the Fagna-FT1, Fagna-FT2 and DIANA-FT1 sites the average values, in the inlet of the buffer strip, ranged between 4 to 6 mg/L. Low concentrations of inorganic nitrogen in the water flow out from the crop can be due to several

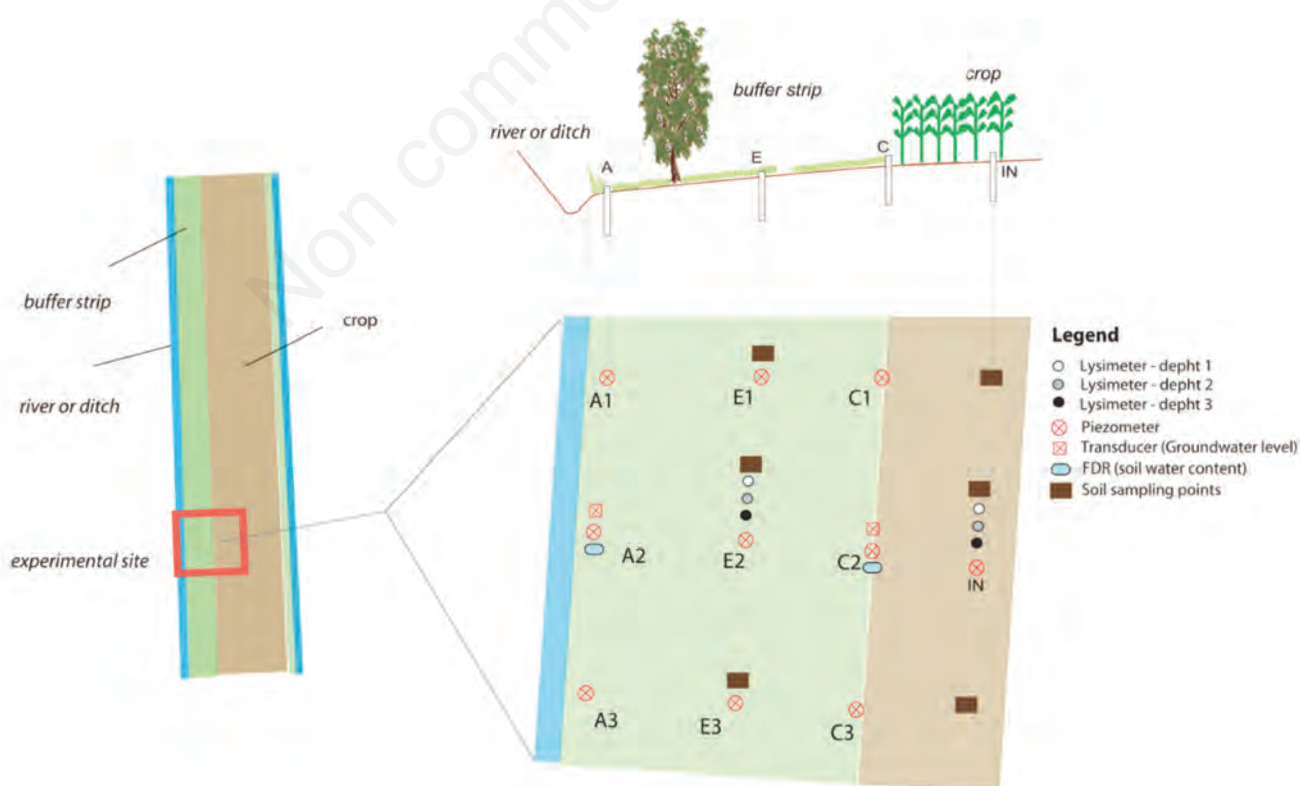


Figure 2. General monitoring scheme.

Table 2. Description of the monitored priority and ancillary parameters.

Priority parameters	Sampling point	Frequency	Methods	Aims
Texture	One complete soil profile, inside the buffer zone, from ground level up to the saturated zone	Only once at the start of monitoring	Pipette method	Understanding of the system and calculation of parameters dependent on texture
Watertable depth (continuously)	One point input (Factual) and 1 point out of the buffer zone (Counterfactual)	Every 30 minutes	Pressure transducers (SLB1 stainless steel, two-wire 4-20mA piezometers and current output, power supply 8-28 Vdc) inserted in dedicated connected to a data logger (data logger WatchDog 1000 Series, model 1650 sensors T / RH external air + 4 doors for external sensors).	To understand the dynamics of the saturated zone and water balance
Watertable depth (instantaneous measurements)	In each piezometer	During the water sampling (approximately every 15 days)	Hanfly freatimeter	To integrate the data recorded in continuous in a single section, with data relating to the whole piezometric net in order to define the groundwater. direction.
Rainfall	One pluviometer in each experimental site	Continuously	Rain gauge connected to a datalogger (WatchDog rain gauge data-logging 3554WD1-Spectrum Technologies attached to a self-emptying tipping bucket).	Water balance, climate trend.
Chemical parameters of water (N-tot, N-NO3, N-NH4, N-NO2)	All piezometers and lysimeters. Occasionally also from the adjacent surface waterbody.	Every 15-30 days	N-NO3, N-NH4, N-NO2: colorimetric analysis Ntot: Thermo Flash 2000 CN soil analyzer	Nitrogen dynamics and budget.
Saturated hydraulic conductivity (Ks)	All piezometers	Once	Slug test	Water balance
Elevation	The whole experimental plot, with a grid functional to obtain a DEM (Digital Elevation Model) with a resolution 20x20 cm)	Once	Leica GPS 1200+ system consisting in two geodetic receivers GPS / GNSS Leica AS10	Groundwater depth and water balance
Ancillary parameters	**Sampling point**	**Frequency**	**Methods**	**Aims**
Volumetric soil water content	Input and output of the buffer strips at different dephts	Every 30 minutes	FDR Probes (Frequency Domain Reflectometry, spectrum SM 100 waterscout soil moisture sensor) connected to a data logger (data-logging WatchDog 1000 Series Spectrum Technologies).	Hydrologic dynamics
Chemical parameters of water (DO, T and Cond.)	All piezometers	Every 15-30 days	Dissolved Oxigen: Oximeter AL20Oxi (Aqualytic, Dortmund, Germany). Temperature and electrical conductivity: portable conductivity meter with integrated temperature sensor (Schott-Geräte Conductivity meter handylab LF).	Ancillary data for a better understanding of the processes.
Chemical parameters of soil (TOC, TN, WSC, NO_3, NH_4).	Three points (replicates) at different depths both in the crop and in the buffer strip	2-3 times for year	TOC and TN: Thermo elemental analyzer Flash 2000 CN soil analyzer; SC: Thermo analyzer Flash 2000 CN Wsoil analyzer; NO_3, NH_4: colorimetric analysis	To estimate nitrogen storing or loss in the soil.

factors, such as the optimal use of nitrogen or heavy rainfall (clearly above the average during the two monitored years) leading to an increase of dilution. The mean values showed that Fagna FT1 and DIANA-FT1 sites were effective in removing nitrogen; the high variability of the values indicates a different seasonal pattern. In DIANA-FT1 a significant increase in nitrogen removal has been observed starting from the second year of monitoring, most likely due to the maturation of the newly-created buffer zone. The results recorded in Fagna-FT2 site, did not show any kind of buffering activities transformation; thus it give us an interesting example of no interaction between subsurface flows and rhizosphere, and as consequence no significant biogeochemical transformations of nitrogen. In TORMA site very low concentrations have been measured. Even if the overall differences between input and output in terms of average values were not significant, the higher stability of the output values compared with the input ones indicates that the occasional nitrogen peaks were effectively removed. The trend of nitrogen concentrations observed in Baroncina site further highlights the lack of hydrological connection between the crop (in the two control points the nitrogen concentrations were clearly influenced by the fertilization) and the buffer zone where the three control sections did not differ significantly and the average values were very low also in the section placed between the buffer strip and the crop. A similar situation has been observed in the site CAMP7, where it was clear that the waters loaded with nitrogen drain into the lateral ditch instead of crossing the buffer strip. The main items of nitrogen balance are summarized in the following Table 5.

The amount of nitrogen transported through subsurface fluxes from the field to the buffer strips ranges from a minimum of 3 kg ha^{-1} $year^{-1}$ to a maximum of 33.2 kg ha^{-1} $year^{-1}$, with percentages of nitrogen leaching ranging between 1.8 and 25.2%. With the exception of the Fagna-FT2 site, all the systems were effective in N_{inorg} removal, with an efficiency ranging between 33 and 61.9%.

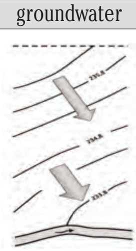
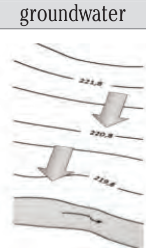
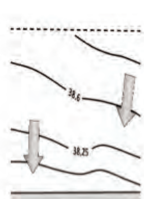
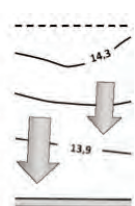
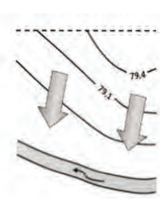
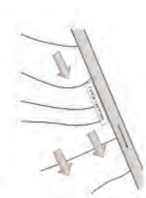
Quantitative indicator

The indicator of basic level chosen to define the suitability of the Standard 5.2 relatively to its environmental target was the efficiency of inorganic nitrogen removal, calculated by the mass balance following the below scheme:

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

The results are shown in Table 6.

Table 3. Main pedological and hydrological characteristics of the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Unsaturated layer (cm from s.l.)°	0-15	0-210	0-70	0-50	0-20	0-10	0-60
Saturated layer (cm from s.l.)°	15-200	210-300	70-200	50-90	20-90	10-200	<60
Unsaturated layer texture#	Silty clay loam (20-36-44)	Loam (40-22-38)	Loam (34-21-45)	Clay loam (26-39-35)	Silt loam (18-65-17)	Loam (32-48-30)	Clay (10-55-35)
Saturated layer texture#	Layer 15-85 cm silty clay loam (20-48-32) Layer 85-200 cm silty clay (7-48-45)	Sandy loam (60-8-32)	Sandy loam (68-13-19)	Silty clay loam (21-50-29)	Silt loam (19-63-18)	Loam (31-44-25)	Clay (3-70-27)
Slug Test Hydraulic conductivity (cm/day)	53.0	1180.0	1234.0	350.0	255.0	64.7	17.3
Groundwater slope in BS (%)	13.0	5.2	n.d.	11.0	1.0	2.3	n.d.
Groundwater depth (from s.l.)	Max: 0; Average: 75; Min: 198	Max: 45,1 Average: 229,6 Min: 277	Max: 0 Average: 74 Min: 200	Max: 0; Average: 48 Min: dry	Max: 0; Average: 20 Min: dry	Max: 0; Average: 39 Min: 104	Max: 16 Average: 80 Min: dry
Type	Permanent groundwater	Permanent groundwater	Permanent groundwater	Temporary perched aquifer	Temporary perched aquifer	Permanent groundwater	Permanent groundwater
Prevalent groundwater direction			No prevalent direction				

°In the most common situations; #the indicated numbers refers to the percent of sand/silt/clay, respectively; BS, Buffer strip; n.d., not detected.

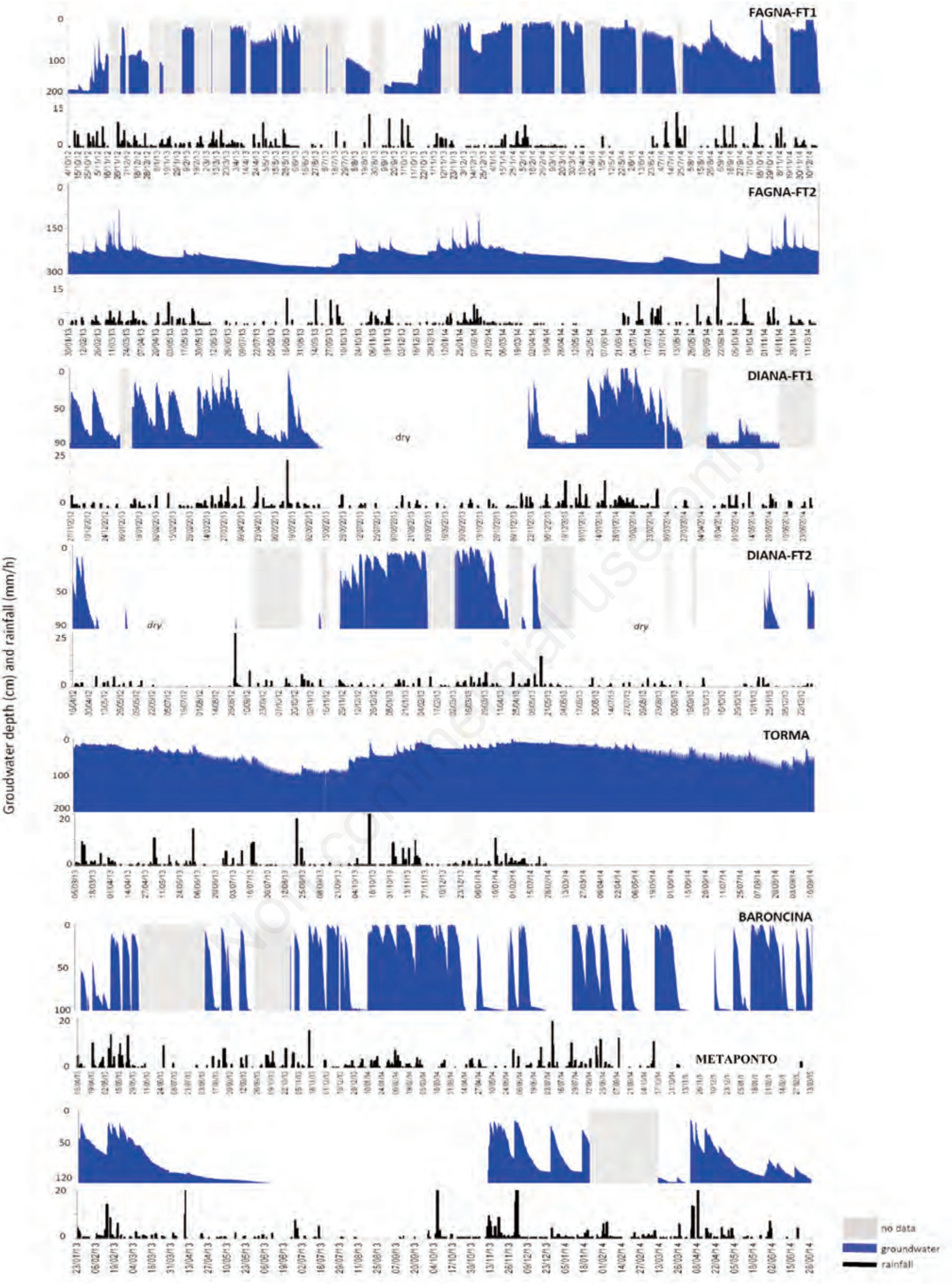


Figure 3. Fluctuation of the water table (data obtained as an average of 2 recordings, 1 every 30 minutes) in the experimental sites and hourly precipitation.

Efficiency judgment

The judgment of effectiveness was based on the percentage of experimental sites which demonstrated to be efficient on nitrogen removal. In the case of Standard 5.2 an improvement has been observed in 4 out of 7 of the monitored sites (57%), corresponding to a judgment of 'Effectiveness medium-high'.

Discussion and conclusions

The results are consistent with those of literature (Haycock and Pinay, 1993; Fennesy and Cronk, 1997; Dhont *et al*., 2004; Gumiero *et al*., 2011; Vidon and Hill, 2004) and the experimental activity contributed to demonstrate the key role of hydrological processes in influencing the effectiveness on nitrogen removal.

In particular, it was noted that in some of the monitored systems (Fagna-FT1, Fagna-FT2, TORMA) the buffer strips setup in accordance with the technical criteria of the cross-compliance Standard 5.2, were able to intercept significant volumes (ranging from 3000 to 8500 m^3 $year^{-1}$ per 100 l m of buffer strip) even if they occupy a surface rather limited compared to the field crops (3-5%).

Conversely, the buffer strips DIANA-FT1 and DIANA-FT2 cover a significant area if compared to the crop (about 30%) and in the same time they intercept low water volumes (around 1000 m^3 per year 100 mL of FT). Consequently to optimize the investment in terms of area occu-

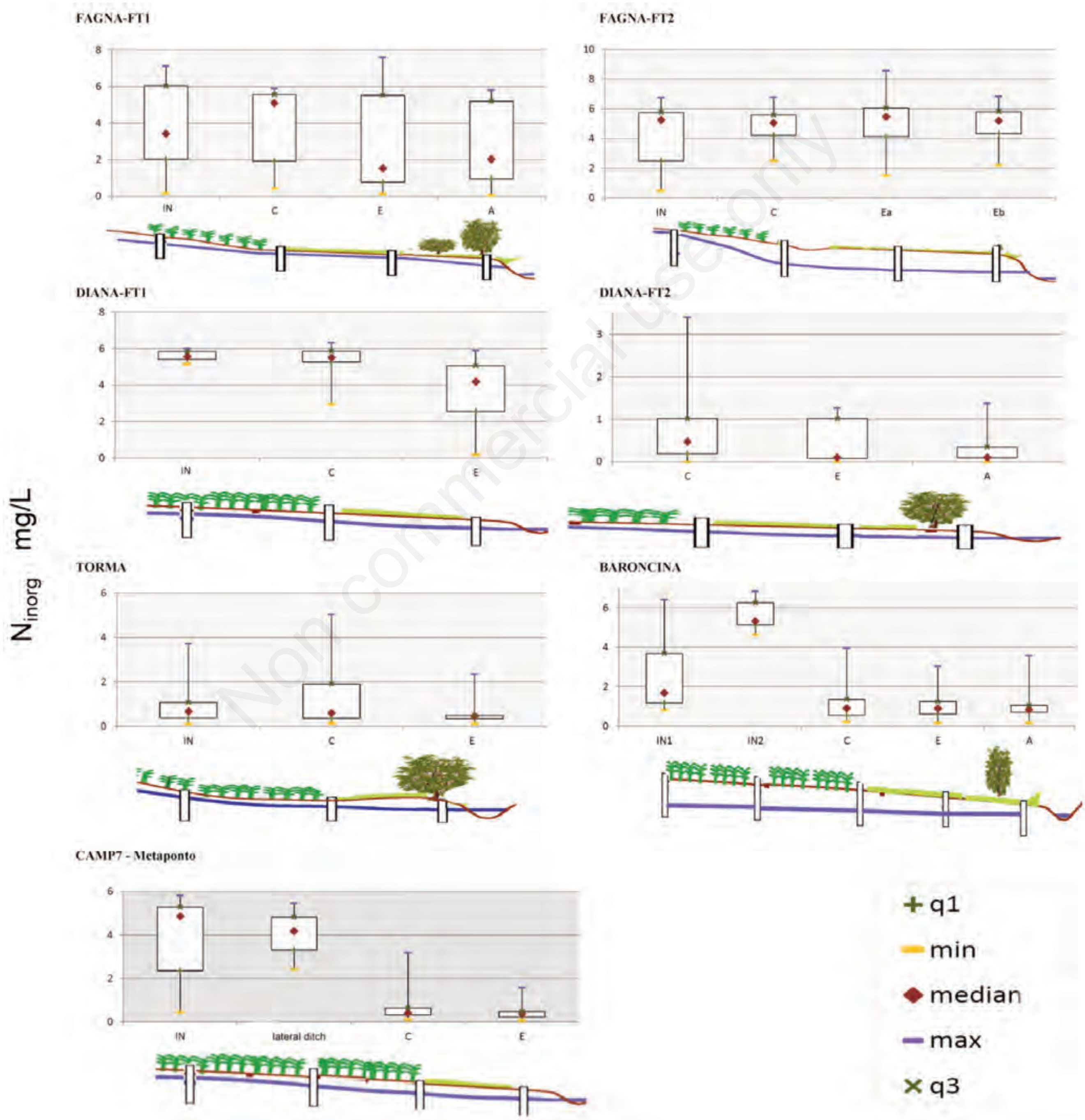


Figure 4. Comparison between the concentration values of dissolved inorganic nitrogen in different points of the monitored systems.

pied, this measure was particularly effective when it was possible to place a buffer zone downstream of a wide agricultural basin, with an optimal ratio between the surface occupied by the buffer strip and the crop of around 5%.

The inefficiency of Fagna-FT2 site, highlighted the importance of interaction between water flow and the rizhosphere for enhancing vegetation uptake and give support to microbial activities by organic matter supply (Pinay *et al*., 2000; Sabater *et al*., 2003; Vidon and Hill, 2004; Gumiero *et al.,* 2011; Boz *et al.* 2013). For different reasons, mentioned above, the Baroncina and the CAMP7 sites represents other cases of non-effective systems.

In all the other cases, the outflows persisted, at least for certain periods of the year, close to the ground surface, in theoretically optimal condition for the activation of the processes that lead to the removal of nitrogen. Despite this, in none of the cases the high levels of removal (80-90%) observed in other contexts (Peterjohn and Correl, 1984; Haycock and Pinay, 1993) have been reached, but rather values of efficiency ranging between 30-60%. This may be due to the short monitoring period (1-2 years) and to the unusual weather conditions (high rainfall); in the same time the low maturity of the monitored buffer strips, in many cases they were converted just before the beginning of the experimental activity, may leaded to an underestimation of the

Table 4. Main hydrological items in the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS AGRIC. (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
Subsurface flow discharge (100 m BS) (m^3 $year^{-1}$)	3152	8587	919	1004	4726
Subsurface flow discharge (100 m BS) (mm)	225	636	613	717	269
Rainfall (mm)	1264	1072	1385	1116	843
Subsurface flow discharge (% rain)	17.8	59.3	55.8	64	31.8

Table 5. Nitrogen balance in the different experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Florence)	FAGNA-FT2 CREA-ABP (Florence)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
N_{inorg} applied (kg ha^{-1} $year^{-1}$)	72	120	250	170	96
IN N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	8.45±1.69	30.29±2.94	33.21±1.34	3.0±0.3	4.66±1.69
N_{inorg} to BZ by subsurface flow / N_{inorg} applied (%)	11.1	25.2	13.3	1.8	1.78
Out N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	5.67±1.63	29.42±5.08	17.29±1.24	1.6±0.2	1.91±0.47
N_{inorg} removal by the BZ (kg ha^{-1} $year^{-1}$)	2.79	0.86	15.93	1.5	2.88
Efficiency (%)	33.0	2.9	48.0	48.6	61.9

Table 6. Judgment of efficiency in the different sites (base level).

Experimental site	Removal (%)	Judgment of indicator efficiency
FAGNA-FT1 CREA-ABP (Florence)	33	Medium
FAGNA-FT2 CREA-ABP (Florence)	2.9	Poor
BARONCINA CREA-FLP (Lodi)	0	Poor
DIANA-FT1 VENETO AGRIC.	48	Medium
DIANA-FT2 VENETO AGRIC.	48.6	Medium
TORMA- CREA-RPS (Rome)	62	High
CAMP7-CREA-SSC (Metaponto)	0	Poor

buffering capacity. This was confirmed by the low levels of organic matter available in the soils (values between 1.5 and 1.7%) as well. In this perspective, an increasing of the buffer capacity could be observed in a more advanced phase starting from the second or the third year after the conversion as observed in other studies (Gumiero *et al*., 2011; Anbumozhi *et al*., 2004; Uusi-Kämppä and Jauhiainen, 2010). During early stages, the influence of the hydrological factors appears to be prevalent instead of the type of vegetation. At the same time the river typology did not affect significantly the efficacy of the buffer zone, although it must be recognized to the past river dynamics a key role in determining the soil layers configuration and properties. This usually leads to observe more heterogeneous soil profiles in the riparian buffer adjacent to natural water bodies better than to artificial water bodies.

The infiltration capacity of water in soil with consequent development of sub-surface outflows was rather significant in all monitored systems (values ranging between 18 and 64% of total rainfall). This was recorded also in systems with high slopes (above 6%) and/or fine grain soil which should facilitate the development of surface runoff phenomena.

This was mainly due to the ploughing activities which, in addition to increase the water infiltration within the field crop, shaped a significant drop of soil surface between the field and the undisturbed buffer zone that could not be overcome by superficial runoff.

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Abstract

Seven buffer strips (BS) adjacent to fresh water bodies, realized according to the technical data contained in the Standard 5.2 of Cross-compliance, located in different areas and climate contexts, were monitored for a period of two years. It was done in order to quantify their effectiveness in removing dissolved inorganic nitrogen conveyed through sub- surface flow from field crops with different cultural practices. Except for two case studies (sites: Lodi and Metaponto) in all monitored systems has been confirmed an outflow, permanent or temporary, through the buffer systems, with flow rates ranging from 919 to 8590 $m^3 y^{-1}$ every 100 meters of buffer stip. The differences in flow rate were mainly due to different sizes of agricultural basins related to buffer systems, which in the case studies ranging from 3.6 to 33.3%. Based on the mass balance, was found percentages of applied inorganic nitrogen, flowing from cultivated fields to the buffer systems, varied between 1.6 and 29.4%. In most of the sites was estimated of BS nitrogen reduction between inlet and outlet of BS, with percentages ranging from 33 to 61.9%. The exceptions were the systems with groundwater that: or have no interaction with the rhizosphere (deep flow) or not crossing the buffer zone. Low percentages of removal shall be justified by the young stage of the monitored sites, being in many cases recently converted to buffer strip. This study confirms the extreme variability of these systems efficiency and the key role of hydrology drives its effectiveness.

Introduction

The point-source pollution has been reduced significantly in recent decades thanks to increasing of efficient sewage treatment plants, while is not the case for widespread source pollution. Researchers have recognized the importance of non-point source pollution starting from the 1980s when improvement in wastewater treatments failed to produce the expected enhancement of streams and rivers water quality (Campbell *et al.,* 2004). Diffuse pollution is difficult to measure and control because it is often intermittent and linked to seasonal agricultural activity or irregular events, such as heavy precipitation, and involve complex transport and transformation through several media like air, soil and water (Dhondt *et al.,* 2004; Zhang *et al.,* 2012; Cheng *et al.,* 2013).

In a watershed, the main sources of nitrates are: i) the microbial processes of organic matter (mineralization and nitrification); ii) the oxidation of organic matter due to human activities: agricultural (manure) or urban (civil waste); iii) chemical fertilizers. In rural environment, two critical contaminant from diffuse pollution are pesticides and nutrients, in particular phosphorus and nitrogen. Fertilizer inputs to crops are generally higher than the amount of nutrients required to maximize plant productivity, hence this surplus may accumulate in soils (Sebilo *et al.,* 2013) and in water bodies. Nutrient load is drained from the agricultural territory or livestock origin, through processes of runoff, leaching and percolation. Nitrogen stored in soils is moved by tillage and erosion and then by water flow from cultivated areas to waterways. Nitrogen can also be delivered to atmosphere through volatilization of NH_3 and microbial generation of N_2O (greenhouse gas) (Carpenter *et al.,* 1998; De Simone *et al.,* 2010; Audet *et al.,* 2014). Despite the increasing efforts at national and European levels (Nitrate Directive 91/976/EEC, currently included in the Water Framework Directive 2000/60/EC) to reduce NO_3 inputs from intensive agriculture, it is still one of the major contaminants of superficial freshwater and groundwater resources (http://isonitrate.brgm.fr). Confined systems like shallow lakes, lagoons and enclosed seas are very sensitive to the excess of nutrients and can have highly impacted consequences like eutrophication (Boesch *et al.,* 2002; Khan and Ansari, 2005; Ansari *et al.,* 2010; Gren and Destouni, 2011). Furthermore, nitrate because of its high solubility in water, tends to be accumulated in groundwater, often used for drinking water, causing problems for human health (Carpenter *et al.,* 1998; Weyer *et al.,* 2001).

Diffuse nitrate decreasing can be reached with two different strategies: by reducing fertilizers inputs following more sustainable agricultural management or by facilitating natural processes of water phytodepuration that are usually very efficient in Buffer Strip and Wetlands systems as were established in many studies (Clement, 2002; Coops and van Geest, 2007; Billy *et al.,* 2013; Gumiero *et al.,* 2011, 2013; Hefting *et al.,* 2013).

In all European legislation related to water resources is emphasized the need to integrate policies of water protection management with the management of production activities, particularly agriculture, in order to achieve the goal of sustainable development. The Directive 2000/60/EC establishes the principle that '*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*'. It requires Member States '*to achieve good status of surface and ground water*' by 2015 (Art. 4 WFD). Member States must draw up plans for the river basin management (RBMP) and the programs of measures. They may implement this policy by using part of the funds of other sectorial policies, such as those provided by Common Agricultural Policy (CAP). As in Europe about 50% of the total surface is an agricultural land, it shapes the landscape and plays a key role in the sustainable management of water resources both in quantity and quality. For this reason the EU Council has pointed out the need to protect water resources within the CAP (COM (2012) 673 of 14th November 2012, 'Blueprint to safeguard Europe's water resources'). To achieve the objectives of the EU policy on water resources, the CAP uses mainly two tools: Cross-compliance and the European Agricultural Funds for Rural Development (EAFRD) (in Italy they are called PSR). These tools help to promote sustainable agriculture by encouraging good agricultural practices and promoting the environmental goods and services. Within the Cross-compliance Standards there are several obligations that directly affect water quality, one of them is GAEC 5.2, concerns the obligation to introduce 'buffer strips' at the edge of the cropland and close to watercourses in order to protect them from diffuse pollution caused mainly by agricultural activities. This requirement in Italy was introduced in 2009 and implemented since 1st January of 2012. Buffer strip is a vegetated area, near watercourses, permanently covered with grass, shrubs, trees, spontaneous or not. The Standard requires a strip 5m wide excluding unvegetated roads or paths. The obligation of buffer strips covers all agricultural areas, with the exception of land under permanent pasture and olive groves. In the requirement of buffer strips the following watercourses are excluded: i) drains, ditches and other hydraulic artificial structures made for the collection and conveyance of storm water, with temporary discharge; ii) irrigation channels; iii) 'suspended' channel; iv) watercourses with consistent levees that cause a discontinuity between the field and the aquatic system (www.agricoltura24.com). Elsewhere in Europe the commitments of Standard 5.2 are almost the same for all member countries. What changes most is the wide of the buffer zone that can range from 2 to 10 meters. Ten meters usually makes reference to the prohibition of organic fertilization. This paper shows the results of diffuse nitrate removal efficiency of different buffer strips, setup according to the technical indications reported in the Standard 5.2, and highlight the major factors that improve or reduce buffer effectiveness.

Materials and methods

Experimental sites

Seven experimental sites, distributed in different Italian regions, were set in order to conduct the experimental activities. The main characteristics of each site are summarized in Table 1. In all sites the management was limited to mowing (1-2 times for year) and, when necessary, to the lateral pruning of trees and shrubs, including the removal of any branches or logs, to allow the passage of agricultural machinery. In accordance with the Cross-compliance Standard 5.2 (M.D. 27417), no distribution of fertilizers or other phytosanitary products has been done in the buffer strips.

In all afferent agricultural catchments, except for DIANA-FT2 (seeding), the usual operations of ploughing (up to 30-40 cm from ground level) and harrowing have been performed. Only in site CAMP7-(Metaponto) irrigation could be provide if necessary.

With the exception of the site TORMA, where the buffer strip was 8.5 m wide, in all sites they were 5 m wide. The experimental sites were well distributed both in term of different territorial context (hilly or lowland areas) and vegetation typology (3 only herbaceous and 4 herbaceous + tree and shrubs buffer strips).

The ratio between the buffer strips and the afferent crop catchment areas, was quite variable from a minimum of 3.6 % in FAGNA-FT2 to a maximum of 33.3% in DIANA-FT1. The catchment surface has not been defined in the sites of Baroncina (Lodi) and CAMP7 (Metaponto), where no hydrological connection between the crop fields and the buffers strips were found.

Experimental design

The experimental designs have been planned in coherence with the indications reported in the Cross-compliance Standard 5.2 (M.D. 27417) (Figure 1).

The monitoring points were choosen as following:

A) Counterfactual: located in the interface zone between the ‘margin of the crop’ and the beginning of buffer strip, where the flow of pollutants from the crop towards the inlet of the buffer zone was monitored. It was considered the reference without Standard application.

B) Factual: section located at the end or in an intermediate portion of the buffer zone to provide information about the effects of the Standard application.

Because of different types of buffer strips, the factual area was further specified according to the following definitions:

Factual I : herbaceous (only) buffer strip at least 5 meters wide;

Factual II: herbaceous buffer strip, at least 3 meters wide, and placed between the edge of the crop and the beginning of a woody buffer strip, in a buffer system given by the combination of the two.

Factual III: outlet point of a buffer zone composed by the combination of an herbaceous strip, at least 3 meters wide, plus a woody strip at least 2 meters wide.

The monitoring scheme for each experimental sites is reported in Figure 1.

In order to monitor both hydrological and chemical-physical parameters, each experimental site was set up as shown in the simplified scheme of Figure 2.

Even if some specific differences between sites existed, in all of them have been set:

a piezometric network, generally consisting in a 3x3 grid, with 3 wells (replicates) placed perpendicularly to the theoretical line of subsurface runoff from the field to the water body and placed respectively in the entry to the buffer zone (counterfactual), in an intermediate zone (generally the zone of transition between herbaceous and woody strips) and in correspondence of the output of buffer zone (factual). In addition a sampling point was also placed in the crop area. The fully screened piezometers had a diameter of 2 inches, and variable depth according to the depth of saturated zones. They were used both for water sampling (through a system of flasks placed inside the piezometer) and for instantaneous measurements of the groundwater level (by a manual freatimeter);

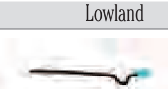
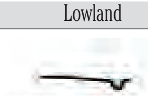
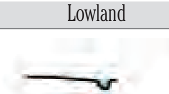
2 electric contact gauges to measure every 30 minutes the piezometric head, placed inside 2 dedicated piezometers: one at the input and the other at the output of the buffer zone;

FDR sensors registered the volumetric soil water content at different soil depths;

3 lysimeters collecting water at different depth (30, 60 and 90 cm), in the crop field.

The soil samples have been drawn at different depth both in the cultivated field and in the buffer strips by a manual drill.

Table 1. Main characteristics of the experimental sites.

Experimental sites	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Geographical coordinates	43°58' 49.90 N 12°18' 43.00 E	43°58' 57.30 N 11°20' 36.75 E	45°17' 24.24 N 9°29' 55.76 E	45°34' 27.88 N 12°19' 01.87 E	45°34' 47.65 N 12°18' 40.65 E	42° 05' 31.19"N 12° 38' 05.46"E	40°22' 12.78 N 16°48' 33.13 E
Geographical context	Hilly	Hilly	Lowland	Lowland	Lowland	Hilly	Lowland
Topography							
Slope° (%)	4.4 / 9.2	6.5 / 1.7	0.2 / 0.7	4.3 / 4.5	3.9 /4.3	7.4 / -2.3	0.52/0.63
Crop	Wheat	Sunflower/maize	Maize	Maize	Ryegrass/maize	Wheat	Vegetables
Waterbody typology	Natural stream	Natural stream	Irrigation ditch	Ditch	Ditch	Collector ditch	Collector ditch
BS cover	Herbaceous + arboreous and shrub	Herbaceous	Herbaceous + arboreous	Herbaceous	Herbaceous+ Harboreous and shrub	Herbaceous+ arboreous and shrub	Herbaceous
Total width of BS (m)	5	5	5	5	5	8.53	5
Upland slope length (m)	135	130	n.d.	10	13	176	n.d.
Area BS/area catchment (%)	3.70	3.57	n.d.	33.33	27.8	4.8	n.d.

°The first number refers to the average slope of the crop catchment, while the second to the average slope of the buffer strip; BS, Buffer strip; n.d., not detected.

Methods

Water balance

The subsurface flow discharge has been calculated by the Darcy's Law in the following form:

$$Q = ks\ S\ \vec{i}$$

where Q is the average inflow flux, *i* is the head gradient between the two considered piezometers set with the transducers and S is the saturated area perpendicular to the groundwater flow.

Parameters

For each site a series of chemical and physical parameters were detected. Some of them were defined as priority parameters (key parameters) some other as ancillary parameters (parameters which are not mandatory but useful as additional information to confirm whether certain interpretations of the results). The parameter type, the location of the sampling points, the frequency and the analytical method used are summarized in Table 2.

Results

Hydrological dynamics

Thanks to the surveys carried out it was possible to describe the main characteristics of the soil and of the hydrological dynamics in the experimental sites. A summary of the most significant characteristics for each site is shown in the Table 3. In most of the case studies, the rain or irrigation waters flow in the agricultural soils above the first impermeable layer of soil (placed at variable depths from a minimum of 90 to a maximum of 300 cm) and generate a saturated zone (suspended groundwater) which could be permanent or temporary (the saturated zone disappears during the warm season). With the exception of the Baroncina site (Lodi), where there was not a clear prevalent direction of the subsurface flows, and CAMP7 (Metaponto) site, where the groundwater flows almost parallel to the buffer strip toward a lateral draining ditch, in all the other cases investigated the groundwater flows perpendicularly from the crop to the buffer system. The groundwater slope varied between a minimum of 1% (DIANA-FT2 site) and a maximum of 13% (Fagna-FT1 site). The hydraulic conductivity meas-

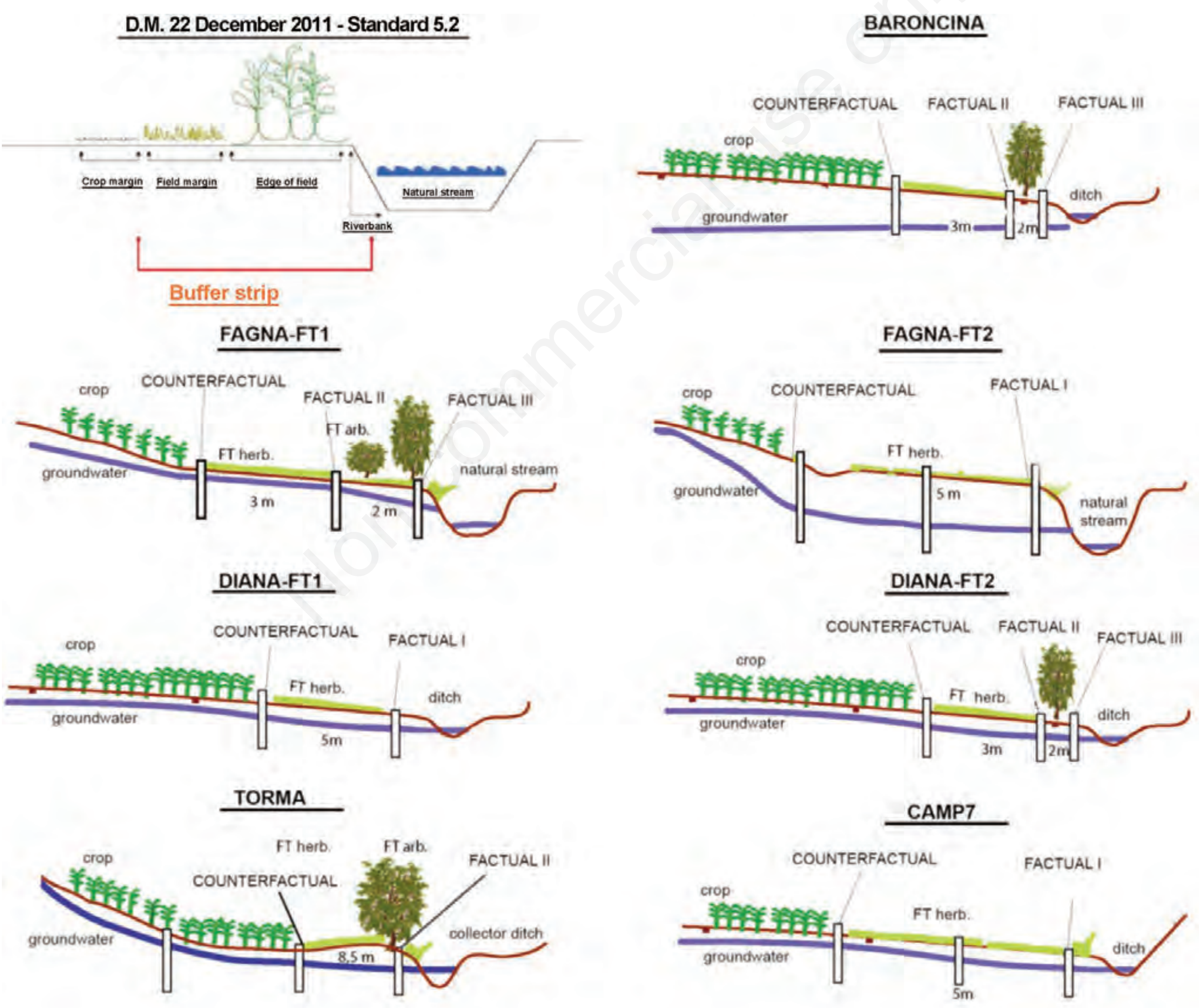


Figure 1. Experimental schemes of the experimental sites and their comparison with the general case contained in M.D. 27417.

ured by slug tests differed considerably (about one order of magnitude) from the theoretical one related to the soil texture. This was generally due to the presence of macro-cracks in the soil caused by the ploughing activities or alternatively by the effect of the vegetation roots (Mastrocicco *et al.,* 2013).

The trend of groundwater fluctuations in all monitored sites is shown in Figure 3. In the two sites located within the experimental farm Diana (DIANA-DIANA-FT1 and FT2) a temporary phase of saturation during the cold months (generally from November to May) has been observed. In the remaining months the soil was unsaturated except during high intensity rainfall events. The water table fluctuations were strongly related to the rainfall events and saturation conditions often reach the ground level. A similar trend has been observed in the experimental site CAMP7 (Metaponto). On the other hand in the site Fagna-FT2 was recorded a permanent water table (at least in the monitored period) laying on an impermeable layer about 3 meters deep; the fluctuations were rather small between 2-3 m from the soil surface. The sites Fagna-FT1 and TORMA have similar hydrological behaviour with an almost complete saturation of the first 2 m of soil for most of the year. This behaviour was favoured by particularly intense and persistent rainfall events during the two years of monitoring; thus it cannot be excluded than during years of drought the soil may result temporary unsaturated. The Baroncina site, in term of saturation, had strong fluctuations correlated with rainfall events.

The main items of the water balance for each of the monitored sites were listed in the Table 4. Since the absence of subsurface flows from crop to the buffer strip both Baroncina and CAMP7 sites were not included in Table 3, about the water balance, and in Table 5, about the nitrogen balance as they were equal to zero.

The discharge of the sub-surface flows which convey the pollutants from the crop to surface waterbodies through the buffer system, are strictly related to the size of the catchment area, the slope and soil characteristics. As an example in the Fagna-FT2 site the high permeability of the sandy soil in the surface layers (further enhanced by the agricultural processing) favoured the infiltration of the rainwater towards the deep (300 cm from the soil surface) impermeable layer of ancient clay. Above this layer, thanks to the slope, groundwater rapidly flows towards the buffer zone. Moreover due to the significant surface of the agricultural basin, the flow rate reached the high value of about 8590 m^3 / year (to 100 m on buffer strips) corresponding to 64% of the rainfall in the basin (the remaining part is subject to processes of evapotranspiration). On the other hand the low values of subsurface discharges in the two sites of DIANA farm were the consequence of small size of the afferent agricultural basin. Also in this case a significant portion of the water volumes tends to be lost through subsurface flows (55.4% and 64.0% of the total rainfall) due to the heavy ploughing operations of the crop field. Catchments basins with steep slope which decreases sharply just before the buffer strip, and a very low hydraulic conductivity of soils like in the Fagna-FT1 and TORMA sites, the subsurface flows discharge represent only a small portion of total rainfall volumes (17.8 and 31.8%, respectively), while the dominating phenomena are surface runoff and evapotranspiration.

Nitrogen dynamics

The comparison between the concentration values of dissolved inorganic nitrogen in different points of the groundwater is shown in Figure 4.

In most cases the concentration values were rather low; the lowest values were recorded in the site of TORMA, while in the Fagna-FT1, Fagna-FT2 and DIANA-FT1 sites the average values, in the inlet of the buffer strip, ranged between 4 to 6 mg/L. Low concentrations of inorganic nitrogen in the water flow out from the crop can be due to several

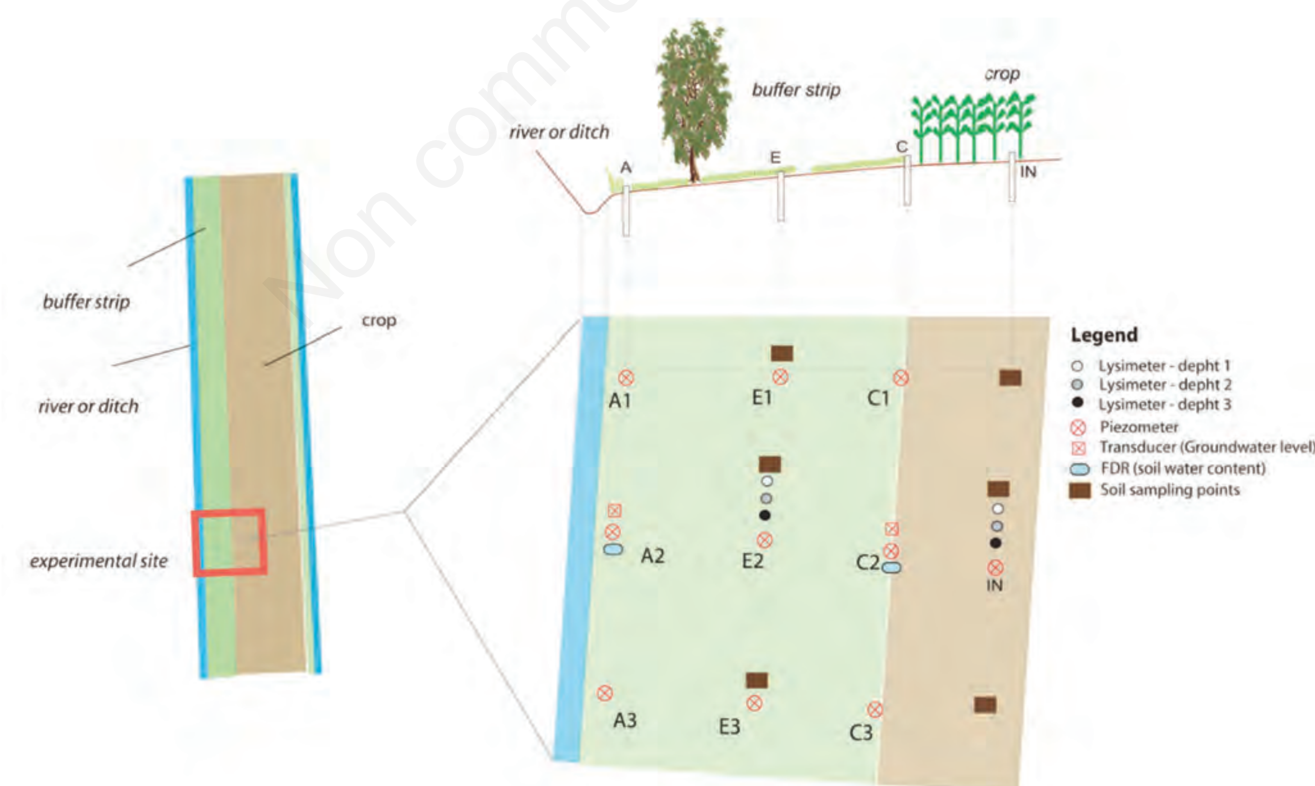


Figure 2. General monitoring scheme.

Table 2. Description of the monitored priority and ancillary parameters.

Priority parameters	Sampling point	Frequency	Methods	Aims
Texture	One complete soil profile, inside the buffer zone, from ground level up to the saturated zone	Only once at the start of monitoring	Pipette method	Understanding of the system and calculation of parameters dependent on texture
Watertable depth (continuously)	One point input (Factual) and 1 point out of the buffer zone (Counterfactual)	Every 30 minutes	Pressure transducers (SLB1 stainless steel, two-wire 4-20mA piezometers and current output, power supply 8-28 Vdc) inserted in dedicated connected to a data logger (data logger WatchDog 1000 Series, model 1650 sensors T / RH external air + 4 doors for external sensors).	To understand the dynamics of the saturated zone and water balance
Watertable depth (instantaneous measurements)	In each piezometer	During the water sampling (approximately every 15 days)	Hanfly freatimeter	To integrate the data recorded in continuous in a single section, with data relating to the whole piezometric net in order to define the groundwater. direction.
Rainfall	One pluviometer in each experimental site	Continuously	Rain gauge connected to a datalogger (WatchDog rain gauge data-logging 3554WD1-Spectrum Technologies attached to a self-emptying tipping bucket).	Water balance, climate trend.
Chemical parameters of water (N-tot, N-NO3, N-NH4, N-NO2)	All piezometers and lysimeters. Occasionally also from the adjacent surface waterbody.	Every 15-30 days	N-NO3, N-NH4, N-NO2: colorimetric analysis Ntot: Thermo Flash 2000 CN soil analyzer	Nitrogen dynamics and budget.
Saturated hydraulic conductivity (Ks)	All piezometers	Once	Slug test	Water balance
Elevation	The whole experimental plot, with a grid functional to obtain a DEM (Digital Elevation Model) with a resolution 20x20 cm)	Once	Leica GPS 1200+ system consisting in two geodetic receivers GPS / GNSS Leica AS10	Groundwater depth and water balance
Ancillary parameters	**Sampling point**	**Frequency**	**Methods**	**Aims**
Volumetric soil water content	Input and output of the buffer strips at different dephts	Every 30 minutes	FDR Probes (Frequency Domain Reflectometry, spectrum SM 100 waterscout soil moisture sensor) connected to a data logger (data-logging WatchDog 1000 Series Spectrum Technologies).	Hydrologic dynamics
Chemical parameters of water (DO, T and Cond.)	All piezometers	Every 15-30 days	Dissolved Oxigen: Oximeter AL20Oxi (Aqualytic, Dortmund, Germany). Temperature and electrical conductivity: portable conductivity meter with integrated temperature sensor (Schott-Geräte Conductivity meter handylab LF).	Ancillary data for a better understanding of the processes.
Chemical parameters of soil (TOC, TN, WSC, NO_3, NH_4).	Three points (replicates) at different depths both in the crop and in the buffer strip	2-3 times for year	TOC and TN: Thermo elemental analyzer Flash 2000 CN soil analyzer; SC: Thermo analyzer Flash 2000 CN Wsoil analyzer; NO_3, NH_4: colorimetric analysis	To estimate nitrogen storing or loss in the soil.

factors, such as the optimal use of nitrogen or heavy rainfall (clearly above the average during the two monitored years) leading to an increase of dilution. The mean values showed that Fagna FT1 and DIANA-FT1 sites were effective in removing nitrogen; the high variability of the values indicates a different seasonal pattern. In DIANA-FT1 a significant increase in nitrogen removal has been observed starting from the second year of monitoring, most likely due to the maturation of the newly-created buffer zone. The results recorded in Fagna-FT2 site, did not show any kind of buffering activities transformation; thus it give us an interesting example of no interaction between subsurface flows and rhizosphere, and as consequence no significant biogeochemical transformations of nitrogen. In TORMA site very low concentrations have been measured. Even if the overall differences between input and output in terms of average values were not significant, the higher stability of the output values compared with the input ones indicates that the occasional nitrogen peaks were effectively removed. The trend of nitrogen concentrations observed in Baroncina site further highlights the lack of hydrological connection between the crop (in the two control points the nitrogen concentrations were clearly influenced by the fertilization) and the buffer zone where the three control sections did not differ significantly and the average values were very low also in the section placed between the buffer strip and the crop. A similar situation has been observed in the site CAMP7, where it was clear that the waters loaded with nitrogen drain into the lateral ditch instead of crossing the buffer strip. The main items of nitrogen balance are summarized in the following Table 5.

The amount of nitrogen transported through subsurface fluxes from the field to the buffer strips ranges from a minimum of 3 kg ha^{-1} year^{-1} to a maximum of 33.2 kg ha^{-1} year^{-1}, with percentages of nitrogen leaching ranging between 1.8 and 25.2%. With the exception of the Fagna-FT2 site, all the systems were effective in N_{inorg} removal, with an efficiency ranging between 33 and 61.9%.

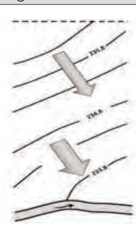
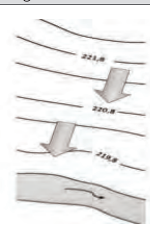
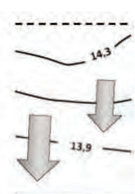
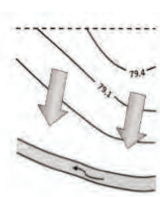
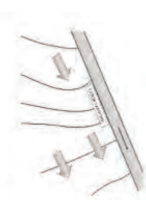
Quantitative indicator

The indicator of basic level chosen to define the suitability of the Standard 5.2 relatively to its environmental target was the efficiency of inorganic nitrogen removal, calculated by the mass balance following the below scheme:

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

The results are shown in Table 6.

Table 3. Main pedological and hydrological characteristics of the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Unsaturated layer (cm from s.l.)°	0-15	0-210	0-70	0-50	0-20	0-10	0-60
Saturated layer (cm from s.l.)°	15-200	210-300	70-200	50-90	20-90	10-200	<60
Unsaturated layer texture#	Silty clay loam (20-36-44)	Loam (40-22-38)	Loam (34-21-45)	Clay loam (26-39-35)	Silt loam (18-65-17)	Loam (32-48-30)	Clay (10-55-35)
Saturated layer texture#	Layer 15-85 cm silty clay loam (20-48-32) Layer 85-200 cm silty clay (7-48-45)	Sandy loam (60-8-32)	Sandy loam (68-13-19)	Silty clay loam (21-50-29)	Silt loam (19-63-18)	Loam (31-44-25)	Clay (3-70-27)
Slug Test Hydraulic conductivity (cm/day)	53.0	1180.0	1234.0	350.0	255.0	64.7	17.3
Groundwater slope in BS (%)	13.0	5.2	n.d.	11.0	1.0	2.3	n.d.
Groundwater depth (from s.l.)	Max: 0; Average: 75; Min: 198	Max: 45,1 Average: 229,6 Min: 277	Max: 0 Average: 74 Min: 200	Max: 0; Average: 48 Min: dry	Max: 0; Average: 20 Min: dry	Max: 0; Average: 39 Min: 104	Max: 16 Average: 80 Min: dry
Type	Permanent groundwater	Permanent groundwater	Permanent groundwater	Temporary perched aquifer	Temporary perched aquifer	Permanent groundwater	Permanent groundwater
Prevalent groundwater direction			No prevalent direction				

°In the most common situations; #the indicated numbers refers to the percent of sand/silt/clay, respectively; BS, Buffer strip; n.d., not detected.

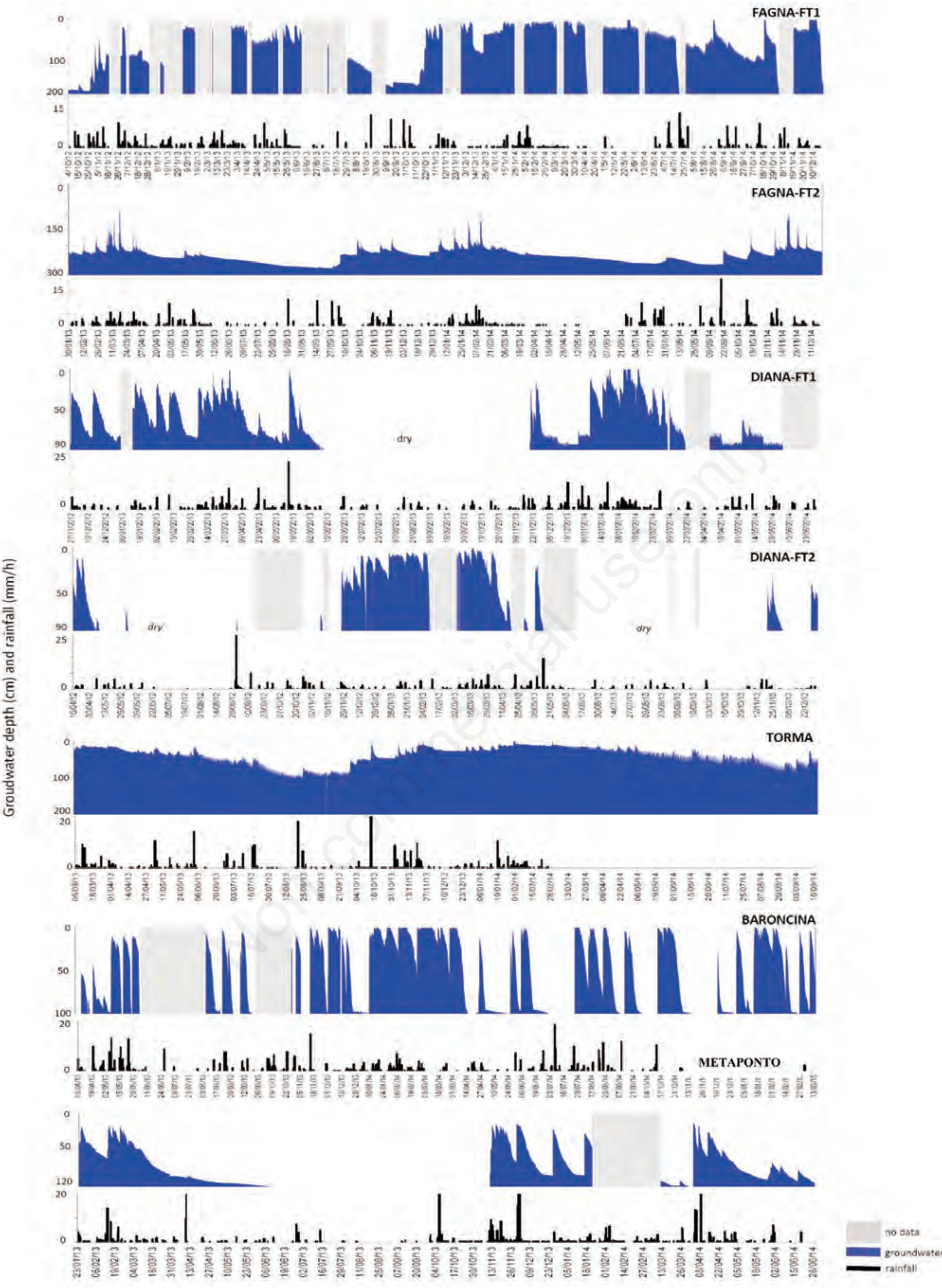


Figure 3. Fluctuation of the water table (data obtained as an average of 2 recordings, 1 every 30 minutes) in the experimental sites and hourly precipitation.

Efficiency judgment

The judgment of effectiveness was based on the percentage of experimental sites which demonstrated to be efficient on nitrogen removal. In the case of Standard 5.2 an improvement has been observed in 4 out of 7 of the monitored sites (57%), corresponding to a judgment of 'Effectiveness medium-high'.

Discussion and conclusions

The results are consistent with those of literature (Haycock and Pinay, 1993; Fennesy and Cronk, 1997; Dhont *et al*., 2004; Gumiero *et al*., 2011; Vidon and Hill, 2004) and the experimental activity contributed to demonstrate the key role of hydrological processes in influencing the effectiveness on nitrogen removal.

In particular, it was noted that in some of the monitored systems (Fagna-FT1, Fagna-FT2, TORMA) the buffer strips setup in accordance with the technical criteria of the cross-compliance Standard 5.2, were able to intercept significant volumes (ranging from 3000 to 8500 m^3 $year^{-1}$ per 100 l m of buffer strip) even if they occupy a surface rather limited compared to the field crops (3-5%).

Conversely, the buffer strips DIANA-FT1 and DIANA-FT2 cover a significant area if compared to the crop (about 30%) and in the same time they intercept low water volumes (around 1000 m^3 per year 100 mL of FT). Consequently to optimize the investment in terms of area occu-

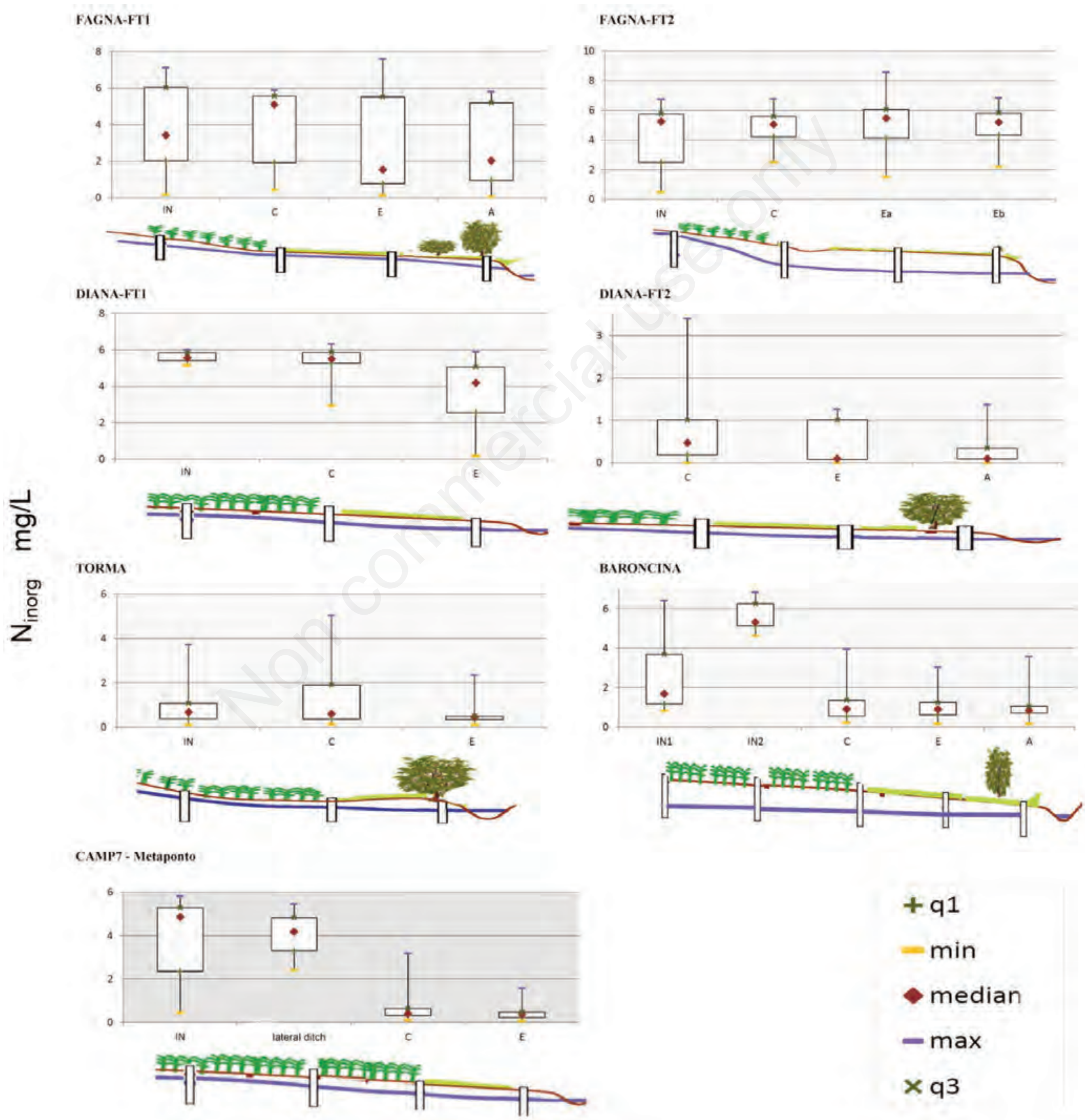


Figure 4. Comparison between the concentration values of dissolved inorganic nitrogen in different points of the monitored systems.

pied, this measure was particularly effective when it was possible to place a buffer zone downstream of a wide agricultural basin, with an optimal ratio between the surface occupied by the buffer strip and the crop of around 5%.

The inefficiency of Fagna-FT2 site, highlighted the importance of interaction between water flow and the rizhosphere for enhancing vegetation uptake and give support to microbial activities by organic matter supply (Pinay *et al*., 2000; Sabater *et al*., 2003; Vidon and Hill, 2004; Gumiero *et al.,* 2011; Boz *et al.* 2013). For different reasons, mentioned above, the Baroncina and the CAMP7 sites represents other cases of non-effective systems.

In all the other cases, the outflows persisted, at least for certain periods of the year, close to the ground surface, in theoretically optimal condition for the activation of the processes that lead to the removal of nitrogen. Despite this, in none of the cases the high levels of removal (80-90%) observed in other contexts (Peterjohn and Correl, 1984; Haycock and Pinay, 1993) have been reached, but rather values of efficiency ranging between 30-60%. This may be due to the short monitoring period (1-2 years) and to the unusual weather conditions (high rainfall); in the same time the low maturity of the monitored buffer strips, in many cases they were converted just before the beginning of the experimental activity, may leaded to an underestimation of the

Table 4. Main hydrological items in the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS AGRIC. (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
Subsurface flow discharge (100 m BS) (m^3 $year^{-1}$)	3152	8587	919	1004	4726
Subsurface flow discharge (100 m BS) (mm)	225	636	613	717	269
Rainfall (mm)	1264	1072	1385	1116	843
Subsurface flow discharge (% rain)	17.8	59.3	55.8	64	31.8

Table 5. Nitrogen balance in the different experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Florence)	FAGNA-FT2 CREA-ABP (Florence)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
N_{inorg} applied (kg ha^{-1} $year^{-1}$)	72	120	250	170	96
IN N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	8.45±1.69	30.29±2.94	33.21±1.34	3.0±0.3	4.66±1.69
N_{inorg} to BZ by subsurface flow / N_{inorg} applied (%)	11.1	25.2	13.3	1.8	1.78
Out N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	5.67±1.63	29.42±5.08	17.29±1.24	1.6±0.2	1.91±0.47
N_{inorg} removal by the BZ (kg ha^{-1} $year^{-1}$)	2.79	0.86	15.93	1.5	2.88
Efficiency (%)	33.0	2.9	48.0	48.6	61.9

Table 6. Judgment of efficiency in the different sites (base level).

Experimental site	Removal (%)	Judgment of indicator efficiency
FAGNA-FT1 CREA-ABP (Florence)	33	Medium
FAGNA-FT2 CREA-ABP (Florence)	2.9	Poor
BARONCINA CREA-FLP (Lodi)	0	Poor
DIANA-FT1 VENETO AGRIC.	48	Medium
DIANA-FT2 VENETO AGRIC.	48.6	Medium
TORMA- CREA-RPS (Rome)	62	High
CAMP7-CREA-SSC (Metaponto)	0	Poor

buffering capacity. This was confirmed by the low levels of organic matter available in the soils (values between 1.5 and 1.7%) as well. In this perspective, an increasing of the buffer capacity could be observed in a more advanced phase starting from the second or the third year after the conversion as observed in other studies (Gumiero *et al*., 2011; Anbumozhi *et al*., 2004; Uusi-Kämppä and Jauhiainen, 2010). During early stages, the influence of the hydrological factors appears to be prevalent instead of the type of vegetation. At the same time the river typology did not affect significantly the efficacy of the buffer zone, although it must be recognized to the past river dynamics a key role in determining the soil layers configuration and properties. This usually leads to observe more heterogeneous soil profiles in the riparian buffer adjacent to natural water bodies better than to artificial water bodies.

The infiltration capacity of water in soil with consequent development of sub-surface outflows was rather significant in all monitored systems (values ranging between 18 and 64% of total rainfall). This was recorded also in systems with high slopes (above 6%) and/or fine grain soil which should facilitate the development of surface runoff phenomena.

This was mainly due to the ploughing activities which, in addition to increase the water infiltration within the field crop, shaped a significant drop of soil surface between the field and the undisturbed buffer zone that could not be overcome by superficial runoff.

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Effectiveness of the cross-compliance Standard 5.2 'buffer strips' on protecting freshwater against diffuse nitrogen pollution

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Key words: Cross-compliance; rural development; Standard 5.2; buffer strips; competitiveness.

Work done under the Project MO.NA.CO. (National network for monitoring the environmental effectiveness of cross compliance and the differential of competitiveness charged against agricultural enterprises) funded by the Ministry of Agricultural, Food and Forestry Policies (MiPAAF) in the context of Action 1.2.2 'Interregional Workshops for development' of the Operational Programme called 'National Rural Network 2007-2013', Coord. Paolo Bazzoffi.

Contributions: Bruna Gumiero: scientific leader for the experimental activity called 'WP14-buffer strips'. Planning and setting of the experimental sites, drafting of the text, definition of the methodological approach, data processing, development of indicators to classify the efficiency of the buffer strips, field surveys (limited to Diana and Fagna experimental farms); contribution in determining the real value of the differential of competitiveness. Bruno Boz: planning and setting of the experimental sites, drafting of the text, definition of the methodological approach, data processing, development of indicators to classify the efficiency of the buffer strips, field surveys (limited to Diana experimental farms); contribution in determining the real value of the differential of competitiveness. Paolo Bazzoffi: project coordinator of MO.NA.CO. project and for the activities of the O.U. CREA-ABP, GPS measurements and GIS processing, hydrological surveys in the field. Alessandra Lagomarsino: responsible for the chemical analysis of water and soil and contribution on the definition of analytical methods. Silvia Carnevale: field surveys, laboratory activities and contribution in determining the real value of the differential of competitiveness (in Fagna farm). Alessandro Elio Agnelli: chemical analysis of water and soil. Andrea Rocchini: physical analysis of soils and field surveys. Rosa Francaviglia: coordinator for the activities of the O.U. CREA-RPS. Rosario Napoli: pedological and geological analysis of the monitoring sites, contribution in planning and setting of the experimental sites (Tor Mancina Farm), contribution in determining the real value of the differential of competitiveness (Tor Mancina Farm), development of indicators to classify the efficiency of the buffer strips. Bruno Pennelli: field surveys for the measurement of hydrological parameters and sampling of soil and water (Tor Mancina Farm). Lamberto Borrelli: coordinator for the activities of the O.U. CREA-FLC Lodi. Giovanni Cabassi: setting of the experimental site, sampling activity and contribution in determining the real value of the differential of competitiveness (all activities limited to the Baronica farm). Giorgio Moretti: setting of the experimental site, sampling activity. Francesco Montemurro: coordinator for the activities of the O.U. CREA-SSC Metaponto. Angelo Fiore: setting of the experimental site, field surveys and sampling activity (Metaponto farm).

Acknowledgments: We thank Dr. Maria Carmen Beltrano, Research Unit for Climatology and Meteorology applied to Agriculture (CREA-CMA), for providing the hourly data of temperature and precipitation measured at the National Agro-meteorological station network of Monterotondo (Rome).

Italian Journal of Agronomy 2015;772
doi:10.4081/ija.2015.772

Abstract

Seven buffer strips (BS) adjacent to fresh water bodies, realized according to the technical data contained in the Standard 5.2 of Cross-compliance, located in different areas and climate contexts, were monitored for a period of two years. It was done in order to quantify their effectiveness in removing dissolved inorganic nitrogen conveyed through sub- surface flow from field crops with different cultural practices. Except for two case studies (sites: Lodi and Metaponto) in all monitored systems has been confirmed an outflow, permanent or temporary, through the buffer systems, with flow rates ranging from 919 to 8590 $m^3 y^{-1}$ every 100 meters of buffer stip. The differences in flow rate were mainly due to different sizes of agricultural basins related to buffer systems, which in the case studies ranging from 3.6 to 33.3%. Based on the mass balance, was found percentages of applied inorganic nitrogen, flowing from cultivated fields to the buffer systems, varied between 1.6 and 29.4%. In most of the sites was estimated of BS nitrogen reduction between inlet and outlet of BS, with percentages ranging from 33 to 61.9%. The exceptions were the systems with groundwater that: or have no interaction with the rhizosphere (deep flow) or not crossing the buffer zone. Low percentages of removal shall be justified by the young stage of the monitored sites, being in many cases recently converted to buffer strip. This study confirms the extreme variability of these systems efficiency and the key role of hydrology drives its effectiveness.

Introduction

The point-source pollution has been reduced significantly in recent decades thanks to increasing of efficient sewage treatment plants, while is not the case for widespread source pollution. Researchers have recognized the importance of non-point source pollution starting from the 1980s when improvement in wastewater treatments failed to produce the expected enhancement of streams and rivers water quality (Campbell *et al.,* 2004). Diffuse pollution is difficult to measure and control because it is often intermittent and linked to seasonal agricultural activity or irregular events, such as heavy precipitation, and involve complex transport and transformation through several media like air, soil and water (Dhondt *et al.,* 2004; Zhang *et al.,* 2012; Cheng *et al.,* 2013).

In a watershed, the main sources of nitrates are: i) the microbial processes of organic matter (mineralization and nitrification); ii) the oxidation of organic matter due to human activities: agricultural (manure) or urban (civil waste); iii) chemical fertilizers. In rural environment, two critical contaminant from diffuse pollution are pesticides and nutrients, in particular phosphorus and nitrogen. Fertilizer inputs to crops are generally higher than the amount of nutrients required to maximize plant productivity, hence this surplus may accumulate in soils (Sebilo *et al.,* 2013) and in water bodies. Nutrient load is drained from the agricultural territory or livestock origin, through processes of runoff, leaching and percolation. Nitrogen stored in soils is moved by tillage and erosion and then by water flow from cultivated areas to waterways. Nitrogen can also be delivered to atmosphere through volatilization of NH_3 and microbial generation of N_2O (greenhouse gas) (Carpenter *et al.,* 1998; De Simone *et al.,* 2010; Audet *et al.,* 2014). Despite the increasing efforts at national and European levels (Nitrate Directive 91/976/EEC, currently included in the Water Framework Directive 2000/60/EC) to reduce NO_3 inputs from intensive agriculture, it is still one of the major contaminants of superficial freshwater and groundwater resources (http://isonitrate.brgm.fr). Confined systems like shallow lakes, lagoons and enclosed seas are very sensitive to the excess of nutrients and can have highly impacted consequences like eutrophication (Boesch *et al.,* 2002; Khan and Ansari, 2005; Ansari *et al.,* 2010; Gren and Destouni, 2011). Furthermore, nitrate because of its high solubility in water, tends to be accumulated in groundwater, often used for drinking water, causing problems for human health (Carpenter *et al.,* 1998; Weyer *et al.,* 2001).

Diffuse nitrate decreasing can be reached with two different strategies: by reducing fertilizers inputs following more sustainable agricultural management or by facilitating natural processes of water phytodepuration that are usually very efficient in Buffer Strip and Wetlands systems as were established in many studies (Clement, 2002; Coops and van Geest, 2007; Billy *et al.,* 2013; Gumiero *et al.,* 2011, 2013; Hefting *et al.,* 2013).

In all European legislation related to water resources is emphasized the need to integrate policies of water protection management with the management of production activities, particularly agriculture, in order to achieve the goal of sustainable development. The Directive 2000/60/EC establishes the principle that '*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*'. It requires Member States '*to achieve good status of surface and ground water*' by 2015 (Art. 4 WFD). Member States must draw up plans for the river basin management (RBMP) and the programs of measures. They may implement this policy by using part of the funds of other sectorial policies, such as those provided by Common Agricultural Policy (CAP). As in Europe about 50% of the total surface is an agricultural land, it shapes the landscape and plays a key role in the sustainable management of water resources both in quantity and quality. For this reason the EU Council has pointed out the need to protect water resources within the CAP (COM (2012) 673 of 14th November 2012, 'Blueprint to safeguard Europe's water resources'). To achieve the objectives of the EU policy on water resources, the CAP uses mainly two tools: Cross-compliance and the European Agricultural Funds for Rural Development (EAFRD) (in Italy they are called PSR). These tools help to promote sustainable agriculture by encouraging good agricultural practices and promoting the environmental goods and services. Within the Cross-compliance Standards there are several obligations that directly affect water quality, one of them is GAEC 5.2, concerns the obligation to introduce 'buffer strips' at the edge of the cropland and close to watercourses in order to protect them from diffuse pollution caused mainly by agricultural activities. This requirement in Italy was introduced in 2009 and implemented since 1st January of 2012. Buffer strip is a vegetated area, near watercourses, permanently covered with grass, shrubs, trees, spontaneous or not. The Standard requires a strip 5m wide excluding unvegetated roads or paths. The obligation of buffer strips covers all agricultural areas, with the exception of land under permanent pasture and olive groves. In the requirement of buffer strips the following watercourses are excluded: i) drains, ditches and other hydraulic artificial structures made for the collection and conveyance of storm water, with temporary discharge; ii) irrigation channels; iii) 'suspended' channel; iv) watercourses with consistent levees that cause a discontinuity between the field and the aquatic system (www.agricoltura24.com). Elsewhere in Europe the commitments of Standard 5.2 are almost the same for all member countries. What changes most is the wide of the buffer zone that can range from 2 to 10 meters. Ten meters usually makes reference to the prohibition of organic fertilization. This paper shows the results of diffuse nitrate removal efficiency of different buffer strips, setup according to the technical indications reported in the Standard 5.2, and highlight the major factors that improve or reduce buffer effectiveness.

Materials and methods

Experimental sites

Seven experimental sites, distributed in different Italian regions, were set in order to conduct the experimental activities. The main characteristics of each site are summarized in Table 1. In all sites the management was limited to mowing (1-2 times for year) and, when necessary, to the lateral pruning of trees and shrubs, including the removal of any branches or logs, to allow the passage of agricultural machinery. In accordance with the Cross-compliance Standard 5.2 (M.D. 27417), no distribution of fertilizers or other phytosanitary products has been done in the buffer strips.

In all afferent agricultural catchments, except for DIANA-FT2 (seeding), the usual operations of ploughing (up to 30-40 cm from ground level) and harrowing have been performed. Only in site CAMP7-(Metaponto) irrigation could be provide if necessary.

With the exception of the site TORMA, where the buffer strip was 8.5 m wide, in all sites they were 5 m wide. The experimental sites were well distributed both in term of different territorial context (hilly or lowland areas) and vegetation typology (3 only herbaceous and 4 herbaceous + tree and shrubs buffer strips).

The ratio between the buffer strips and the afferent crop catchment areas, was quite variable from a minimum of 3.6 % in FAGNA-FT2 to a maximum of 33.3% in DIANA-FT1. The catchment surface has not been defined in the sites of Baroncina (Lodi) and CAMP7 (Metaponto), where no hydrological connection between the crop fields and the buffers strips were found.

Experimental design

The experimental designs have been planned in coherence with the indications reported in the Cross-compliance Standard 5.2 (M.D. 27417) (Figure 1).

The monitoring points were choosen as following:

A) Counterfactual: located in the interface zone between the 'margin of the crop' and the beginning of buffer strip, where the flow of pollutants from the crop towards the inlet of the buffer zone was monitored. It was considered the reference without Standard application.

B) Factual: section located at the end or in an intermediate portion of the buffer zone to provide information about the effects of the Standard application.

Because of different types of buffer strips, the factual area was further specified according to the following definitions:

Factual I : herbaceous (only) buffer strip at least 5 meters wide;

Factual II: herbaceous buffer strip, at least 3 meters wide, and placed between the edge of the crop and the beginning of a woody buffer strip, in a buffer system given by the combination of the two.

Factual III: outlet point of a buffer zone composed by the combination of an herbaceous strip, at least 3 meters wide, plus a woody strip at least 2 meters wide.

The monitoring scheme for each experimental sites is reported in Figure 1.

In order to monitor both hydrological and chemical-physical parameters, each experimental site was set up as shown in the simplified scheme of Figure 2.

Even if some specific differences between sites existed, in all of them have been set:

a piezometric network, generally consisting in a 3x3 grid, with 3 wells (replicates) placed perpendicularly to the theoretical line of subsurface runoff from the field to the water body and placed respectively in the entry to the buffer zone (counterfactual), in an intermediate zone (generally the zone of transition between herbaceous and woody strips) and in correspondence of the output of buffer zone (factual). In addition a sampling point was also placed in the crop area. The fully screened piezometers had a diameter of 2 inches, and variable depth according to the depth of saturated zones. They were used both for water sampling (through a system of flasks placed inside the piezometer) and for instantaneous measurements of the groundwater level (by a manual freatimeter);

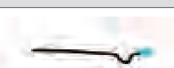
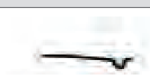
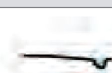
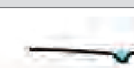
2 electric contact gauges to measure every 30 minutes the piezometric head, placed inside 2 dedicated piezometers: one at the input and the other at the output of the buffer zone;

FDR sensors registered the volumetric soil water content at different soil depths;

3 lysimeters collecting water at different depth (30, 60 and 90 cm), in the crop field.

The soil samples have been drawn at different depth both in the cultivated field and in the buffer strips by a manual drill.

Table 1. Main characteristics of the experimental sites.

Experimental sites	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Geographical coordinates	43°58' 49.90 N 12°18' 43.00 E	43°58' 57.30 N 11°20' 36.75 E	45°17' 24.24 N 9°29' 55.76 E	45°34' 27.88 N 12°19' 01.87 E	45°34' 47.65 N 12°18' 40.65 E	42° 05' 31.19"N 12° 38' 05.46"E	40°22' 12.78 N 16°48' 33.13 E
Geographical context	Hilly	Hilly	Lowland	Lowland	Lowland	Hilly	Lowland
Topography							
Slope° (%)	4.4 / 9.2	6.5 / 1.7	0.2 / 0.7	4.3 / 4.5	3.9 /4.3	7.4 / -2.3	0.52/0.63
Crop	Wheat	Sunflower/maize	Maize	Maize	Ryegrass/maize	Wheat	Vegetables
Waterbody typology	Natural stream	Natural stream	Irrigation ditch	Ditch	Ditch	Collector ditch	Collector ditch
BS cover	Herbaceous + arboreous and shrub	Herbaceous	Herbaceous + arboreous	Herbaceous	Herbaceous+ Harboreous and shrub	Herbaceous+ arboreous and shrub	Herbaceous
Total width of BS (m)	5	5	5	5	5	8.53	5
Upland slope length (m)	135	130	n.d.	10	13	176	n.d.
Area BS/area catchment (%)	3.70	3.57	n.d.	33.33	27.8	4.8	n.d.

°The first number refers to the average slope of the crop catchment, while the second to the average slope of the buffer strip; BS, Buffer strip; n.d., not detected.

Methods

Water balance

The subsurface flow discharge has been calculated by the Darcy's Law in the following form:

$$Q = ks\, S\, \vec{i}$$

where Q is the average inflow flux, i is the head gradient between the two considered piezometers set with the transducers and S is the saturated area perpendicular to the groundwater flow.

Parameters

For each site a series of chemical and physical parameters were detected. Some of them were defined as priority parameters (key parameters) some other as ancillary parameters (parameters which are not mandatory but useful as additional information to confirm whether certain interpretations of the results). The parameter type, the location of the sampling points, the frequency and the analytical method used are summarized in Table 2.

Results

Hydrological dynamics

Thanks to the surveys carried out it was possible to describe the main characteristics of the soil and of the hydrological dynamics in the experimental sites. A summary of the most significant characteristics for each site is shown in the Table 3. In most of the case studies, the rain or irrigation waters flow in the agricultural soils above the first impermeable layer of soil (placed at variable depths from a minimum of 90 to a maximum of 300 cm) and generate a saturated zone (suspended groundwater) which could be permanent or temporary (the saturated zone disappears during the warm season). With the exception of the Baroncina site (Lodi), where there was not a clear prevalent direction of the subsurface flows, and CAMP7 (Metaponto) site, where the groundwater flows almost parallel to the buffer strip toward a lateral draining ditch, in all the other cases investigated the groundwater flows perpendicularly from the crop to the buffer system. The groundwater slope varied between a minimum of 1% (DIANA-FT2 site) and a maximum of 13% (Fagna-FT1 site). The hydraulic conductivity meas-

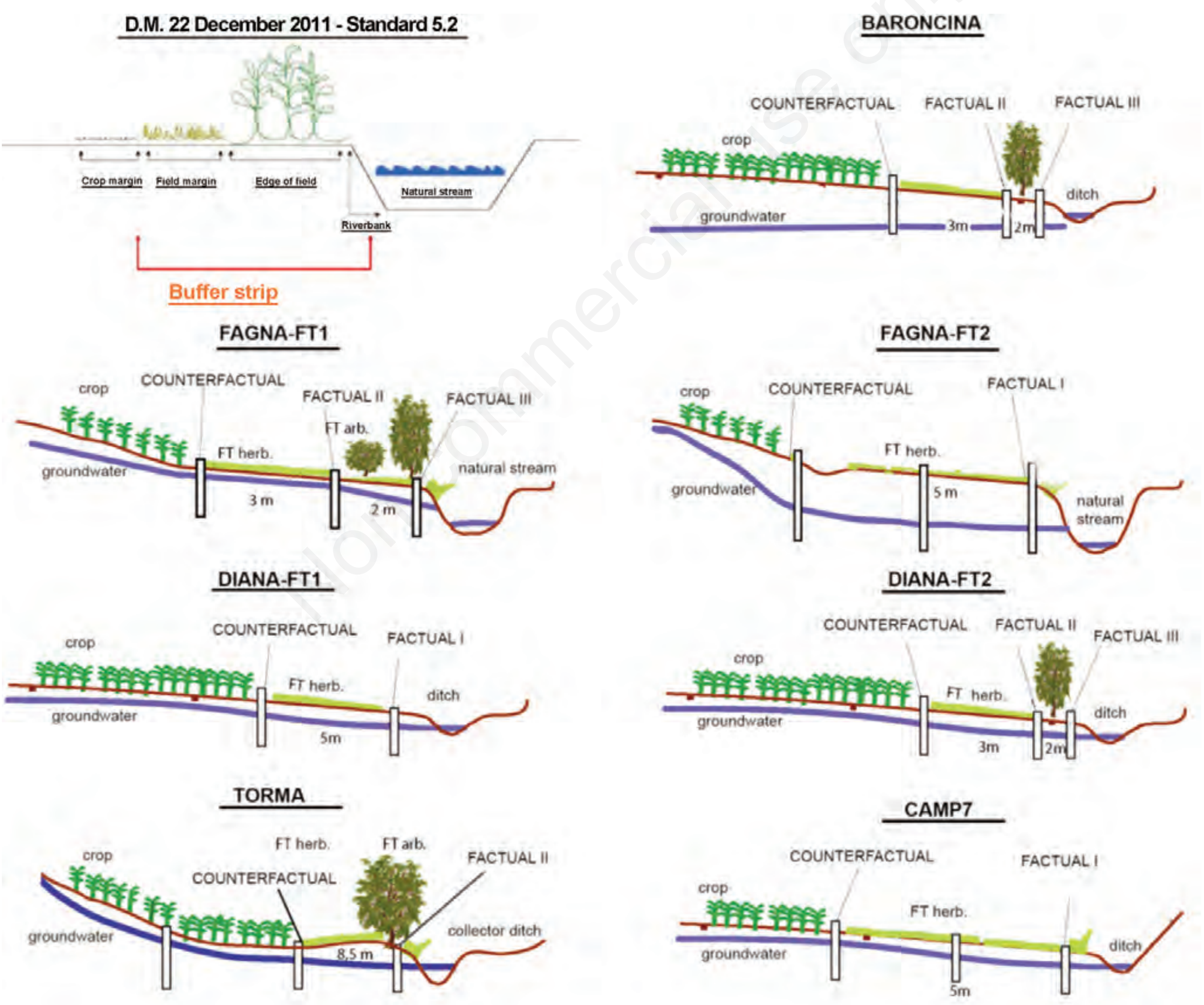


Figure 1. Experimental schemes of the experimental sites and their comparison with the general case contained in M.D. 27417.

ured by slug tests differed considerably (about one order of magnitude) from the theoretical one related to the soil texture. This was generally due to the presence of macro-cracks in the soil caused by the ploughing activities or alternatively by the effect of the vegetation roots (Mastrocicco *et al.,* 2013).

The trend of groundwater fluctuations in all monitored sites is shown in Figure 3. In the two sites located within the experimental farm Diana (DIANA-DIANA-FT1 and FT2) a temporary phase of saturation during the cold months (generally from November to May) has been observed. In the remaining months the soil was unsaturated except during high intensity rainfall events. The water table fluctuations were strongly related to the rainfall events and saturation conditions often reach the ground level. A similar trend has been observed in the experimental site CAMP7 (Metaponto). On the other hand in the site Fagna-FT2 was recorded a permanent water table (at least in the monitored period) laying on an impermeable layer about 3 meters deep; the fluctuations were rather small between 2-3 m from the soil surface. The sites Fagna-FT1 and TORMA have similar hydrological behaviour with an almost complete saturation of the first 2 m of soil for most of the year. This behaviour was favoured by particularly intense and persistent rainfall events during the two years of monitoring; thus it cannot be excluded than during years of drought the soil may result temporary unsaturated. The Baroncina site, in term of saturation, had strong fluctuations correlated with rainfall events.

The main items of the water balance for each of the monitored sites were listed in the Table 4. Since the absence of subsurface flows from crop to the buffer strip both Baroncina and CAMP7 sites were not included in Table 3, about the water balance, and in Table 5, about the nitrogen balance as they were equal to zero.

The discharge of the sub-surface flows which convey the pollutants from the crop to surface waterbodies through the buffer system, are strictly related to the size of the catchment area, the slope and soil characteristics. As an example in the Fagna-FT2 site the high permeability of the sandy soil in the surface layers (further enhanced by the agricultural processing) favoured the infiltration of the rainwater towards the deep (300 cm from the soil surface) impermeable layer of ancient clay. Above this layer, thanks to the slope, groundwater rapidly flows towards the buffer zone. Moreover due to the significant surface of the agricultural basin, the flow rate reached the high value of about 8590 m^3 / year (to 100 m on buffer strips) corresponding to 64% of the rainfall in the basin (the remaining part is subject to processes of evapotranspiration). On the other hand the low values of subsurface discharges in the two sites of DIANA farm were the consequence of small size of the afferent agricultural basin. Also in this case a significant portion of the water volumes tends to be lost through subsurface flows (55.4% and 64.0% of the total rainfall) due to the heavy ploughing operations of the crop field. Catchments basins with steep slope which decreases sharply just before the buffer strip, and a very low hydraulic conductivity of soils like in the Fagna-FT1 and TORMA sites, the subsurface flows discharge represent only a small portion of total rainfall volumes (17.8 and 31.8%, respectively), while the dominating phenomena are surface runoff and evapotranspiration.

Nitrogen dynamics

The comparison between the concentration values of dissolved inorganic nitrogen in different points of the groundwater is shown in Figure 4.

In most cases the concentration values were rather low; the lowest values were recorded in the site of TORMA, while in the Fagna-FT1, Fagna-FT2 and DIANA-FT1 sites the average values, in the inlet of the buffer strip, ranged between 4 to 6 mg/L. Low concentrations of inorganic nitrogen in the water flow out from the crop can be due to several

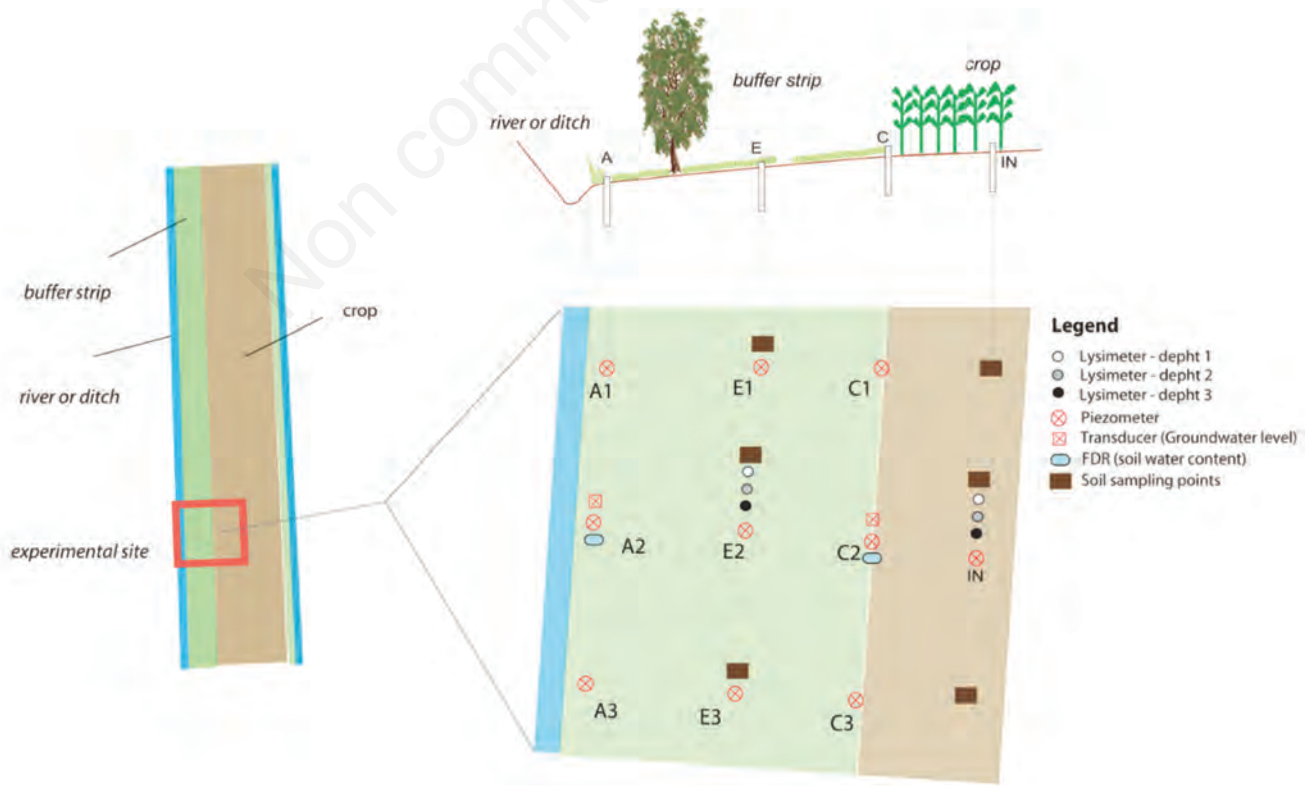


Figure 2. General monitoring scheme.

Table 2. Description of the monitored priority and ancillary parameters.

Priority parameters	Sampling point	Frequency	Methods	Aims
Texture	One complete soil profile, inside the buffer zone, from ground level up to the saturated zone	Only once at the start of monitoring	Pipette method	Understanding of the system and calculation of parameters dependent on texture
Watertable depth (continuously)	One point input (Factual) and 1 point out of the buffer zone (Counterfactual)	Every 30 minutes	Pressure transducers (SLB1 stainless steel, two-wire 4-20mA piezometers and current output, power supply 8-28 Vdc) inserted in dedicated connected to a data logger (data logger WatchDog 1000 Series, model 1650 sensors T / RH external air + 4 doors for external sensors).	To understand the dynamics of the saturated zone and water balance
Watertable depth (instantaneous measurements)	In each piezometer	During the water sampling (approximately every 15 days)	Hanfly freatimeter	To integrate the data recorded in continuous in a single section, with data relating to the whole piezometric net in order to define the groundwater. direction.
Rainfall	One pluviometer in each experimental site	Continuously	Rain gauge connected to a datalogger (WatchDog rain gauge data-logging 3554WD1-Spectrum Technologies attached to a self-emptying tipping bucket).	Water balance, climate trend.
Chemical parameters of water (N-tot, N-NO3, N-NH4, N-NO2)	All piezometers and lysimeters. Occasionally also from the adjacent surface waterbody.	Every 15-30 days	N-NO3, N-NH4, N-NO2: colorimetric analysis Ntot: Thermo Flash 2000 CN soil analyzer	Nitrogen dynamics and budget.
Saturated hydraulic conductivity (Ks)	All piezometers	Once	Slug test	Water balance
Elevation	The whole experimental plot, with a grid functional to obtain a DEM (Digital Elevation Model) with a resolution 20x20 cm)	Once	Leica GPS 1200+ system consisting in two geodetic receivers GPS / GNSS Leica AS10	Groundwater depth and water balance
Ancillary parameters	**Sampling point**	**Frequency**	**Methods**	**Aims**
Volumetric soil water content	Input and output of the buffer strips at different dephts	Every 30 minutes	FDR Probes (Frequency Domain Reflectometry, spectrum SM 100 waterscout soil moisture sensor) connected to a data logger (data-logging WatchDog 1000 Series Spectrum Technologies).	Hydrologic dynamics
Chemical parameters of water (DO, T and Cond.)	All piezometers	Every 15-30 days	Dissolved Oxigen: Oximeter AL20Oxi (Aqualytic, Dortmund, Germany). Temperature and electrical conductivity: portable conductivity meter with integrated temperature sensor (Schott-Geräte Conductivity meter handylab LF).	Ancillary data for a better understanding of the processes.
Chemical parameters of soil (TOC, TN, WSC, NO_3, NH_4).	Three points (replicates) at different depths both in the crop and in the buffer strip	2-3 times for year	TOC and TN: Thermo elemental analyzer Flash 2000 CN soil analyzer; SC: Thermo analyzer Flash 2000 CN Wsoil analyzer; NO_3, NH_4: colorimetric analysis	To estimate nitrogen storing or loss in the soil.

factors, such as the optimal use of nitrogen or heavy rainfall (clearly above the average during the two monitored years) leading to an increase of dilution. The mean values showed that Fagna FT1 and DIANA-FT1 sites were effective in removing nitrogen; the high variability of the values indicates a different seasonal pattern. In DIANA-FT1 a significant increase in nitrogen removal has been observed starting from the second year of monitoring, most likely due to the maturation of the newly-created buffer zone. The results recorded in Fagna-FT2 site, did not show any kind of buffering activities transformation; thus it give us an interesting example of no interaction between subsurface flows and rhizosphere, and as consequence no significant biogeochemical transformations of nitrogen. In TORMA site very low concentrations have been measured. Even if the overall differences between input and output in terms of average values were not significant, the higher stability of the output values compared with the input ones indicates that the occasional nitrogen peaks were effectively removed. The trend of nitrogen concentrations observed in Baroncina site further highlights the lack of hydrological connection between the crop (in the two control points the nitrogen concentrations were clearly influenced by the fertilization) and the buffer zone where the three control sections did not differ significantly and the average values were very low also in the section placed between the buffer strip and the crop. A similar situation has been observed in the site CAMP7, where it was clear that the waters loaded with nitrogen drain into the lateral ditch instead of crossing the buffer strip. The main items of nitrogen balance are summarized in the following Table 5.

The amount of nitrogen transported through subsurface fluxes from the field to the buffer strips ranges from a minimum of 3 kg ha^{-1} year^{-1} to a maximum of 33.2 kg ha^{-1} year^{-1}, with percentages of nitrogen leaching ranging between 1.8 and 25.2%. With the exception of the Fagna-FT2 site, all the systems were effective in N_{inorg} removal, with an efficiency ranging between 33 and 61.9%.

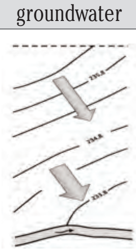
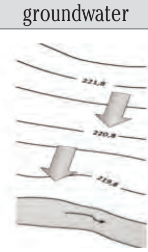
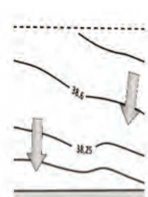
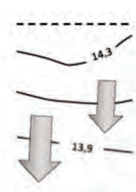
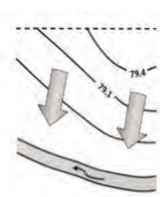
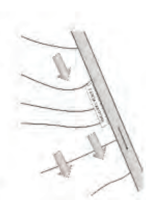
Quantitative indicator

The indicator of basic level chosen to define the suitability of the Standard 5.2 relatively to its environmental target was the efficiency of inorganic nitrogen removal, calculated by the mass balance following the below scheme:

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

The results are shown in Table 6.

Table 3. Main pedological and hydrological characteristics of the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Unsaturated layer (cm from s.l.)°	0-15	0-210	0-70	0-50	0-20	0-10	0-60
Saturated layer (cm from s.l.)°	15-200	210-300	70-200	50-90	20-90	10-200	<60
Unsaturated layer texture#	Silty clay loam (20-36-44)	Loam (40-22-38)	Loam (34-21-45)	Clay loam (26-39-35)	Silt loam (18-65-17)	Loam (32-48-30)	Clay (10-55-35)
Saturated layer texture#	Layer 15-85 cm silty clay loam (20-48-32) Layer 85-200 cm silty clay (7-48-45)	Sandy loam (60-8-32)	Sandy loam (68-13-19)	Silty clay loam (21-50-29)	Silt loam (19-63-18)	Loam (31-44-25)	Clay (3-70-27)
Slug Test Hydraulic conductivity (cm/day)	53.0	1180.0	1234.0	350.0	255.0	64.7	17.3
Groundwater slope in BS (%)	13.0	5.2	n.d.	11.0	1.0	2.3	n.d.
Groundwater depth (from s.l.)	Max: 0; Average: 75; Min: 198	Max: 45,1 Average: 229,6 Min: 277	Max: 0 Average: 74 Min: 200	Max: 0; Average: 48 Min: dry	Max: 0; Average: 20 Min: dry	Max: 0; Average: 39 Min: 104	Max: 16 Average: 80 Min: dry
Type	Permanent groundwater	Permanent groundwater	Permanent groundwater	Temporary perched aquifer	Temporary perched aquifer	Permanent groundwater	Permanent groundwater
Prevalent groundwater direction			No prevalent direction				

°In the most common situations; #the indicated numbers refers to the percent of sand/silt/clay, respectively; BS, Buffer strip; n.d., not detected.

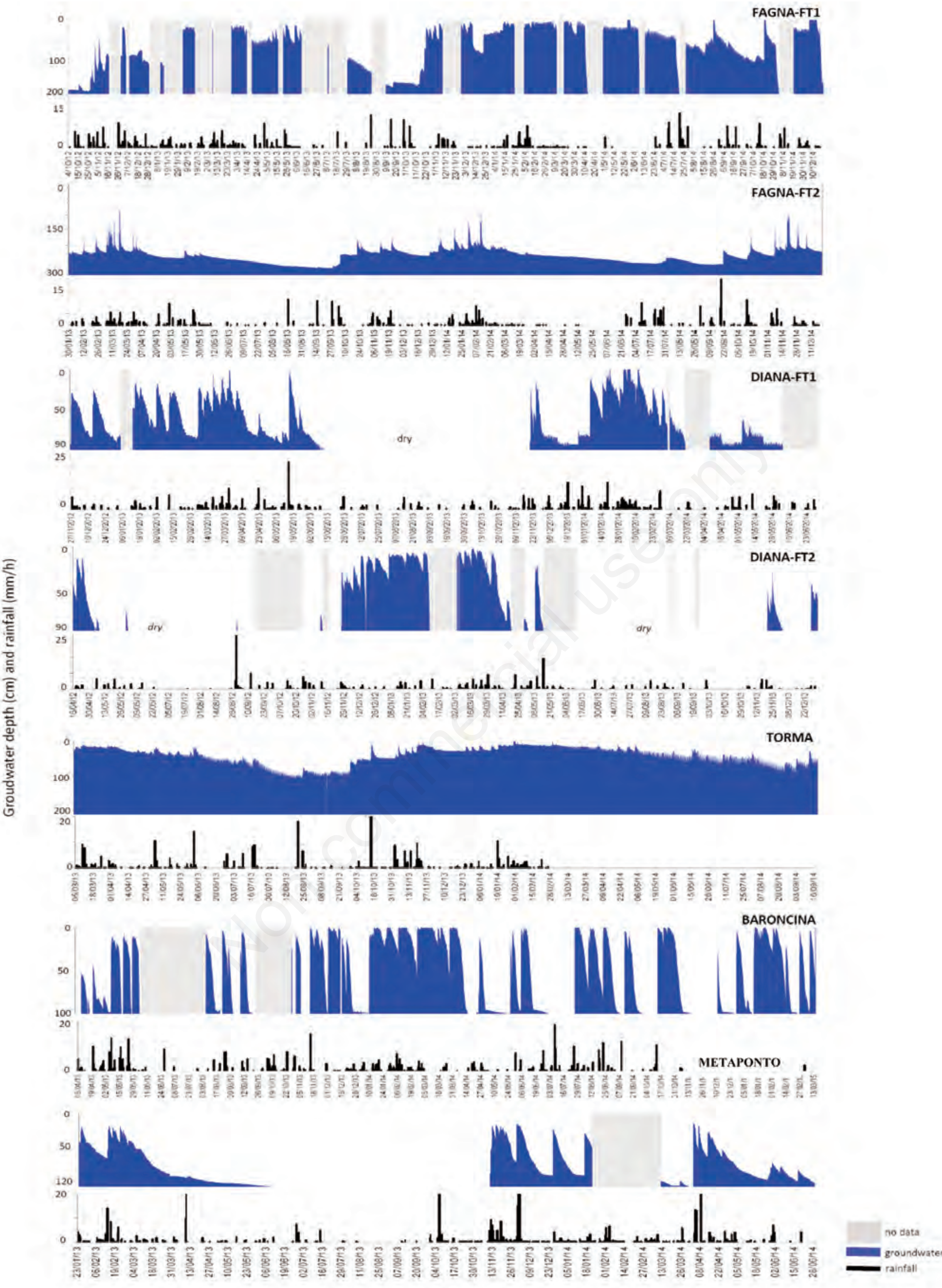


Figure 3. Fluctuation of the water table (data obtained as an average of 2 recordings, 1 every 30 minutes) in the experimental sites and hourly precipitation.

Efficiency judgment

The judgment of effectiveness was based on the percentage of experimental sites which demonstrated to be efficient on nitrogen removal. In the case of Standard 5.2 an improvement has been observed in 4 out of 7 of the monitored sites (57%), corresponding to a judgment of 'Effectiveness medium-high'.

Discussion and conclusions

The results are consistent with those of literature (Haycock and Pinay, 1993; Fennesy and Cronk, 1997; Dhont *et al*., 2004; Gumiero *et al*., 2011; Vidon and Hill, 2004) and the experimental activity contributed to demonstrate the key role of hydrological processes in influencing the effectiveness on nitrogen removal.

In particular, it was noted that in some of the monitored systems (Fagna-FT1, Fagna-FT2, TORMA) the buffer strips setup in accordance with the technical criteria of the cross-compliance Standard 5.2, were able to intercept significant volumes (ranging from 3000 to 8500 m^3 $year^{-1}$ per 100 l m of buffer strip) even if they occupy a surface rather limited compared to the field crops (3-5%).

Conversely, the buffer strips DIANA-FT1 and DIANA-FT2 cover a significant area if compared to the crop (about 30%) and in the same time they intercept low water volumes (around 1000 m^3 per year 100 mL of FT). Consequently to optimize the investment in terms of area occu-

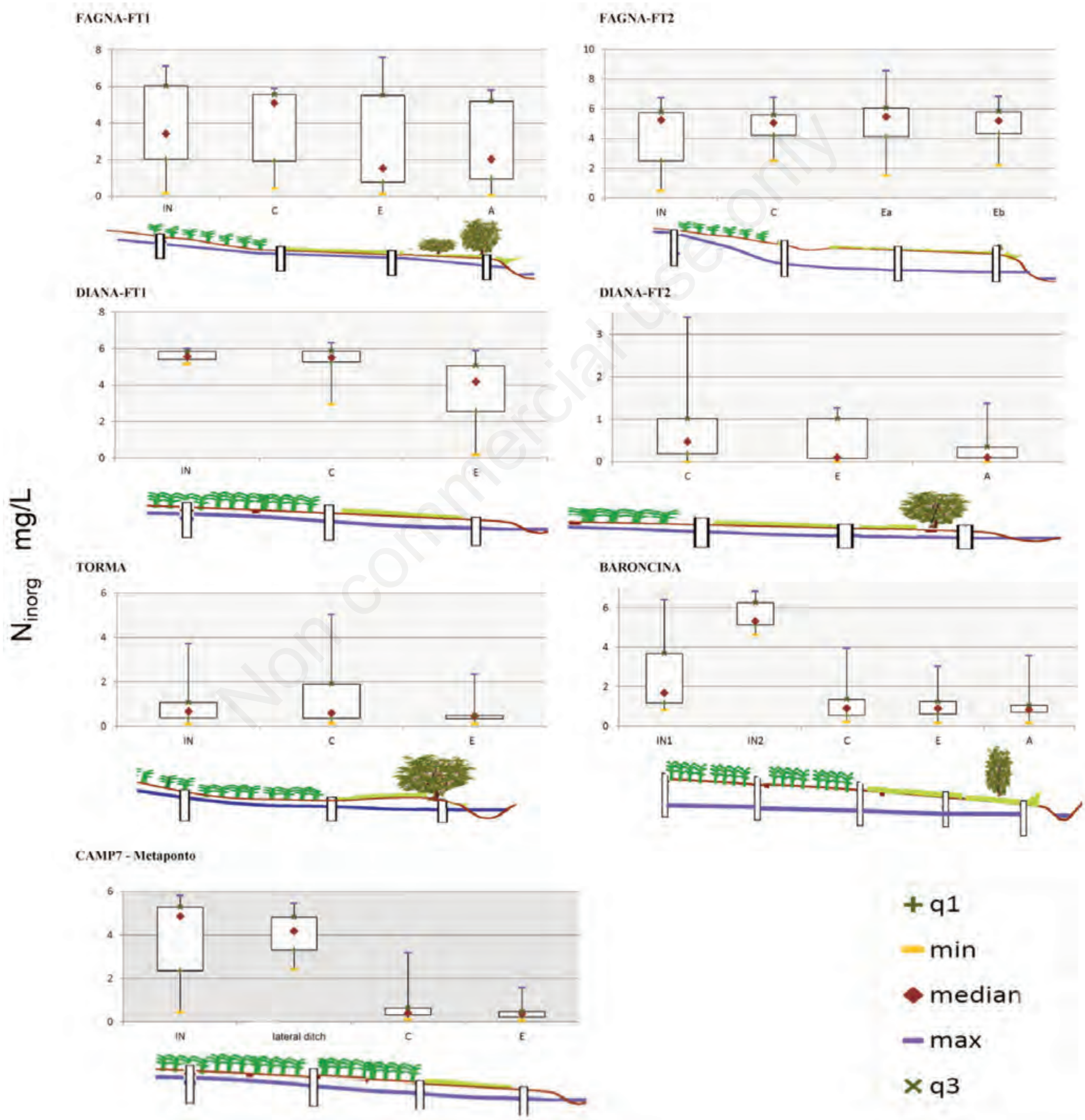


Figure 4. Comparison between the concentration values of dissolved inorganic nitrogen in different points of the monitored systems.

pied, this measure was particularly effective when it was possible to place a buffer zone downstream of a wide agricultural basin, with an optimal ratio between the surface occupied by the buffer strip and the crop of around 5%.

The inefficiency of Fagna-FT2 site, highlighted the importance of interaction between water flow and the rizhosphere for enhancing vegetation uptake and give support to microbial activities by organic matter supply (Pinay *et al*., 2000; Sabater *et al*., 2003; Vidon and Hill, 2004; Gumiero *et al.,* 2011; Boz *et al.* 2013). For different reasons, mentioned above, the Baroncina and the CAMP7 sites represents other cases of non-effective systems.

In all the other cases, the outflows persisted, at least for certain periods of the year, close to the ground surface, in theoretically optimal condition for the activation of the processes that lead to the removal of nitrogen. Despite this, in none of the cases the high levels of removal (80-90%) observed in other contexts (Peterjohn and Correl, 1984; Haycock and Pinay, 1993) have been reached, but rather values of efficiency ranging between 30-60%. This may be due to the short monitoring period (1-2 years) and to the unusual weather conditions (high rainfall); in the same time the low maturity of the monitored buffer strips, in many cases they were converted just before the beginning of the experimental activity, may leaded to an underestimation of the

Table 4. Main hydrological items in the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS AGRIC. (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
Subsurface flow discharge (100 m BS) (m^3 $year^{-1}$)	3152	8587	919	1004	4726
Subsurface flow discharge (100 m BS) (mm)	225	636	613	717	269
Rainfall (mm)	1264	1072	1385	1116	843
Subsurface flow discharge (% rain)	17.8	59.3	55.8	64	31.8

Table 5. Nitrogen balance in the different experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Florence)	FAGNA-FT2 CREA-ABP (Florence)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
N_{inorg} applied (kg ha^{-1} $year^{-1}$)	72	120	250	170	96
IN N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	8.45±1.69	30.29±2.94	33.21±1.34	3.0±0.3	4.66±1.69
N_{inorg} to BZ by subsurface flow / N_{inorg} applied (%)	11.1	25.2	13.3	1.8	1.78
Out N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	5.67±1.63	29.42±5.08	17.29±1.24	1.6±0.2	1.91±0.47
N_{inorg} removal by the BZ (kg ha^{-1} $year^{-1}$)	2.79	0.86	15.93	1.5	2.88
Efficiency (%)	33.0	2.9	48.0	48.6	61.9

Table 6. Judgment of efficiency in the different sites (base level).

Experimental site	Removal (%)	Judgment of indicator efficiency
FAGNA-FT1 CREA-ABP (Florence)	33	Medium
FAGNA-FT2 CREA-ABP (Florence)	2.9	Poor
BARONCINA CREA-FLP (Lodi)	0	Poor
DIANA-FT1 VENETO AGRIC.	48	Medium
DIANA-FT2 VENETO AGRIC.	48.6	Medium
TORMA- CREA-RPS (Rome)	62	High
CAMP7-CREA-SSC (Metaponto)	0	Poor

buffering capacity. This was confirmed by the low levels of organic matter available in the soils (values between 1.5 and 1.7%) as well. In this perspective, an increasing of the buffer capacity could be observed in a more advanced phase starting from the second or the third year after the conversion as observed in other studies (Gumiero *et al*., 2011; Anbumozhi *et al*., 2004; Uusi-Kämppä and Jauhiainen, 2010). During early stages, the influence of the hydrological factors appears to be prevalent instead of the type of vegetation. At the same time the river typology did not affect significantly the efficacy of the buffer zone, although it must be recognized to the past river dynamics a key role in determining the soil layers configuration and properties. This usually leads to observe more heterogeneous soil profiles in the riparian buffer adjacent to natural water bodies better than to artificial water bodies.

The infiltration capacity of water in soil with consequent development of sub-surface outflows was rather significant in all monitored systems (values ranging between 18 and 64% of total rainfall). This was recorded also in systems with high slopes (above 6%) and/or fine grain soil which should facilitate the development of surface runoff phenomena.

This was mainly due to the ploughing activities which, in addition to increase the water infiltration within the field crop, shaped a significant drop of soil surface between the field and the undisturbed buffer zone that could not be overcome by superficial runoff.

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Abstract

Seven buffer strips (BS) adjacent to fresh water bodies, realized according to the technical data contained in the Standard 5.2 of Cross-compliance, located in different areas and climate contexts, were monitored for a period of two years. It was done in order to quantify their effectiveness in removing dissolved inorganic nitrogen conveyed through sub- surface flow from field crops with different cultural practices. Except for two case studies (sites: Lodi and Metaponto) in all monitored systems has been confirmed an outflow, permanent or temporary, through the buffer systems, with flow rates ranging from 919 to 8590 $m^3 y^{-1}$ every 100 meters of buffer stip. The differences in flow rate were mainly due to different sizes of agricultural basins related to buffer systems, which in the case studies ranging from 3.6 to 33.3%. Based on the mass balance, was found percentages of applied inorganic nitrogen, flowing from cultivated fields to the buffer systems, varied between 1.6 and 29.4%. In most of the sites was estimated of BS nitrogen reduction between inlet and outlet of BS, with percentages ranging from 33 to 61.9%. The exceptions were the systems with groundwater that: or have no interaction with the rhizosphere (deep flow) or not crossing the buffer zone. Low percentages of removal shall be justified by the young stage of the monitored sites, being in many cases recently converted to buffer strip. This study confirms the extreme variability of these systems efficiency and the key role of hydrology drives its effectiveness.

Introduction

The point-source pollution has been reduced significantly in recent decades thanks to increasing of efficient sewage treatment plants, while is not the case for widespread source pollution. Researchers have recognized the importance of non-point source pollution starting from the 1980s when improvement in wastewater treatments failed to produce the expected enhancement of streams and rivers water quality (Campbell *et al.,* 2004). Diffuse pollution is difficult to measure and control because it is often intermittent and linked to seasonal agricultural activity or irregular events, such as heavy precipitation, and involve complex transport and transformation through several media like air, soil and water (Dhondt *et al.,* 2004; Zhang *et al.,* 2012; Cheng *et al.,* 2013).

In a watershed, the main sources of nitrates are: i) the microbial processes of organic matter (mineralization and nitrification); ii) the oxidation of organic matter due to human activities: agricultural (manure) or urban (civil waste); iii) chemical fertilizers. In rural environment, two critical contaminant from diffuse pollution are pesticides and nutrients, in particular phosphorus and nitrogen. Fertilizer inputs to crops are generally higher than the amount of nutrients required to maximize plant productivity, hence this surplus may accumulate in soils (Sebilo *et al.,* 2013) and in water bodies. Nutrient load is drained from the agricultural territory or livestock origin, through processes of runoff, leaching and percolation. Nitrogen stored in soils is moved by tillage and erosion and then by water flow from cultivated areas to waterways. Nitrogen can also be delivered to atmosphere through volatilization of NH_3 and microbial generation of N_2O (greenhouse gas) (Carpenter *et al.,* 1998; De Simone *et al.,* 2010; Audet *et al.,* 2014). Despite the increasing efforts at national and European levels (Nitrate Directive 91/976/EEC, currently included in the Water Framework Directive 2000/60/EC) to reduce NO_3 inputs from intensive agriculture, it is still one of the major contaminants of superficial freshwater and groundwater resources (http://isonitrate.brgm.fr). Confined systems like shallow lakes, lagoons and enclosed seas are very sensitive to the excess of nutrients and can have highly impacted consequences like eutrophication (Boesch *et al.,* 2002; Khan and Ansari, 2005; Ansari *et al.,* 2010; Gren and Destouni, 2011). Furthermore, nitrate because of its high solubility in water, tends to be accumulated in groundwater, often used for drinking water, causing problems for human health (Carpenter *et al.,* 1998; Weyer *et al.,* 2001).

Diffuse nitrate decreasing can be reached with two different strategies: by reducing fertilizers inputs following more sustainable agricultural management or by facilitating natural processes of water phytodepuration that are usually very efficient in Buffer Strip and Wetlands systems as were established in many studies (Clement, 2002; Coops and van Geest, 2007; Billy *et al.,* 2013; Gumiero *et al.,* 2011, 2013; Hefting *et al.,* 2013).

In all European legislation related to water resources is emphasized the need to integrate policies of water protection management with the management of production activities, particularly agriculture, in order to achieve the goal of sustainable development. The Directive 2000/60/EC establishes the principle that '*Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such*'. It requires Member States '*to achieve good status of surface and ground water*' by 2015 (Art. 4 WFD). Member States must draw up plans for the river basin management (RBMP) and the programs of measures. They may implement this policy by using part of the funds of other sectorial policies, such as those provided by Common Agricultural Policy (CAP). As in Europe about 50% of the total surface is an agricultural land, it shapes the landscape and plays a key role in the sustainable management of water resources both in quantity and quality. For this reason the EU Council has pointed out the need to protect water resources within the CAP (COM (2012) 673 of 14th November 2012, 'Blueprint to safeguard Europe's water resources'). To achieve the objectives of the EU policy on water resources, the CAP uses mainly two tools: Cross-compliance and the European Agricultural Funds for Rural Development (EAFRD) (in Italy they are called PSR). These tools help to promote sustainable agriculture by encouraging good agricultural practices and promoting the environmental goods and services. Within the Cross-compliance Standards there are several obligations that directly affect water quality, one of them is GAEC 5.2, concerns the obligation to introduce 'buffer strips' at the edge of the cropland and close to watercourses in order to protect them from diffuse pollution caused mainly by agricultural activities. This requirement in Italy was introduced in 2009 and implemented since 1st January of 2012. Buffer strip is a vegetated area, near watercourses, permanently covered with grass, shrubs, trees, spontaneous or not. The Standard requires a strip 5m wide excluding unvegetated roads or paths. The obligation of buffer strips covers all agricultural areas, with the exception of land under permanent pasture and olive groves. In the requirement of buffer strips the following watercourses are excluded: i) drains, ditches and other hydraulic artificial structures made for the collection and conveyance of storm water, with temporary discharge; ii) irrigation channels; iii) 'suspended' channel; iv) watercourses with consistent levees that cause a discontinuity between the field and the aquatic system (www.agricoltura24.com). Elsewhere in Europe the commitments of Standard 5.2 are almost the same for all member countries. What changes most is the wide of the buffer zone that can range from 2 to 10 meters. Ten meters usually makes reference to the prohibition of organic fertilization. This paper shows the results of diffuse nitrate removal efficiency of different buffer strips, setup according to the technical indications reported in the Standard 5.2, and highlight the major factors that improve or reduce buffer effectiveness.

Materials and methods

Experimental sites

Seven experimental sites, distributed in different Italian regions, were set in order to conduct the experimental activities. The main characteristics of each site are summarized in Table 1. In all sites the management was limited to mowing (1-2 times for year) and, when necessary, to the lateral pruning of trees and shrubs, including the removal of any branches or logs, to allow the passage of agricultural machinery. In accordance with the Cross-compliance Standard 5.2 (M.D. 27417), no distribution of fertilizers or other phytosanitary products has been done in the buffer strips.

In all afferent agricultural catchments, except for DIANA-FT2 (seeding), the usual operations of ploughing (up to 30-40 cm from ground level) and harrowing have been performed. Only in site CAMP7-(Metaponto) irrigation could be provide if necessary.

With the exception of the site TORMA, where the buffer strip was 8.5 m wide, in all sites they were 5 m wide. The experimental sites were well distributed both in term of different territorial context (hilly or lowland areas) and vegetation typology (3 only herbaceous and 4 herbaceous + tree and shrubs buffer strips).

The ratio between the buffer strips and the afferent crop catchment areas, was quite variable from a minimum of 3.6 % in FAGNA-FT2 to a maximum of 33.3% in DIANA-FT1. The catchment surface has not been defined in the sites of Baroncina (Lodi) and CAMP7 (Metaponto), where no hydrological connection between the crop fields and the buffers strips were found.

Experimental design

The experimental designs have been planned in coherence with the indications reported in the Cross-compliance Standard 5.2 (M.D. 27417) (Figure 1).

The monitoring points were choosen as following:

A) Counterfactual: located in the interface zone between the 'margin of the crop' and the beginning of buffer strip, where the flow of pollutants from the crop towards the inlet of the buffer zone was monitored. It was considered the reference without Standard application.

B) Factual: section located at the end or in an intermediate portion of the buffer zone to provide information about the effects of the Standard application.

Because of different types of buffer strips, the factual area was further specified according to the following definitions:

Factual I : herbaceous (only) buffer strip at least 5 meters wide;

Factual II: herbaceous buffer strip, at least 3 meters wide, and placed between the edge of the crop and the beginning of a woody buffer strip, in a buffer system given by the combination of the two.

Factual III: outlet point of a buffer zone composed by the combination of an herbaceous strip, at least 3 meters wide, plus a woody strip at least 2 meters wide.

The monitoring scheme for each experimental sites is reported in Figure 1.

In order to monitor both hydrological and chemical-physical parameters, each experimental site was set up as shown in the simplified scheme of Figure 2.

Even if some specific differences between sites existed, in all of them have been set:

a piezometric network, generally consisting in a 3x3 grid, with 3 wells (replicates) placed perpendicularly to the theoretical line of subsurface runoff from the field to the water body and placed respectively in the entry to the buffer zone (counterfactual), in an intermediate zone (generally the zone of transition between herbaceous and woody strips) and in correspondence of the output of buffer zone (factual). In addition a sampling point was also placed in the crop area. The fully screened piezometers had a diameter of 2 inches, and variable depth according to the depth of saturated zones. They were used both for water sampling (through a system of flasks placed inside the piezometer) and for instantaneous measurements of the groundwater level (by a manual freatimeter);

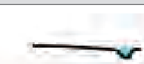
2 electric contact gauges to measure every 30 minutes the piezometric head, placed inside 2 dedicated piezometers: one at the input and the other at the output of the buffer zone;

FDR sensors registered the volumetric soil water content at different soil depths;

3 lysimeters collecting water at different depth (30, 60 and 90 cm), in the crop field.

The soil samples have been drawn at different depth both in the cultivated field and in the buffer strips by a manual drill.

Table 1. Main characteristics of the experimental sites.

Experimental sites	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Geographical coordinates	43°58' 49.90 N 12°18' 43.00 E	43°58' 57.30 N 11°20' 36.75 E	45°17' 24.24 N 9°29' 55.76 E	45°34' 27.88 N 12°19' 01.87 E	45°34' 47.65 N 12°18' 40.65 E	42° 05' 31.19"N 12° 38' 05.46"E	40°22' 12.78 N 16°48' 33.13 E
Geographical context	Hilly	Hilly	Lowland	Lowland	Lowland	Hilly	Lowland
Topography							
Slope° (%)	4.4 / 9.2	6.5 / 1.7	0.2 / 0.7	4.3 / 4.5	3.9 /4.3	7.4 / -2.3	0.52/0.63
Crop	Wheat	Sunflower/maize	Maize	Maize	Ryegrass/maize	Wheat	Vegetables
Waterbody typology	Natural stream	Natural stream	Irrigation ditch	Ditch	Ditch	Collector ditch	Collector ditch
BS cover	Herbaceous + arboreous and shrub	Herbaceous	Herbaceous + arboreous	Herbaceous	Herbaceous+ Harboreous and shrub	Herbaceous+ arboreous and shrub	Herbaceous
Total width of BS (m)	5	5	5	5	5	8.53	5
Upland slope length (m)	135	130	n.d.	10	13	176	n.d.
Area BS/area catchment (%)	3.70	3.57	n.d.	33.33	27.8	4.8	n.d.

°The first number refers to the average slope of the crop catchment, while the second to the average slope of the buffer strip; BS, Buffer strip; n.d., not detected.

Methods

Water balance

The subsurface flow discharge has been calculated by the Darcy's Law in the following form:

$$Q = ks\ S\ \vec{i}$$

where Q is the average inflow flux, *i* is the head gradient between the two considered piezometers set with the transducers and S is the saturated area perpendicular to the groundwater flow.

Parameters

For each site a series of chemical and physical parameters were detected. Some of them were defined as priority parameters (key parameters) some other as ancillary parameters (parameters which are not mandatory but useful as additional information to confirm whether certain interpretations of the results). The parameter type, the location of the sampling points, the frequency and the analytical method used are summarized in Table 2.

Results

Hydrological dynamics

Thanks to the surveys carried out it was possible to describe the main characteristics of the soil and of the hydrological dynamics in the experimental sites. A summary of the most significant characteristics for each site is shown in the Table 3. In most of the case studies, the rain or irrigation waters flow in the agricultural soils above the first impermeable layer of soil (placed at variable depths from a minimum of 90 to a maximum of 300 cm) and generate a saturated zone (suspended groundwater) which could be permanent or temporary (the saturated zone disappears during the warm season). With the exception of the Baroncina site (Lodi), where there was not a clear prevalent direction of the subsurface flows, and CAMP7 (Metaponto) site, where the groundwater flows almost parallel to the buffer strip toward a lateral draining ditch, in all the other cases investigated the groundwater flows perpendicularly from the crop to the buffer system. The groundwater slope varied between a minimum of 1% (DIANA-FT2 site) and a maximum of 13% (Fagna-FT1 site). The hydraulic conductivity meas-

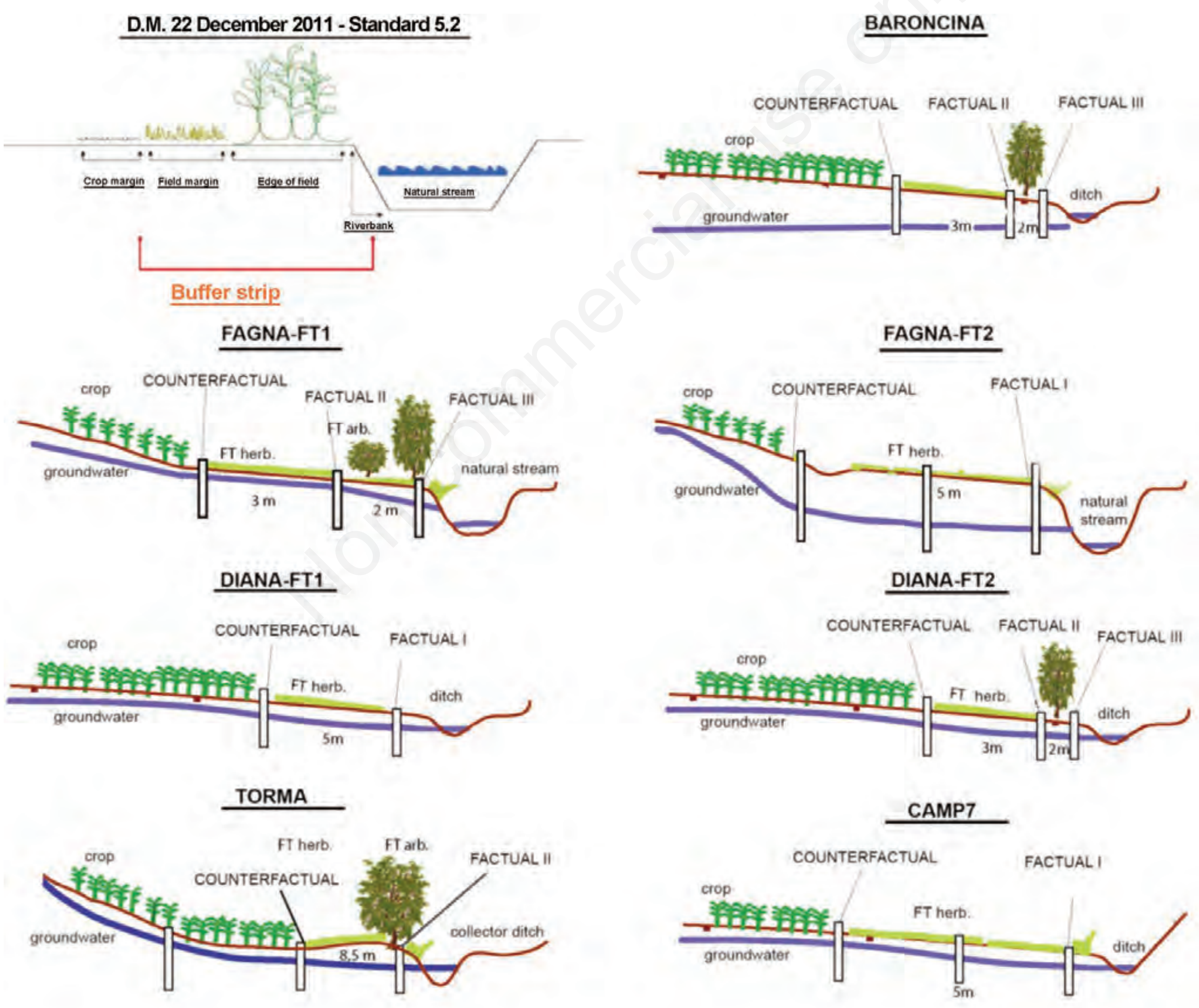


Figure 1. Experimental schemes of the experimental sites and their comparison with the general case contained in M.D. 27417.

ured by slug tests differed considerably (about one order of magnitude) from the theoretical one related to the soil texture. This was generally due to the presence of macro-cracks in the soil caused by the ploughing activities or alternatively by the effect of the vegetation roots (Mastrocicco *et al.,* 2013).

The trend of groundwater fluctuations in all monitored sites is shown in Figure 3. In the two sites located within the experimental farm Diana (DIANA-DIANA-FT1 and FT2) a temporary phase of saturation during the cold months (generally from November to May) has been observed. In the remaining months the soil was unsaturated except during high intensity rainfall events. The water table fluctuations were strongly related to the rainfall events and saturation conditions often reach the ground level. A similar trend has been observed in the experimental site CAMP7 (Metaponto). On the other hand in the site Fagna-FT2 was recorded a permanent water table (at least in the monitored period) laying on an impermeable layer about 3 meters deep; the fluctuations were rather small between 2-3 m from the soil surface. The sites Fagna-FT1 and TORMA have similar hydrological behaviour with an almost complete saturation of the first 2 m of soil for most of the year. This behaviour was favoured by particularly intense and persistent rainfall events during the two years of monitoring; thus it cannot be excluded than during years of drought the soil may result temporary unsaturated. The Baroncina site, in term of saturation, had strong fluctuations correlated with rainfall events.

The main items of the water balance for each of the monitored sites were listed in the Table 4. Since the absence of subsurface flows from crop to the buffer strip both Baroncina and CAMP7 sites were not included in Table 3, about the water balance, and in Table 5, about the nitrogen balance as they were equal to zero.

The discharge of the sub-surface flows which convey the pollutants from the crop to surface waterbodies through the buffer system, are strictly related to the size of the catchment area, the slope and soil characteristics. As an example in the Fagna-FT2 site the high permeability of the sandy soil in the surface layers (further enhanced by the agricultural processing) favoured the infiltration of the rainwater towards the deep (300 cm from the soil surface) impermeable layer of ancient clay. Above this layer, thanks to the slope, groundwater rapidly flows towards the buffer zone. Moreover due to the significant surface of the agricultural basin, the flow rate reached the high value of about 8590 m^3 / year (to 100 m on buffer strips) corresponding to 64% of the rainfall in the basin (the remaining part is subject to processes of evapotranspiration). On the other hand the low values of subsurface discharges in the two sites of DIANA farm were the consequence of small size of the afferent agricultural basin. Also in this case a significant portion of the water volumes tends to be lost through subsurface flows (55.4% and 64.0% of the total rainfall) due to the heavy ploughing operations of the crop field. Catchments basins with steep slope which decreases sharply just before the buffer strip, and a very low hydraulic conductivity of soils like in the Fagna-FT1 and TORMA sites, the subsurface flows discharge represent only a small portion of total rainfall volumes (17.8 and 31.8%, respectively), while the dominating phenomena are surface runoff and evapotranspiration.

Nitrogen dynamics

The comparison between the concentration values of dissolved inorganic nitrogen in different points of the groundwater is shown in Figure 4.

In most cases the concentration values were rather low; the lowest values were recorded in the site of TORMA, while in the Fagna-FT1, Fagna-FT2 and DIANA-FT1 sites the average values, in the inlet of the buffer strip, ranged between 4 to 6 mg/L. Low concentrations of inorganic nitrogen in the water flow out from the crop can be due to several

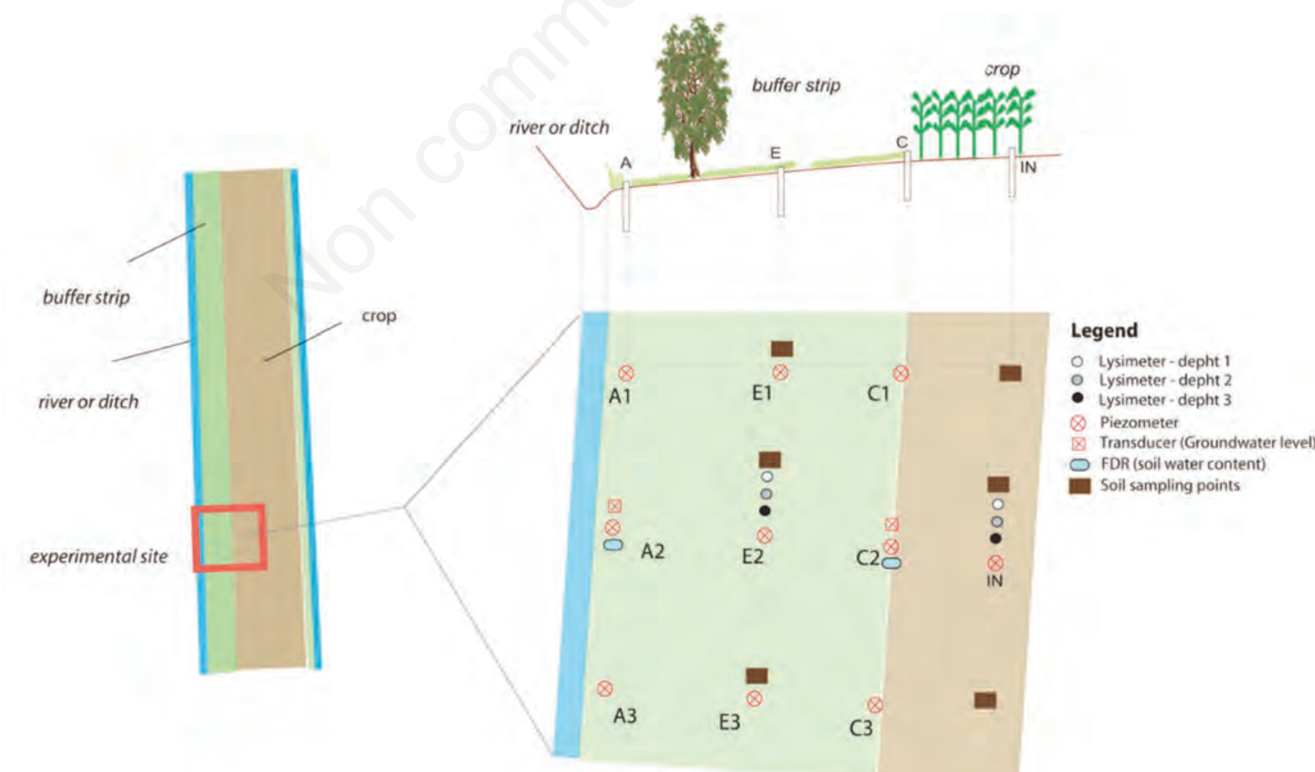


Figure 2. General monitoring scheme.

Table 2. Description of the monitored priority and ancillary parameters.

Priority parameters	Sampling point	Frequency	Methods	Aims
Texture	One complete soil profile, inside the buffer zone, from ground level up to the saturated zone	Only once at the start of monitoring	Pipette method	Understanding of the system and calculation of parameters dependent on texture
Watertable depth (continuously)	One point input (Factual) and 1 point out of the buffer zone (Counterfactual)	Every 30 minutes	Pressure transducers (SLB1 stainless steel, two-wire 4-20mA piezometers and current output, power supply 8-28 Vdc) inserted in dedicated connected to a data logger (data logger WatchDog 1000 Series, model 1650 sensors T/RH external air + 4 doors for external sensors).	To understand the dynamics of the saturated zone and water balance
Watertable depth (instantaneous measurements)	In each piezometer	During the water sampling (approximately every 15 days)	Hanfly freatimeter	To integrate the data recorded in continuous in a single section, with data relating to the whole piezometric net in order to define the groundwater. direction.
Rainfall	One pluviometer in each experimental site	Continuously	Rain gauge connected to a datalogger (WatchDog rain gauge data-logging 3554WD1-Spectrum Technologies attached to a self-emptying tipping bucket).	Water balance, climate trend.
Chemical parameters of water (N-tot, N-NO3, N-NH4, N-NO2)	All piezometers and lysimeters. Occasionally also from the adjacent surface waterbody.	Every 15-30 days	N-NO3, N-NH4, N-NO2: colorimetric analysis Ntot: Thermo Flash 2000 CN soil analyzer	Nitrogen dynamics and budget.
Saturated hydraulic conductivity (Ks)	All piezometers	Once	Slug test	Water balance
Elevation	The whole experimental plot, with a grid functional to obtain a DEM (Digital Elevation Model) with a resolution 20x20 cm)	Once	Leica GPS 1200+ system consisting in two geodetic receivers GPS / GNSS Leica AS10	Groundwater depth and water balance
Ancillary parameters	**Sampling point**	**Frequency**	**Methods**	**Aims**
Volumetric soil water content	Input and output of the buffer strips at different dephts	Every 30 minutes	FDR Probes (Frequency Domain Reflectometry, spectrum SM 100 waterscout soil moisture sensor) connected to a data logger (data-logging WatchDog 1000 Series Spectrum Technologies).	Hydrologic dynamics
Chemical parameters of water (DO, T and Cond.)	All piezometers	Every 15-30 days	Dissolved Oxigen: Oximeter AL20Oxi (Aqualytic, Dortmund, Germany). Temperature and electrical conductivity: portable conductivity meter with integrated temperature sensor (Schott-Geräte Conductivity meter handylab LF).	Ancillary data for a better understanding of the processes.
Chemical parameters of soil (TOC, TN, WSC, NO_3, NH_4).	Three points (replicates) at different depths both in the crop and in the buffer strip	2-3 times for year	TOC and TN: Thermo elemental analyzer Flash 2000 CN soil analyzer; SC: Thermo analyzer Flash 2000 CN Wsoil analyzer; NO_3, NH_4: colorimetric analysis	To estimate nitrogen storing or loss in the soil.

factors, such as the optimal use of nitrogen or heavy rainfall (clearly above the average during the two monitored years) leading to an increase of dilution. The mean values showed that Fagna FT1 and DIANA-FT1 sites were effective in removing nitrogen; the high variability of the values indicates a different seasonal pattern. In DIANA-FT1 a significant increase in nitrogen removal has been observed starting from the second year of monitoring, most likely due to the maturation of the newly-created buffer zone. The results recorded in Fagna-FT2 site, did not show any kind of buffering activities transformation; thus it give us an interesting example of no interaction between subsurface flows and rhizosphere, and as consequence no significant biogeochemical transformations of nitrogen. In TORMA site very low concentrations have been measured. Even if the overall differences between input and output in terms of average values were not significant, the higher stability of the output values compared with the input ones indicates that the occasional nitrogen peaks were effectively removed. The trend of nitrogen concentrations observed in Baroncina site further highlights the lack of hydrological connection between the crop (in the two control points the nitrogen concentrations were clearly influenced by the fertilization) and the buffer zone where the three control sections did not differ significantly and the average values were very low also in the section placed between the buffer strip and the crop. A similar situation has been observed in the site CAMP7, where it was clear that the waters loaded with nitrogen drain into the lateral ditch instead of crossing the buffer strip. The main items of nitrogen balance are summarized in the following Table 5.

The amount of nitrogen transported through subsurface fluxes from the field to the buffer strips ranges from a minimum of 3 kg ha^{-1} $year^{-1}$ to a maximum of 33.2 kg ha^{-1} $year^{-1}$, with percentages of nitrogen leaching ranging between 1.8 and 25.2%. With the exception of the Fagna-FT2 site, all the systems were effective in N_{inorg} removal, with an efficiency ranging between 33 and 61.9%.

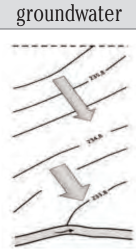
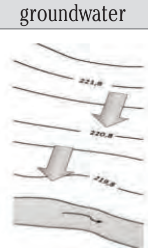
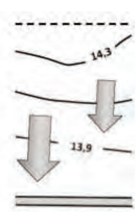
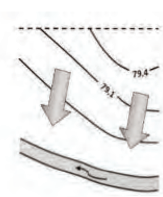
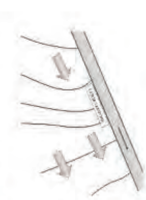
Quantitative indicator

The indicator of basic level chosen to define the suitability of the Standard 5.2 relatively to its environmental target was the efficiency of inorganic nitrogen removal, calculated by the mass balance following the below scheme:

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

The results are shown in Table 6.

Table 3. Main pedological and hydrological characteristics of the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	BARONCINA CREA-FLC (Lodi)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)	CAMP7- CREA-SSC (Metaponto)
Unsaturated layer (cm from s.l.)°	0-15	0-210	0-70	0-50	0-20	0-10	0-60
Saturated layer (cm from s.l.)°	15-200	210-300	70-200	50-90	20-90	10-200	<60
Unsaturated layer texture#	Silty clay loam (20-36-44)	Loam (40-22-38)	Loam (34-21-45)	Clay loam (26-39-35)	Silt loam (18-65-17)	Loam (32-48-30)	Clay (10-55-35)
Saturated layer texture#	Layer 15-85 cm silty clay loam (20-48-32) Layer 85-200 cm silty clay (7-48-45)	Sandy loam (60-8-32)	Sandy loam (68-13-19)	Silty clay loam (21-50-29)	Silt loam (19-63-18)	Loam (31-44-25)	Clay (3-70-27)
Slug Test Hydraulic conductivity (cm/day)	53.0	1180.0	1234.0	350.0	255.0	64.7	17.3
Groundwater slope in BS (%)	13.0	5.2	n.d.	11.0	1.0	2.3	n.d.
Groundwater depth (from s.l.)	Max: 0; Average: 75; Min: 198	Max: 45,1 Average: 229,6 Min: 277	Max: 0 Average: 74 Min: 200	Max: 0; Average: 48 Min: dry	Max: 0; Average: 20 Min: dry	Max: 0; Average: 39 Min: 104	Max: 16 Average: 80 Min: dry
Type	Permanent groundwater	Permanent groundwater	Permanent groundwater	Temporary perched aquifer	Temporary perched aquifer	Permanent groundwater	Permanent groundwater
Prevalent groundwater direction			No prevalent direction				

°In the most common situations; #the indicated numbers refers to the percent of sand/silt/clay, respectively; BS, Buffer strip; n.d., not detected.

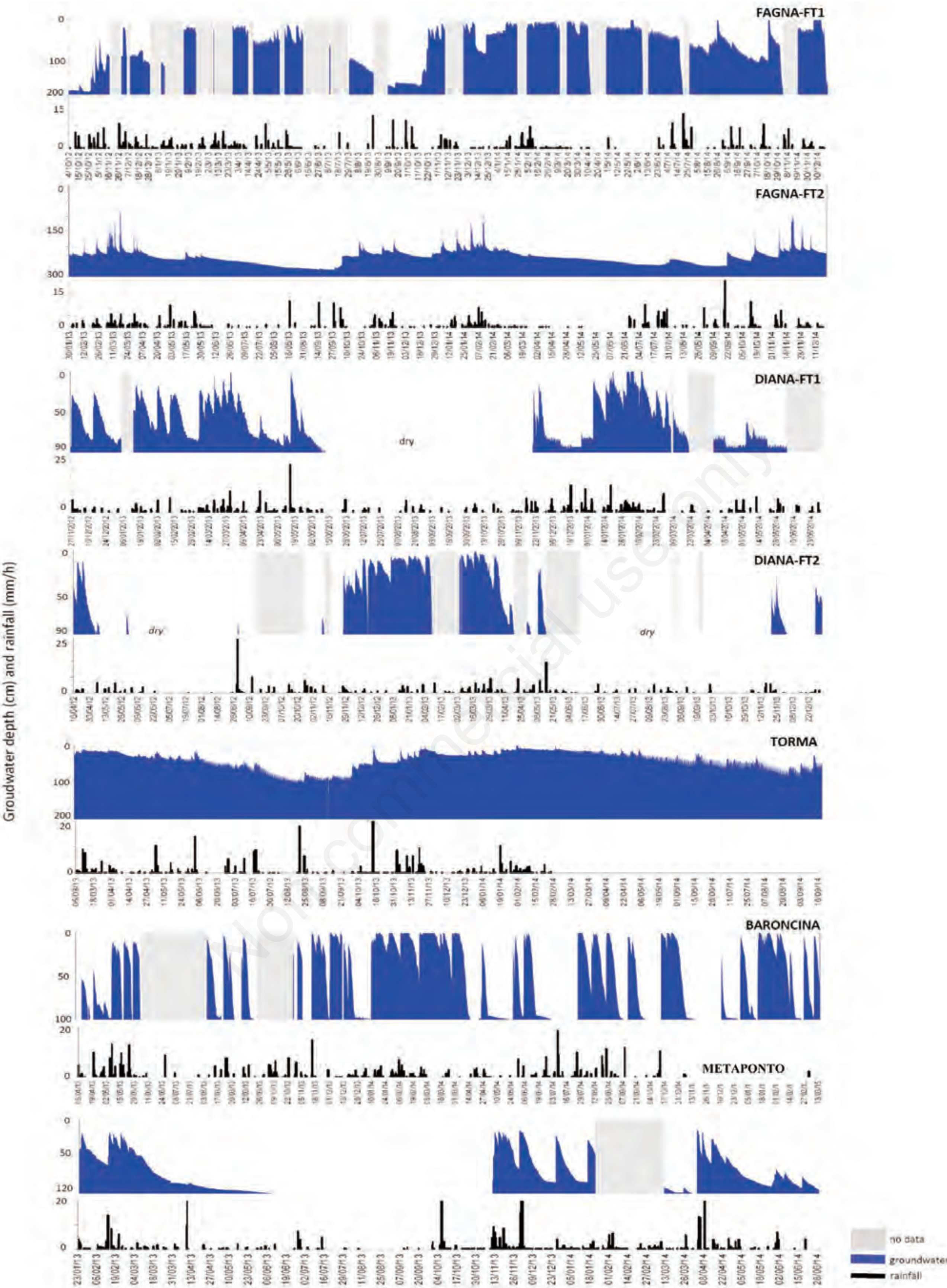


Figure 3. Fluctuation of the water table (data obtained as an average of 2 recordings, 1 every 30 minutes) in the experimental sites and hourly precipitation.

Efficiency judgment

The judgment of effectiveness was based on the percentage of experimental sites which demonstrated to be efficient on nitrogen removal. In the case of Standard 5.2 an improvement has been observed in 4 out of 7 of the monitored sites (57%), corresponding to a judgment of 'Effectiveness medium-high'.

Discussion and conclusions

The results are consistent with those of literature (Haycock and Pinay, 1993; Fennesy and Cronk, 1997; Dhont *et al*., 2004; Gumiero *et al*., 2011; Vidon and Hill, 2004) and the experimental activity contributed to demonstrate the key role of hydrological processes in influencing the effectiveness on nitrogen removal.

In particular, it was noted that in some of the monitored systems (Fagna-FT1, Fagna-FT2, TORMA) the buffer strips setup in accordance with the technical criteria of the cross-compliance Standard 5.2, were able to intercept significant volumes (ranging from 3000 to 8500 m^3 $year^{-1}$ per 100 l m of buffer strip) even if they occupy a surface rather limited compared to the field crops (3-5%).

Conversely, the buffer strips DIANA-FT1 and DIANA-FT2 cover a significant area if compared to the crop (about 30%) and in the same time they intercept low water volumes (around 1000 m^3 per year 100 mL of FT). Consequently to optimize the investment in terms of area occu-

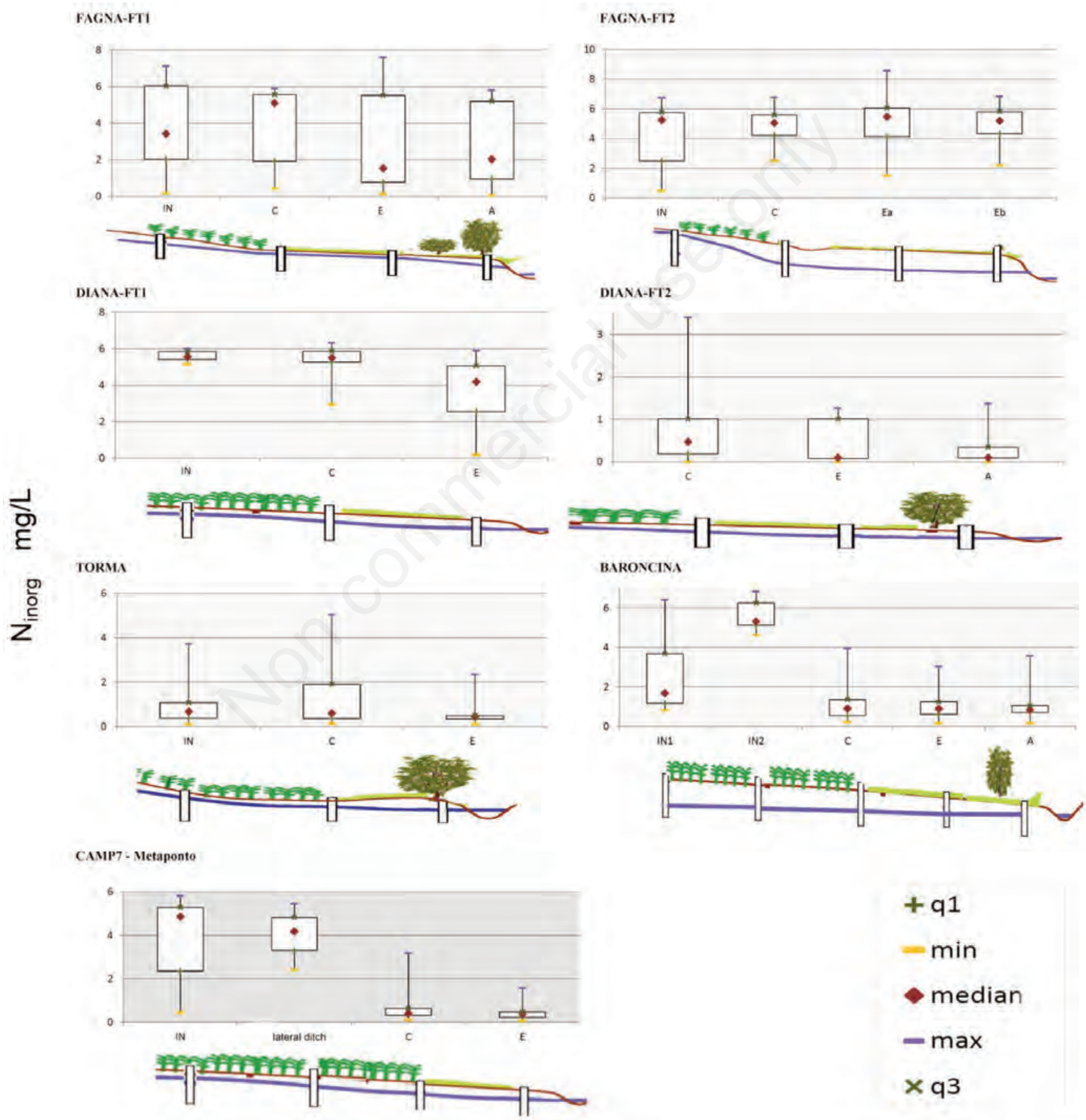


Figure 4. Comparison between the concentration values of dissolved inorganic nitrogen in different points of the monitored systems.

pied, this measure was particularly effective when it was possible to place a buffer zone downstream of a wide agricultural basin, with an optimal ratio between the surface occupied by the buffer strip and the crop of around 5%.

The inefficiency of Fagna-FT2 site, highlighted the importance of interaction between water flow and the rizhosphere for enhancing vegetation uptake and give support to microbial activities by organic matter supply (Pinay *et al*., 2000; Sabater *et al*., 2003; Vidon and Hill, 2004; Gumiero *et al.,* 2011; Boz *et al.* 2013). For different reasons, mentioned above, the Baroncina and the CAMP7 sites represents other cases of non-effective systems.

In all the other cases, the outflows persisted, at least for certain periods of the year, close to the ground surface, in theoretically optimal condition for the activation of the processes that lead to the removal of nitrogen. Despite this, in none of the cases the high levels of removal (80-90%) observed in other contexts (Peterjohn and Correl, 1984; Haycock and Pinay, 1993) have been reached, but rather values of efficiency ranging between 30-60%. This may be due to the short monitoring period (1-2 years) and to the unusual weather conditions (high rainfall); in the same time the low maturity of the monitored buffer strips, in many cases they were converted just before the beginning of the experimental activity, may leaded to an underestimation of the

Table 4. Main hydrological items in the experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Firenze)	FAGNA-FT2 CREA-ABP (Firenze)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS AGRIC. (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
Subsurface flow discharge (100 m BS) (m^3 $year^{-1}$)	3152	8587	919	1004	4726
Subsurface flow discharge (100 m BS) (mm)	225	636	613	717	269
Rainfall (mm)	1264	1072	1385	1116	843
Subsurface flow discharge (% rain)	17.8	59.3	55.8	64	31.8

Table 5. Nitrogen balance in the different experimental sites.

Experimental site	FAGNA-FT1 CREA-ABP (Florence)	FAGNA-FT2 CREA-ABP (Florence)	DIANA-FT1 VENETO AGRIC.	DIANA-FT2 VENETO AGRIC.	TORMA- CREA-RPS (Roma)
Period	01/01/2013 31/12/2013	01/02/2013 31/01/2014	01/05/2013 30/04/2014	01/01/2013 31/12/2013	01/05/2013 30/04/2014
N_{inorg} applied (kg ha^{-1} $year^{-1}$)	72	120	250	170	96
IN N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	8.45±1.69	30.29±2.94	33.21±1.34	3.0±0.3	4.66±1.69
N_{inorg} to BZ by subsurface flow / N_{inorg} applied (%)	11.1	25.2	13.3	1.8	1.78
Out N_{inorg} sub-surface flow (kg ha^{-1} $year^{-1}$)	5.67±1.63	29.42±5.08	17.29±1.24	1.6±0.2	1.91±0.47
N_{inorg} removal by the BZ (kg ha^{-1} $year^{-1}$)	2.79	0.86	15.93	1.5	2.88
Efficiency (%)	33.0	2.9	48.0	48.6	61.9

Table 6. Judgment of efficiency in the different sites (base level).

Experimental site	Removal (%)	Judgment of indicator efficiency
FAGNA-FT1 CREA-ABP (Florence)	33	Medium
FAGNA-FT2 CREA-ABP (Florence)	2.9	Poor
BARONCINA CREA-FLP (Lodi)	0	Poor
DIANA-FT1 VENETO AGRIC.	48	Medium
DIANA-FT2 VENETO AGRIC.	48.6	Medium
TORMA- CREA-RPS (Rome)	62	High
CAMP7-CREA-SSC (Metaponto)	0	Poor

buffering capacity. This was confirmed by the low levels of organic matter available in the soils (values between 1.5 and 1.7%) as well. In this perspective, an increasing of the buffer capacity could be observed in a more advanced phase starting from the second or the third year after the conversion as observed in other studies (Gumiero *et al*., 2011; Anbumozhi *et al*., 2004; Uusi-Kämppä and Jauhiainen, 2010). During early stages, the influence of the hydrological factors appears to be prevalent instead of the type of vegetation. At the same time the river typology did not affect significantly the efficacy of the buffer zone, although it must be recognized to the past river dynamics a key role in determining the soil layers configuration and properties. This usually leads to observe more heterogeneous soil profiles in the riparian buffer adjacent to natural water bodies better than to artificial water bodies.

The infiltration capacity of water in soil with consequent development of sub-surface outflows was rather significant in all monitored systems (values ranging between 18 and 64% of total rainfall). This was recorded also in systems with high slopes (above 6%) and/or fine grain soil which should facilitate the development of surface runoff phenomena.

This was mainly due to the ploughing activities which, in addition to increase the water infiltration within the field crop, shaped a significant drop of soil surface between the field and the undisturbed buffer zone that could not be overcome by superficial runoff.

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