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Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards

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Abstract

When soil nitrate levels are inadequate, plants suffer nitrogen deficiency but when the levels are excessive, nitrates (NO_3-N) can pollute surface and subsurface waters. Strategies to reduce the nitrate pollution are necessary to reach a sustainable use of resources such as soil, water and plant. Buffer strips and cover crops can contribute to the management of soil nitrates, but little is known of their effectiveness in semiarid vineyards plantations. The experimental site, a 10 m wide and 80 m long area at the bottom of a vineyard was selected in Sicily. The soil between vine rows and upslope of the buffer strip (seeded with *Lolium perenne*) and non-buffer strips (control) was managed conventionally and with one of two cover crops (*Triticum durum* and *Vicia sativa* cover crop). Soil nitrate was measured monthly and nitrate movement was monitored by application of a ^{15}N tracer to a narrow strip between the bottom of vineyard and the buffer and non-buffer strips. *L. perenne* biomass yield in the buffer strips and its isotopic nitrogen content were monitored. *V. sativa* cover crop management contribute with an excess of nitrogen, and the soil management determined the nitrogen content at the buffer areas. A 6 m buffer strip reduce the nitrate by 42 % with and by 46 % with a 9 m buffer strip.

1 Introduction

Mediterranean agriculture soils are suffering from intense land degradation (Cerdà et al., 2010) due to the intensification of the agriculture practices. This intensification results in herbicides and pesticides abuse, which trigger a biological degradation of the soil (García Orenes et al., 2009), and increase in soil erosion (Cerdà et al., 2009a). The impact of new agriculture systems (highly mechanized, chemical farming and irrigated; see Cerda et al., 2009b) contribute to new environmental problems, and soil and water pollution is one of those (Semaan et al., 2007) due to the intensification of agriculture and the lack of new strategies to avoid these problems. A new generation of farmers applies new strategies to avoid those environmental problems. An example is the use of catch crops to maintain the soil fertility (Novara et al., 2011), or the use of geotextiles to reduce the soil losses (Giménez Morera et al., 2011).

Over the last decades in the semiarid Mediterranean environment, high external inputs of nitrate and irrigation in intensively managed agricultural systems have reduced surface and subsurface water quality (Butturini et al., 2003; Lassaletta et al., 2009). In particular, vineyard soils that are conventionally managed and frequently tilled, and thus frequently have bare soil, are prone to a high rate of organic matter mineralization and to nitrate leaching (Cerejeira et al., 2000). There are other crops in the Mediterranean that suffers similar problems such as the olive plantations (Gomez et al., 2009) under rainfed production; but also on drip irrigated land Cerdà et al. (2009) found an increase in soil erosion rated and soil degradation. However, and although vineyards are moving fast to drip irrigation and chemical fertilization, little research is being conducted to determine the environmental impacts of the land management change.

To reduce the loss of nitrate in soils and the pollution of ground and surface water, European directives have favored good agricultural practices, such as the reduction of mineral nitrogen fertilization or the establishment of vegetated buffer strips (Council Directive 91/676/EEC, 1991). Buffer strips are vegetated zone adjacent to agroforestry or crop fields that intercept and "treat" the water leaving the cropland (Dillaha et al., 1988; Dosskey, 2001). By filtering the runoff water and by taking up nutrients, buffer strips reduce the movement of sediment, nutrients, and pesticides from agricultural lands into the ecosystem (Borin et al., 2002, 2010; Patty et al., 1997; Popov et al., 2005; Rankins et al., 2001; Schmitt et al., 1999; Tingle et al., 1998). Buffer effectiveness depends on buffer characteristics such as surface hydraulic properties, vegetation species, soil type and slope morphology, and buffer width (Balestrini et al., 2011; Bharati et al., 2002; Dunn et al., 2011; Schmitt et al., 1999). Buffer strip efficacy is also affected by the agricultural system (land management and crop) and the management practices used in the buffered area.

Nitrate leaching can also be reduced by cover cropping, which reduces soil erosion, (Novara et al., 2011; Quinton and Catt, 2004) and increases organic matter, soil aggregation, water infiltration, and water-holding capacity (Kuo et al., 1997; Villamil et al., 2006). Although cover crops can decrease nitrate leaching (Ritter et al., 1998; Thomsen, 2005; Tonitto et al., 2006), leguminous cover crops can result in excess nitrate content in soil due to his capacity to fix nitrogen. This is a research field to be explored.

For vineyards, little information is available on how leguminous versus cereal cover crops affect the distribution and retention of soil nitrate during the year. That information is needed to avoid an excess or deficit in soil nitrate according to grapevine needs.

The goals of this study are to: (i) evaluate the spatial and temporal variation in soil nitrate content in a vineyard; (ii) compare the effects of alternative and conventional soil management on soil nitrate content; (iii) compare the effect of leguminous vs. cereal cover crops on soil nitrate dynamics over time; and (iv) evaluate the ability of buffer strips of different widths to retain nitrate.

2 Materials and method

The separated and combined effect of cover crop and buffer strip on nitrate dynamics in vineyard was evaluate in Agrigento province (37°35′12″ N–13°01′41″ E), Sicily (Italy). Soils around the study area (Fig. 1) are at high risk of nitrate contamination according to a "map of nitrate vulnerable zone in Sicily" (scale 1 : 250 000) developed by the Sicilian regional government (Regione Sicilia, Decreto D.D.G. n. 121, 2005). Farmers in this area apply conventional soil management, which increases the levels of soil nitrate in the groundwater. The nitrate content of the groundwater exceeds 50 $mg\,L^{-1}$, which is considered polluted (Nitrates Directive, 1991). During the period of observation (March 2006 to May 2009), the ground water nitrate concentration always exceeded 130 $mg\,L^{-1}$, with a maximum of 190 $mg\,L^{-1}$ in summer (Fig. 1).

The study was conducted in a vineyard that lies on a 260° slope with 7 % angle slope. The area has a typical Mediterranean climate with dry, hot summers and moist

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winters. The mean annual precipitation is 516 mm. Most rain falls in autumn and winter, and rainfall is highest in October (monthly mean rainfall of 81 mm) and lowest in July (monthly mean rainfall of 2 mm). On average, 3 % of the mean annual rainfall occurs during summer (June, July, and August) while 42 % occurs during winter (November, December, and January). The mean annual temperature is 18 °C; the hottest months are July and August (monthly means of about 25 °C), and the coldest months are January and February (monthly means of 11 °C). Soil in the experimental field was classified as a Hapli–Eutric Vertisol according to the Word Reference Base for Soil Resources (WRB, 2006) and contains 57.1 % clay, 34. % silt, and 8.9 % sand in the top soil (0–20 cm) based on the pipette method (Day, 1965).

The research was carried out in a non-irrigated 10 yr old vineyard of the Merlot variety. Vine plant density was 4500 plant ha^{-1}, rows were 80 m long with 2.2 m between rows. The experiment included three treatments in which the soil between the vine rows (along slope) was managed with *Triticum durum* L. cover crop (T), with a *Vicia sativa* L. cover crop (V), and by conventional tillage (C) in a randomized block design. The first block or replicate of the experiment is represented in Fig. 2. Within each block, each treatment was applied to six adjacent inter-rows, giving 18 adjacent inter-row per block. Cover crops were seeded in October 2006 and in October 2007 with specialized sodseeding equipment, and cover crop biomass was turned into the soil by rotary tillage in April 2007 and April 2008. For treatment C, the soil was ploughed 3–4 times per year (0.15 m deep, starting after the first rain in September) depending on weeds control needs and to aerate the topsoil. The vineyard was not fertilized.

At the bottom of the vineyard a 10 m wide, area was divided into buffer strips and nonbuffer, as shown in Fig. 2. The buffer strips were seeded with *Lolium perenne* (40 kg of seed per ha) in October 2005, one year before the beginning of experiment. The nonbuffer strips were managed by conventional tillage. The experiment had a total of three blocks.

The dynamics of N in the soil and vegetation of the buffer strip were monitored with nitrogen isotopes, which are stable and nonradioactive (Powlson and Barraclough, 1993). We used an ^{15}N enriched tracer, and the natural abundance background levels of ^{15}N was measured before the application. The tracer was sprayed onto the surface of a 1 m strip of soil that separated the buffer and nonbuffer strips from the rows treated with T, V, and C (Fig. 2) in the first week of February for both years (2007 and 2008). The tracer was an aqueous solution of ammonium sulphate (1.57 % ^{15}N atom) sprayed at 80 $kg\,ha^{-1}$.

Soil samples were collected once per month from January 2007 to June 2008 from the central inter-row of each treatment. Soil samples were taken at 0–20 cm depth along the slope at intervals of 20 m in the vineyard plot and at intervals of 3 m in the buffer zone; the samples within each plot were kept separate so that nitrate content along the slope could be quantified. The positions with respect to slope for both the treatment and strip plots are referred to as upper, middle, and lower. Aboveground biomass of *L. perenne* in the buffer strips was collected in April, May, and June of 2007 and 2008 for determination of yield and ^{15}N content. *V. sativa* and *T. durum* biomass were sampled in April of both years (before the cover crops were incorporated into the soil) by removing the aboveground biomass in three 1 m^2 areas per replicate; dry weight and N content were determined.

To monitor water and sediment yield, a 1 m wide Gerlach (Gerlach, 1967; Morgan, 1977) with a 40 L deposit was installed at the bottom buffer and non-buffer site. During the studying period no water runoff was recorded at the bottom of the plot in both treatments. The cover of *T. durum* and *V. sativa* and the tillage management enhanced the infiltration and, as a consequence, overland flow was negligible.

The NO_3-N content of the soil samples was determined by aqueous extraction with a Dionex D120 ion chromatograph. Soil and plant samples were subjected to isotopic analysis with an EA-IRMS (elemental analyser-isotopic ratio mass spectrometer). An automatic sampler was used, and the samples were combusted in the presence of oxygen at 1050 °C.

Isotopic levels for the soils and plants are reported as atom % ^{15}N excess (IE), which refers to the amount of ^{15}N present relative to the average naturally occur-

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ring background ^{15}N levels occuring in the biomass and the soil under the specific experimental conditions. Background levels are based on pre-application samples. Where possible, atom % ^{15}N excess amounts were extrapolated to get the total amount of ^{15}N in a given pool by weight and thus to determine a ^{15}N budget (Bedard-Haughn and van Kessel, 2004).

The international standard for N is atmospheric nitrogen (Mariotti, 1983, 1984), for which the $^{15}N/^{14}N$ ratio is 0.003676. The international reference materials IAEA-N1 ($\delta^{15}N$=0.03‰), IAEA-N2 ($\delta^{15}N$=20.1‰) and IAEA-N3 ($\delta^{15}N$=4.5‰) were used for calibration and normalization following the study of Bohlke et al. (2003). Analytical precision is about 0.2‰.

A linear mixed effects model (SAS, 2002) and repeated ANOVAs were used to evaluate the fixed effects and temporal effects of soil management (treatments T, V, or C) on the quantity of ^{15}N detected in buffer strips and nonbuffer strips below the treatment plot. Statistical analysis was carried out separately for the managed area and the buffer strip/nonbuffer strip area. A split plot design with three replications was used in which management was the main plot and elevations (position on slope, i.e. upper, middle, and lower) were subplots. Nitrate content was also compared between buffer strips and nonbuffer strips using repeated measure ANOVA carried out according the used experimental design.

3 Results and discussion

3.1 Soil nitrate content in the vineyard

The nitrate content was 12.4% greater in treatment V vs. C but only 1.71% greater in treatment T vs. C. These significant differences (Table 1) can be explained by the ability of the legume, *V. sativa*, to fix N and by the high N content of the legume tissue. Before the cover crops were incorporated into the soil, the aboveground dry biomass

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was $11 \pm 1.2\,\mathrm{Mg\,ha^{-1}}$ (with 2.8 % N content) for treatment V and $8.33 \pm 2.1\,\mathrm{Mg\,ha^{-1}}$ (with 1.3 % N content) for treatment T.

Our results are in agreement with those of several other studies showing that cover crops increase soil N content and soil organic matter (SOM) content (Jackson et al., 2004; Sainju et al., 2000; Ramos et al., 2010). At the Agrigento experimental site, the catch crops were plough and then, the soil increased in organic matter. The potential to immobilize and retain soil N increases with SOM content (Barretta and Burke, 2000). Continuous tillage under conventional management, in contrast, causes bare soil (weed free) and an increased N loss due to leaching, short term bursts of mineralization of organic N substrates, and nitrous dioxide efflux (Grandy and Robertson, 2006). Consequently, soil nitrate content was lower in the conventionally managed plots than in the plots with catch crops.

Soil nitrate content changed during the year, apparently because of precipitation, mineralization, uptake by vines and uptake by the cover crops. Cover crops have direct and indirect effects on soil fertility and vine nutrition. Incorporation of leguminous catch crops directly adds organic nitrogen to the soil (Nakhone and Tabatabai, 2008). After mineralization, which begins within weeks after incorporation, this nitrogen is available for vine uptake (Rupp, 1996). In contrast, nonleguminous cover crops often result in the depletion of the vineyard nitrogen pool (Celette et al., 2009). The interactions between cover crop, soil fertility, and vine growth are complex and dynamic. Measuring and predicting changes in soil nutrient status can be far more difficult in cover-cropped vineyards than in vineyards managed with chemical fertilizers alone, as the farmer controls the source of nitrogen.

Soil nitrate values, which were lowest in spring and highest in late summer or autumn (Fig. 3), ranged from 1.45 to $26.56\,\mathrm{mg\,L^{-1}}$ under conventional tillage, from 1.71 to $28.14\,\mathrm{mg\,L^{-1}}$ under the *V. sativa* cover crop, and from 1.87 to $19.71\,\mathrm{mg\,L^{-1}}$ under the *T. durum* cover crop.

The strong decrease of nitrate from winter to early spring can mainly be attributed to leaching in response to precipitation under conventional tillage (Davidson, 1992) and to plant uptake of N in the cover crop treatments (Steenwerth and Belina, 2008). In summer, the high increase in nitrate under the *V. sativa* cover crop and with conventional tillage might be explained by rapid mineralization of organic matter. The peak in soil nitrate was lower with the *T. durum* treatment than with the other two treatments, probably because of the relatively high carbon to nitrogen ratio and lignin content of *T. durum*, which would reduce its rate of mineralization when it was incorporated into the soil.

Seasonal soil nitrate contents were similar ($P > 0.05$, when the data were analysed by season) for the first vs. the second year of sampling in the conventionally managed plots and in the *V. sativa* plots. However, the values were higher in the second year in the *T. durum* plots. The latter difference is consistent with previous reports that N can be immobilized following the planting of some cereal cover crops (Fageria et al., 2005).

In all treatments, soil nitrate content increased down the slope. The soil nitrate content in the middle and lower tram of the slope increased by 48 and 112 % in the *V. sativa* plots, by 47 and 123 % in the *T. durum* plots, and by 37 and 94 % in the conventionally managed plots. This data demonstrate the leaching of nitrates by the surface wash and subsurface wash, and confirm that the bottom slope buffer strips of the slope can be a good strategy to avoid the pollution with nitrates.

3.2 Soil nitrate in the buffer and nonbuffer strips

Soil nitrate content was higher in the nonbuffer strips (without *L. perenne*) than in the buffer strips (with *L. perenne*) and was higher in late summer and autumn than in spring (Fig. 3). Soil nitrate content ranged from 2.26 to 12.5 $mg L^{-1}$ in buffer strips and from 1.5 to 30.5 $mg L^{-1}$ in the nonbuffer strip (Fig. 3). This result is consistent with the idea that a buffer strip can capture excess nitrate during the whole year around and retain nitrate in soil during the rainiest periods and thereby reduce leaching (Leeds-Harrison et al., 1999). Note that large quantity of nitrate that accumulated during summer (a period with low precipitation) in the nonbuffer strips was completely lost by the end of winter in both years of observation due to runoff and leaching.

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Soil nitrate content was 25 % and 35 % higher in the middle and lower slope positions than in the upper slope position. In the buffer strips, however, nitrate content was only 12 % and 14 % higher in the middle and lower positions than in the upper position. These results agree with other research concerning N removal as a function of buffer width (Bedard-Haughn et al., 2005; Dillaha et al., 1989). Statistical analysis showed differences only between upper and middle position and between the upper and lowest position of the strips.

Soil nitrate content in buffer (Table 1) and nonbuffer strips was significantly affected by vineyard soil management (treatments V, T, and C). In the nonbuffer strip, differences were significant only during summer, when soil nitrate content was highest with treatment V, lowest with treatment C, and intermediate with treatment T. In the buffer strips, soil nitrate over all sampling times tended to be highest with treatment C (8.1 $mg L^{-1}$), followed by treatment T (6.1 $mg L^{-1}$), and treatment V (5.7 $mg L^{-1}$). These differences are consistent with the effects of vineyard soil management on losses of nitrate by subsurface water flow.

3.3 ^{15}N tracer in biomass

The mean dry biomass of *L. perenne* in the buffer strips was unaffected by soil management treatments and averaged 4.14 ± 0.85 $Mg ha^{-1}$. The ^{15}N uptake by *L. perenne* tended to decrease with distance from the narrow strip where ^{15}N was applied, and was significantly greater at 3 m downslope than at 6 or 9 m downslope but did not differ between 6 and 9 m downslope (Fig. 4). The *L. perenne* located 6 m and 9 m from the application zone contained 72 and 76 % less isotopic excess, respectively, than the *L. perenne* located only 3 m from the application zone. Values of isotopic excess ranged from 0.01 ± 0.038 ‰ to 0.0018 ± 0.0007 ‰ after the first application and from 0.0329 ± 0.011 ‰ to 0.0019 ± 0.0006 ‰ after the second application of ^{15}N tracer (Fig. 4).

The ^{15}N excess decreased over time after each application (Fig. 4), indicating dilution of the ^{15}N signature caused by uptake of non-enriched N (Bedard-Haughn et al., 2004).

3.4 ^{15}N tracer in soil

^{15}N isotopic excess in the soil was significantly higher in the nonbuffer strips than in the buffer strips (Fig. 5). In the buffer strip soil, atom % ^{15}N excess ranged from 0.0028 ± 0.0011‰ to 0.0042 ± 0.0013‰ after the first application, and from 0.0026 ± 0.0002‰ to 0.0074 ± 0.0017‰ after the second application of ^{15}N tracer (Fig. 5). Averaged over time and location in the strip, values were 15 % higher in the nonbuffer strips than in the buffer strips.

With respect to ^{15}N tracer in soil, the interaction between treatment (buffer strip vs. nonbuffer strip) and position in the strip (upper, middle, and lower) was statistically significant ($P < 0.05$). Relative to the content of ^{15}N tracer in the buffer strip soil at 3 m from the application site, the content was 42 % and 46 % lower at 6 m and 9 m, respectively, from the application zone (Fig. 5). In contrast, the content of ^{15}N tracer in the nonbuffer strip increased with distance down the slope from the application site. Relative to the content of ^{15}N tracer in the nonbuffer strip soil at 3 m from the application site, the content in the buffer strip was 4 and 91 % higher at 6 m and 9 m, respectively, from the application zone (Fig. 5).

3.5 Implications

Vineyard plantations in the Mediterranean region must be managed with a cover crop and a vegetative buffer strip in order to avoid nitrates pollution in soils and water. Relative to conventional tillage, a cover crop provides a better distribution of soil nitrogen in time and space with respect to grapevine growth requirements, while the vegetative buffer strip captures the excess nitrate and thereby reduces pollution of surface and ground water by nitrate. Soil nitrate content was lower with conventional tillage (108 kg ha^{-1}) than with the cover crops (110 kg ha^{-1} for *T. durum* and 122 kg ha^{-1} for *V. sativa*), with a peak during the hottest period of the year (August). This temporal distribution of soil nitrate does not fit to grapevine nutrients needs and as a consequence there is a nutrient deficit during the growing period and an excess in summer until the

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first rain in autumn, when nitrate are leached and eroded by the surface wash. Soil under conventional tillage is unable to retain nitrate, and then, N fertilization is applied. This will increase the N wash.

In the Mediterranean area, soil management with a cover crop in the winter reduces the soil, water and nitrates losses. This research demonstrates that cover or catch crops contribute to the nitrogen fixation (*V. sativa*). Because of biological fixation of N, leguminous cover crops provide a net N input to vineyards (King and Berry, 2005; Drinkwater et al., 1998).

Although cover crops therefore are a valuable alternative to chemical fertilizers in vineyards, it is important to evaluate not only the amount of N added to the system but also the N availability during the year. In our case, the *V. sativa* cover crop experienced a high mineralization rate in summer, when grapevines cannot utilize nitrate. Because it contributes less nitrogen and has a higher C : N ratio, the *T. durum* cover crop may result in less pollution and greater retention of N than either the *V. sativa* cover crop or the conventional soil management system.

The high nitrate content at the edge of vineyard is likely to move into water supplies unless captured by a buffer strip. Buffer effectiveness in reducing nitrate loss was demonstrated by the use of a ^{15}N tracer. Most of the applied ^{15}N tracer was found in the biomass of *L. perenne* in the first 3 m of the buffer strip, indicating that the ^{15}N tracer in soil decreased down the slope of the buffer strips. Although nitrate decrease varied with buffer width, we considered a 6 m buffer strip sufficient to control nitrate pollution in vineyards, like the most of Sicilian vineyards, with a slope of about 7 %.

4 Conclusions

Cover crops in vineyard under Mediterranean climatic conditions inter-row reduce water runoff and act as catch crop regulating nitrate availability during the year. Thanks to catch crop, farmers can manage the N content and its distribution into the soil over the year. In this way, vineyard managers can reduce fertilizer wastage and reduce N pollution of surface and ground water. The main contribution of this research is that nitrate losses can be managed in vineyards successfully by the use of appropriate soil conservation practices and by installation of buffer strips.

References

Balestrini, R., Arese, C., Del Conte, C. A., Lotti, A., and Salerno, F.: Nitrogen removal in subsurface water by narrow buffer strips in the intensive farming landscape of the Po River 20 watershed, Italy, Ecol. Eng., 6, 148–157, 2011.

Barretta, J. E. and Burke, I. C.:. Potential nitrogen immobilization in grassland soils across a soil organic matter gradient, Soil Biol. Biochem., 32, 1707–1716, 2000.

Bedard-Haughn, A., Tate, K. W., and van Kessel, C.: Using nitrogen-15 to quantify vegetative buffer effectiveness for sequestering nitrogen in runoff, J. Environ. Qual. 33, 2252–2262, 2004.

Bedard-Haughn, A., Tate, K. W., and van Kessel, C.: Quantifying the impact of regular cutting on vegetative buffer efficacy for nitrogen-15 sequestration, J. Environ. Qual., 34, 1651–1664, doi:10.2134/jeq2005.0033, 2005.

Bharati, L., Lee, K. H., Isenhart, T. M., and Schultz, R. C.: Soil water infiltration under crops, pasture, and established riparian buffer in Midwestern USA, Agroforest. Syst., 56, 249–257, 2002.

Bohlke, J. K., Mroczkoski, S. J., and Coplen, T. B.: Oxygen isotopes in nitrate: new reference materials for $^{18}O:^{17}O:^{16}O$ measurements and observations on nitrate–water equilibration, Rapid Commun. Mass Sp., 17, 1835–1846, 2003.

Borin, M. and Bigon, E.: Abatement of NO_3-N concentration in agricultural waters by narrow buffer strips, Environ. Pollut, 117, 165–168, 2002.

Borin, M., Passoni, M., Thiene, M., and Tempesta, T.: Multiple functions of buffer strips in farming areas, Eur. J. Agronomy, 32, 103–111, 2010.

Butturini, A., Bernal, S., Hellin, C., Nin, E., Rivero, L., Sabater, S., and Sabater, F.: Influences of the stream groundwater hydrology on nitrate concentration in unsaturated riparian area bounded by an intermittent Mediterranean stream, Water Resour. Res., 39, 1–13, 2003.

Celette, F., Findeling, A., and Gary, C.: Competition for nitrogen in an unfertilized intercropping system: the case of an association of grapevine and grass cover in a Mediterranean climate, Eur. J. Agronomy, 30, 41–51, 2009.
Cerdà, A., Flanagan, D. C., le Bissonnais, Y., and Boardman, J.: Soil erosion and agriculture, Soil Tillage Res., 106, 107–108, doi:10.1016/j.still.2009.10.006, 2009a.
Cerdà, A., Giménez-Morera, A., and Bodí, M. B.:. Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean Basin, Earth Surf. Proc. Land., 34, 1822–1830, doi:10.1002/esp.1889, 2009b.
Cerdà, A., Lavee, H., Romero-Díaz, A., Hooke, J., and Montanarella, L.: Soil erosion and degradation in mediterranean type ecosystems, Land Degrad. Dev., 21, 71–74, doi:10.1002/ldr.968, 2010.
Cerejeira, M. J., Silva, E., Batista, S., Trancoso, A., Centeno, M. S. L., and Silva Fernandes, A.: Simazine, metribuzine and nitrates in ground water of agricultural areas of Portugal, Toxicol. Environ. Chem., 75, 245–253, 2000.
Council Directive 91/676/EEC: available at: http://ec.europa.eu/environment/water/water-nitrates/directiv.html, 1991.
Davidson, E. A.: Sources of nitric oxide and nitrous oxide following wetting of dry soil, Soil Sci. Soc. Am. J., 56, 95–102, 1992.
Day, P. R.: Particle fractionation and particle-size analysis, in: Methods of Soil Analysis, Part 1, edited by: Black, C. A., American Society of Agronomy, Inc., Madison, WI, 545–567, 1965.
Dillaha, T. A., Sherrard, J. H., Lee, D., Mostaghimi, S., and Shanholtz, V. O.: Evaluation of vegetative filter strips as a best management practice for feed lots, J. Water Pollut. Control Fed., 60, 1231–1238, 1988.
Dillaha, T. A., Reneau, R. B., Mostaghimi, S., and Lee, D.: Vegetative filter strips for agricultural non point source pollution control, Trans. ASAE, 32, 513–519, 1989.
Dosskey, M. G.: Toward quantifying water pollution in response to installing buffers on crop land, Environ. Manage., 28, 577–598, 2001.
Drinkwater, L., Wagoner, P., and Sarrantonio, M.: Legume based cropping systems have reduced carbon and nitrogen losses, Nature, 396, 262–265, 1998.
Dunn, A. M., Julien, G., Ernst, W. R., Cook, A., Doe, K. G., and Jackman, P. M.: Evaluation of buffer zone effectiveness in mitigating the risks associated with agricultural runoff in Prince Edward Island, Sci. Total Environ., 409, 868–882, 2011.

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Fageria, N. K., Baligar, V. C., and Bailey, B. A.: Role of cover crops in improving soil and row crop productivity, Commun. Soil Sci. Plann., 36, 2733–2757, doi:10.1080/00103620500303939, 2005.

García-Orenes, F., Cerdà, A., Mataix-Solera, J., Guerrero, C., Bodí, M. B., Arcenegui, V., Zornoza, R., and Sempere, J. G.: Effects of agricultural management on surface soil properties and soil-water losses in eastern Spain, Soil Tillage Res., 109, 110–115, doi:10.1016/j.still.2009.06.002, 2009.

Gerlach, T.: Hillslope troughs for measuring sediment movement, Rev. Geom. Dyn., 4, 173–175, 1967.

Giménez-Morera, A., Ruiz Sinoga, J. D., and Cerdà, A.: The impact of cotton geotextiles on soil and water losses in Mediterranean rainfed agricultural land, Land Degrad. Dev., 21, 210–217, doi:10.1002/ldr.971, 2010.

Grandy, A. S. and Robertson, G. P.: Initial cultivation of a temperate-region soil immediately accelerates aggregate turnover and CO_2 and N_2O fluxes, Glob. Change Biol., 12, 1507–1520, 2006.

Jackson, L. E., Ramirez, I., Yokota, R., Fennimore, S. A., Koike, S. T., Henderson, D. M., Chaney, W. E., Calderon, F. J., and Klonsky, K.: On-farm assessment of organic matter and tillage management on vegetable yield, soil, weeds, pests, and economics in California, Agr. Ecosyst. Environ., 103, 443–463, 2004.

King, A. P. and Berry, A. M.: Vineyard $\delta^{15}N$, nitrogen and water status in perennial clover and bunch grass cover crop systems of California's central valley, Agr. Ecosyst. Environ., 109, 262–272, 2005.

Kuo, S., Sainju, U. M., and Jellum, E. J.: Winter cover crop effects on soil organic carbon and carbohydrate in soil, Soil Sci. Soc. Am. J., 61, 145–152, 1997.

Lassaletta, L., García-Gómez, H., Gimeno, B. S., and Rovira, J. V.: Agriculture-induced increase in nitrate concentrations in stream waters of a large Mediterranean catchment over 25 yr (1981–2005), Sci. Total Environ., 407, 6034–6043, doi:10.1016/j.scitotenv.2009.08.002, 2009.

Leeds-Harrison, P. B., Quinton, J. N., Walker, M. J., Sanders, C. L., and Harrod, T.: Grassed buffer strips for the control of nitrate leaching to surface waters in headwater catchments, Ecol. Eng., 3, 299–313, 1999.

Mariotti, A.: Atmospheric nitrogen is a reliable standard for natural ^{15}N abundance measurements, Nature, 303, 685–687, 1983.

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Mariotti, A.: Natural ^{15}N abundance measurements and atmospheric nitrogen standard calibration, Nature, 311, 251–252, 1984.
Morgan, R. P. C.: Soil Erosion and Conservation, 3rd edn., Blackwell, Oxford, 2005.
Nakhone, L. N. and Tabatabai, M. A.: Nitrogen mineralization of leguminous crops in soils, J. Plant Nutr. Soil Sc., 171, 231–241, 2008.
Novara, A., Gristina, L., Saladino, S. S., Santoro, A., and Cerdà, A.: Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard, Soil Tillage Res., 117, 140–147, 2011.
Patty, L., Réal, B., and Gril, J.: The use of grassed buffer strips to remove pesticides, nitrate and soluble phosphorus compounds from runoff water, Pestic. Sci., 49, 243–251, 1997.
Popov, V. H., Cornish, P. S., and Sun, H.: Vegetative biofilters: the relative importance of infiltration and adsorption in reducing loads of water-soluble herbicides in agricultural runoff, Agr. Ecosyst. Environ., 114, 351–359, 2005.
Powlson, D. S. and Barraclough, D.: Mineralization and assimilation in soil-plant systems, in: Nitrogen Isotope Techniques, edited by: Blackburn, T. H., Academic Press, New York, 209–239, 1993.
Quinton, J. N. and Catt, J. A.: The effects of minimal tillage and contour cultivation on surface runoff, soil loss and crop yield in the long-term Woburn Erosion Reference Experiment on sandy soil at Woburn, England, Soil Use Manage., 20, 343–349, doi:10.1111/j.1475-2743.2004.tb00379.x, 2004.
Ramos, M. E., Benítez, E., García, P. A., and Robles, A. R.: Cover crops under different managements vs. frequent tillage in almond orchards in semiarid conditions: effects on soil quality, Appl. Soil Ecol., 44, 6–14, 2010.
Rankins, J. A., Shaw, D. R., and Boyette, M.: Perennial grass filter strips for reducing herbicide losses in runoff, Weed Sci., 49, 647–651, 2011.
Regione Sicilia: Decreto D. D. G. n. 121, available at: http://www.regione.sicilia.it/Agricolturaeforeste/Assessorato/CartaNitratiHome.htm, 2005.
Ritter, W. F., Scarborough, R. W., and Chirnside, A. E. M.: Winter cover crops as a best management practice for reducing nitrogen leaching, J. Contam. Hydrol., 34, 1–15, 1998.
Rupp, D.: Green cover management to optimize the nitrogen supply of grapevines, in: Proc. Workshop Strategies to Optimize Wine Grape Quality, Acta Hort., 427, 57–62, 1996.

Sainju, U. M., Singh, B. P., and Whitehead, W. F.: Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA, Soil Tillage Res., 63, 167–179, 2002.

SAS Institute: The SAS System for Microsoft Windows, Release 8.2., SAS Institute, Cary, NC, 2002.

Schmitt, T. J., Dosskey, M. G., and Hoagland, K. D.: Filter strip performance and processes for different vegetation, widths, and contaminants, J. Environ. Qual., 28, 1479–1489, earch1999.

Semaan, J., Flichman, G., Scardigno, A., and Steduto, P.: Analysis of nitrate pollution control policies in the irrigated agriculture of Apulia region (southern Italy): a bio-economic modelling approach, Agr. Syst., 92, 357–367, doi:10.1016/j.agsy.2006.10.003, 2007.

Steenwerth, K. L. and Belina, K. M.: Cover crops and cultivation: impacts on soil N dynamics, nitrous oxide efflux, and microbiological function in a Mediterranean vineyard agroecosystem, Appl. Soil Ecol., 40, 370–380, 2008.

Thomsen, I. K.: Nitrate leaching during under spring barley is influences by the presence of a ryegrass catch crop: results from a lysimeter experiment, Agr. Ecosyst. Environ., 11, 21–29, 2005.

Tingle, C. H., Shaw, D. R., Boyette, M., and Murphy, G. P.: Metolachlor and metribuzin losses in runoff as affected by width of vegetative filter strips, Weed Sci., 46, 475–479, 1998.

Tonitto, C., David, M. B., and Drinkwater, L. E.: Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: a meta-analysis of crop yield and N dynamics, Agr. Ecosyst. Environ., 112, 58–72, 2006.

Villamil, M. B., Bollero, G. A., Darmody, R. G., Simmons, F. W., and Bullock, D. G.: No till corn/soybean systems including winter cover crops: effects on soil properties, Soil Sci. Soc. Am. J., 70, 1936–1944, 2006.

World Reference Base for Soil Resources: A framework for international classification, correlation and communication, Rome, Italy, 128 pp., 2006.

Table 1. Results of the Anova test for NO_3-N in vineyard and buffer zone.

	DF	Vineyard	Buffer
Soil Management (*M*)	2	< 0.0001	< 0.0001
Altitude (*A*)	2	0.0307	0.0302
$M \times A$	4	0.9221	0.5857
Time (*T*)	17	< 0.0001	< 0.0001
$M \times T$	34	< 0.0001	0.2378

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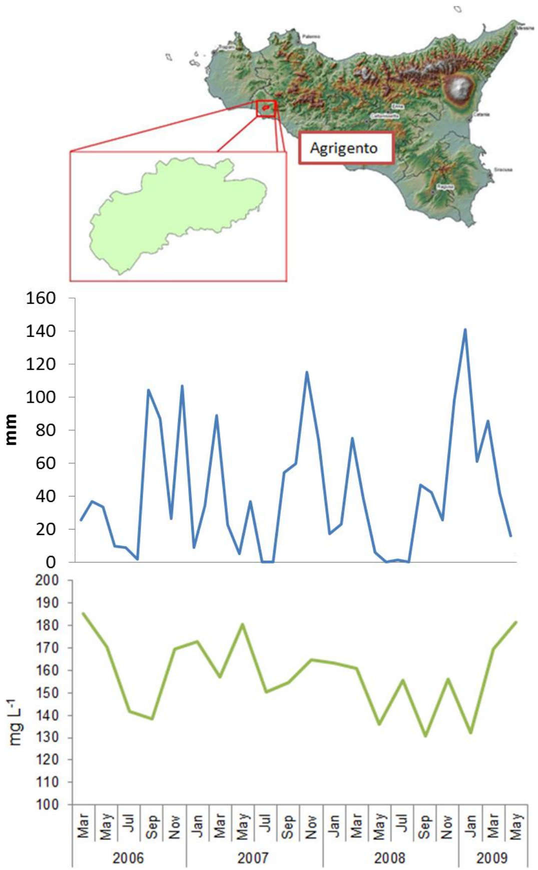

Fig. 1. Study area (top), monthly rainfall (red bars) and average groundwater nitrate concentration from 2006 to 2008 (green line).

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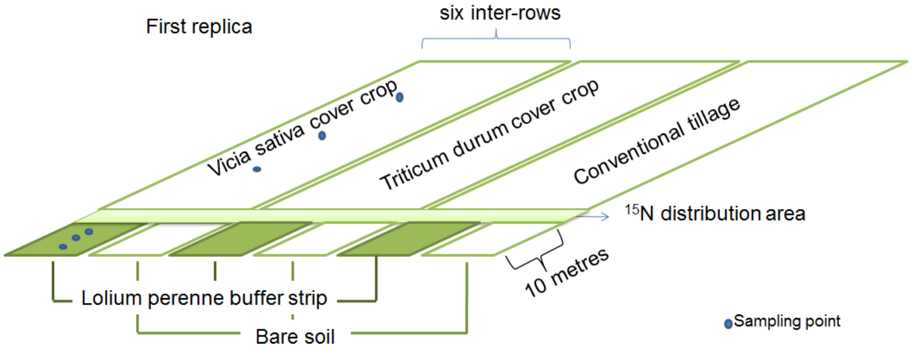

Fig. 2. Experimental design.

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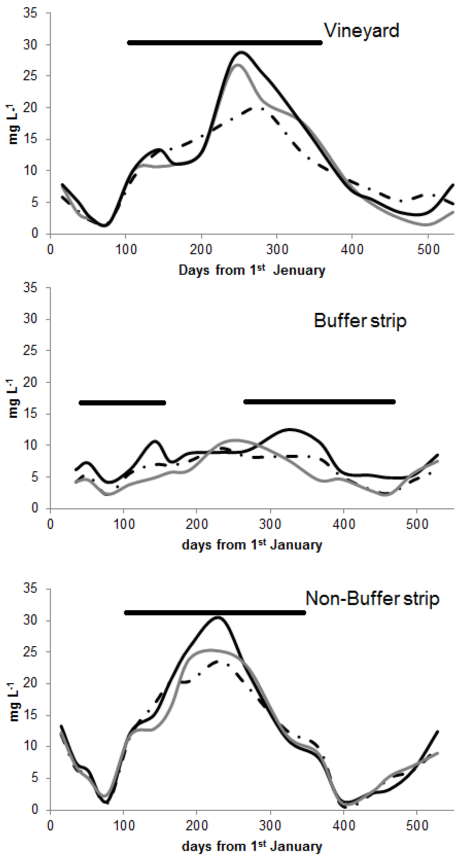

Fig. 3. Soil nitrate content in vineyard plot (average of upper, middle and lower position), buffer strips and nonbuffer strips below the *V. sativa* cover crop (black line), the *Triticum durum* cover crop (grey line), and conventional tillage (broken line). Horizontal lines represent statistical difference according to repeated measure statistical analysis.

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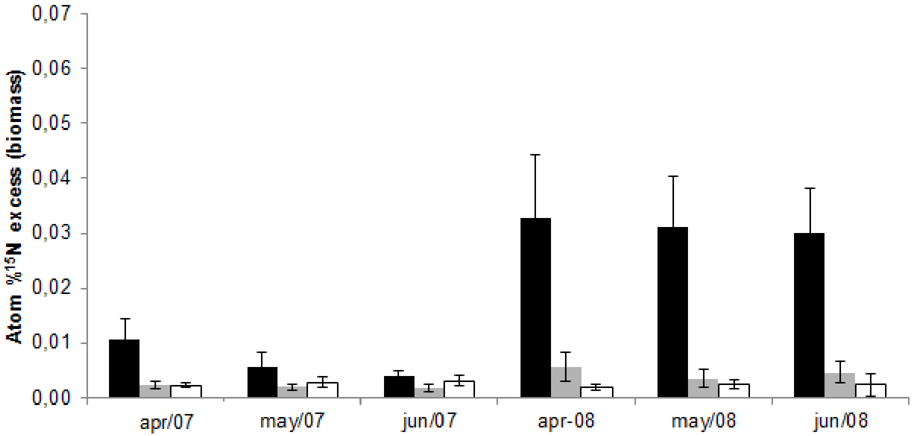

Fig. 4. Atom % ^{15}N excess in *Lolium perenne* in the buffer strips vs. the time. Black, grey, and white histograms represent 3, 6, and 9 m distances, respectively, from the ^{15}N application zone.

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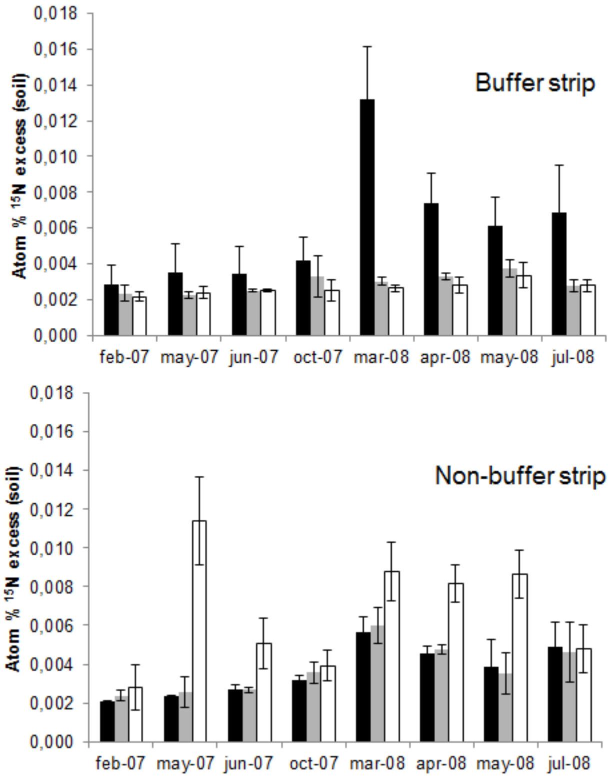

Fig. 5. Atom % ^{15}N excess in soil over the time in the buffer strips and nonbuffer strips. Black, grey, and white histograms represent 3, 6, and 9 m distances, respectively, from the ^{15}N application zone.

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