Grassed buffer strips as nitrate diffuse pollution remediation tools: management impact on the denitrification enzyme activity

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M. Cors and B. Tychon

Département des Sciences et Gestion de l'environnement, Université de Liège, Avenue de Longwy, 185 B-6700 Arlon, Belgium (E-mail: *marie.cors@ulg.ac.be*)

Abstract The management of grassed buffer strips proved to be an efficient remediation technique in controlling nitrogen losses to surface water. In south Belgium, agri-environmental policies have encouraged farmers to seed buffer strips along rivers, in zones where the soil was previously devoted to agricultural production.

We wanted to assess how important denitrification is in a buffer strip in comparison with a cropped field. The study investigated the denitrifiying enzyme activity (DEA) of two contiguous buffer strips with different management stories. The eastern part of the buffer strip was seeded in 1999. The western part of the buffer strip is a piece of crop field abandoned by the farmer 20 years ago and not managed for the last 10 years.

This experimental study demonstrates that the denitrification enzyme activity in a riparian buffer strip is significantly higher than in the adjacent cropped field (3.67 and 2.12 $mgNkg^{-1}d^{-1}$ respectively). The DEA was significantly different between the two buffer strips under comparison, assessing that the management of the buffer strips has a dominant effect on DEA. The old unmown buffer strip is potentially more efficient in the nitrate removal process than the 6-year-old seeded buffer strip.

Keywords Denitrifying enzyme activity; riparian grass buffer strip

Introduction

In the Walloon Region (Belgium), a best management practices programme was started in 1999 to cope with diffuse pollution caused by agricultural nutrient runoff. The programme is based on volunteer participation, together with some financial supports. The management of grassed buffer strips proved to be an efficient remediation technique in controlling nutrients and pesticides losses to surface waters (Correll, 1996; Martino, 2001; Campbell *et al.*, 2004; Puckett, 2004). Farmers were therefore encouraged to seed buffer strips along rivers and ridges, in zones where the soil was previously devoted to agricultural production.

But two questions arise: (1) what is the nitrate removal efficiency due to the denitrification process and hence, is this removal efficiency improved by creating a buffer strip, in comparison to what occurs in the cropped field; (2) is there any difference between the denitrification potential of a newly established buffer strip, which is subject to restricted management options, and of a piece of fallow land?

To answer these questions, our study focuses on a site made of a cropped field separated from a brooklet by a grassed buffer strip. The eastern part of the buffer strip was seeded in 1999. The western part of the buffer strip is a piece of crop field abandoned by the farmer 20 years ago and not managed for the last 10 years.

Nitrate concentrations were measured in the river as well as in porous cup samples from the unsaturated soil zone. We measured the denitrification enzyme activity (DEA) to assess the importance of the denitrification in the buffer strip compared to the cropped field.

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Material and methods

Experimental site

The experimental site is along a tributary of the Attert River (Southern Belgium). The study site (Figure 1) is composed of: a cropped field, a 6-year-old seeded buffer strip (eastern part of the buffer zone, "MAN"), and a 20-year-old unmanaged buffer strip (western part, "NOT").

The field is cropped with a rotation of maize and wheat. The buffer strip is 11 m wide. MAN was seeded with a mix of *Lolium perenne*, *Phleum pratense* and *Trifolium pratense*. It is mown once a year and receives no fertiliser. NOT is located between the crop field and the river, just upstream of the managed buffer strip. It has neither been seeded nor fertilised for the last 20 years and was not mown for the past 10 years. It is mainly covered by *Urtica dioica* and *Filipendula ulmaria*. *Polygonum bistorta* is also present. Soil is a sandy silt to clayey sandy silt. Soil characteristics and N fertilisation are described in Cors and Tychon (2003).

Soil sampling and nitrate analysis

Each sampling point is equipped with a ceramic porous cup sampler (SDEC), collecting soil solution from the unsaturated soil, at a depth of 15 cm. Nitrate content was determined weekly from 2001 to 2004 when water was available in the porous cup samplers. Nitrate was analysed by the sulfanilamid method with a spectrophotometer under continuous flow (San +, Skalar).

Soil sampling dedicated to achieve DEA measurements was carried out 9 times in spring and summer 2004. Topsoil (0–20 cm) was collected with an auger (Edelman type, Eijkelkamp) at each sampling point (Figure 1). Additional triplicate sub-sampling was achieved in the buffer strips. When not specified, results for the buffer strip include both NOT and MAN areas. Fresh soil was sieved through a 6.7 mm mesh and homogenised by hand.

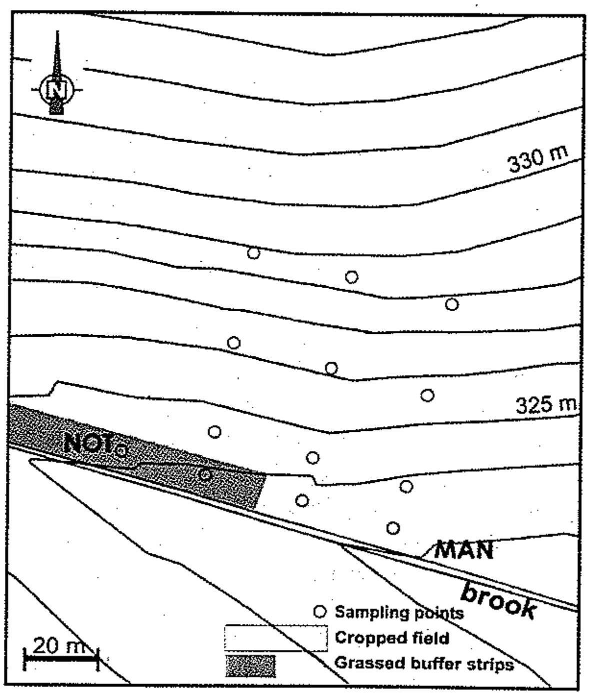

Figure 1 Experimental site: localisation of the cropped field, the 20-year-old unmanaged buffer strip (NOT) and the managed buffer strip (MAN)

Oxidizable organic carbon was analysed on air-dried soil samples by dichromate reduction.

DEA

As Simek and Webster (2000) showed that storage at 4°C led to a reduction in DEA, the storage of soil samples was avoided and an immediate analysis occurred most of the time. Nitrous oxide emissions rates were measured according to the DEA method (Tiedje, 1994). Slurries of the samples are prepared in a silicone-capped glass bottle which allows gas tight syringe sampling (500 μl) of the headspace. 20 ml of a 0.1 gl^{-1} chloramphenicol, 0.3 gl^{-1} glucose and 0.05 gl^{-1} KNO_3 solution is added to 25 g fresh soil to inhibit de novo synthesis of enzyme, and to ensure that the denitrification reaction will not lack carbon or nitrate (Murray and Knowles, 1999).

Anaerobic condition is imposed by a 10 minute N_2 flush. Following the acetylene inhibition technique, 1–10% volume of acetylene is added to block the transformation of N_2O to N_2. A one-way vent ensures pressure balance with local atmospheric pressure. Soil slurries were continually agitated on an orbital shaker. Analysis of N_2O is performed on a gas chromatograph (HP6890) equipped with an electron capture detector (ECD) and a Poraplot Q column (25 m, 0.32 inner diameter; Varian Inc.) with He as carrier gas. N_2O content of each bottle is analysed every 15 minutes, for 90 minutes. N_2O production was adjusted for N_2O dissolved in the solution using a Bunsen absorption coefficient of 0.544 (Tiedje, 1994). The production rate of N_2O was calculated on the basis of the linear regression slope of the evolution of N_2O concentration vs. time. All results are expressed on a dry weight basis.

Results and discussion

Efficiency in protecting surface waters from agricultural nitrate runoff

Nitrate concentrations in the cropped field ground water ranged from 0 to 118 $mgNl^{-1}$. The highest concentrations form summer peaks, clearly identified in 2001 and 2004 (Figure 2),

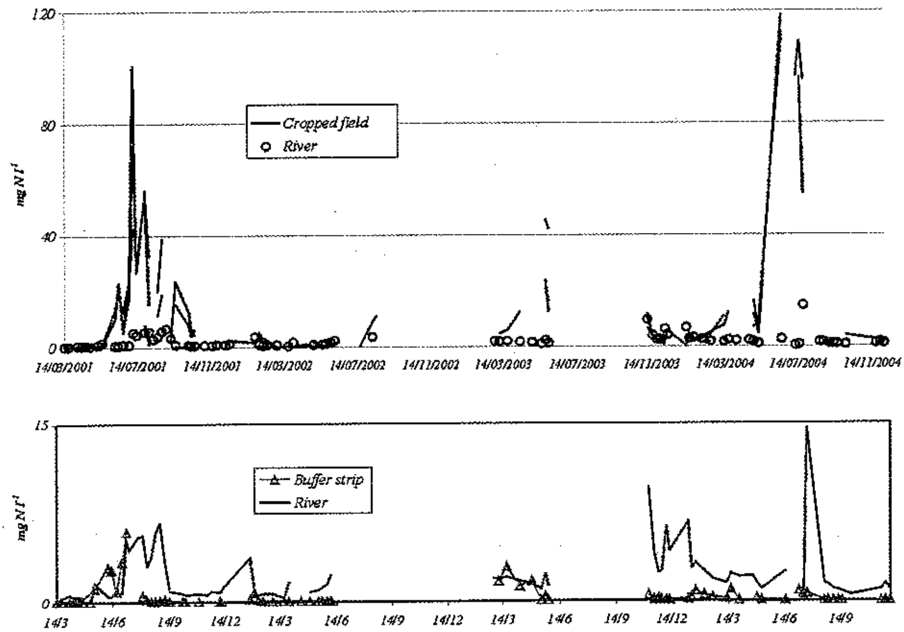

Figure 2 Evolution of nitrate concentrations in the river and in the porous cup samplers located in the cropped field. The lower part of the graph shows a detailed comparison of the concentrations in the buffer strip and in the river

when maize was cropped. The buffer strip shows much weaker nitrate concentrations: they range from 0 to 5.9 mgNl^{-1}. From these observations, we can conclude that without buffer strip nitrate concentrations as high as 8 times the standards would reach the river. When comparing the concentrations in the river and in the buffer strip, we noticed that most of the time concentrations were lower in the buffer strip than in the river. Runoff from other fields in the watershed cannot be responsible for this, as the watershed was specially chosen for its unfertilised meadows land use. Moreover, the parcel was located in the head watershed area.

The higher nitrate concentrations observed in the river could be due to the action of drain pipes, whose presence was attested during the study. Numerous drain pipes were set down in the Walloon Region from the 1950s, drying up the valleys, and hence, yielding land suitable for agriculture. Nowadays grassed buffer strips are installed without any care about the presence of draining pipes. Their efficiency could therefore be limited to the surface runoff (Puckett, 2004). Nitrate that would reach the pipes in the cropped area would be taken away from the removal processes of the buffer strips.

Further research will have to answer the question of the ability of buffer strips to deal with the discharge water from the pipes running down the cropped areas. The pipes should end at the surface, within the first few metres of the buffer strip. Special design should be proposed to avoid any bypass by concentrated flow. In specifications addressing the design of riparian buffers, Welsch (1991) considered the use of reshaping techniques to meet the purpose of the grassed buffer strip of converting concentrated flow to sheet flow.

DEA

The DEA of the cropped area was always below 4 mgNkg^{-1}d^{-1} while in the buffer zone, DEA was between 2 and 8 mgNkg^{-1}d^{-1}(Figure 3). The DEA in the buffer zone is

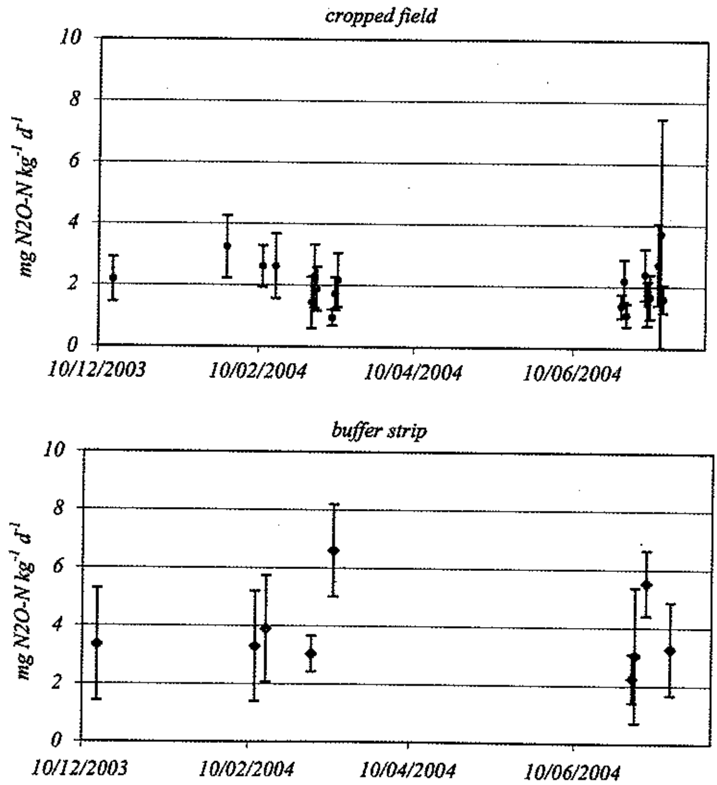

Figure 3 DEA trends in the spring and summer of 2004. Values are means of three replicates; bars represent standard deviations

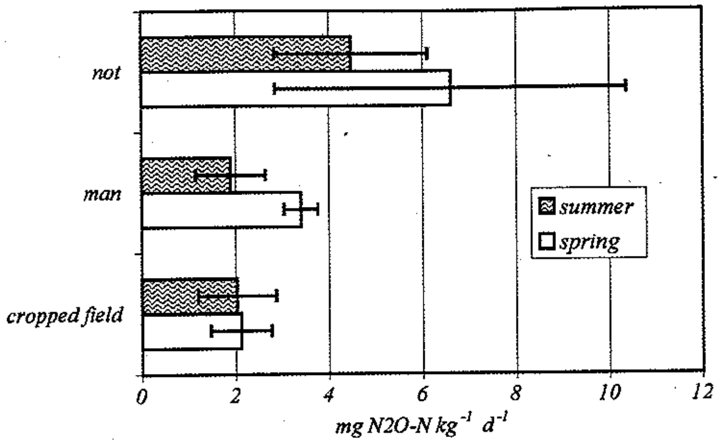

Figure 4 Mean values ($n = 12$) of spring and summer DEA in the 20-year-old buffer strip (NOT), in the seeded buffer strip (MAN) and in the cropped field. Bars are standard deviations

significantly higher ($p < 0.005$) than in the adjacent cropped field (3.67 and 2.12 mg N $kg^{-1}d^{-1}$ respectively). This finding fits in with the observed higher denitrification of pastures and grasslands relative to cropped areas in Sotomayor and Rice (1996) and in Dobbie and Smith (2001). This is in opposition to Parry *et al.* (1999) who concluded that land use did not affect the potential denitrification rate. They could not relate the higher C content of the pasture to any effect in the denitrification. This trend is somewhat different from what was observed from our experiments: the higher carbon and water contents of the studied buffer strip were identified as responsible for the higher DEA values.

Moreover, the DEA was significantly different between the two buffer strips under comparison ($p < 0.000001$). The oxidizable carbon content of the old unmowed buffer strip (NOT) was significantly ($p < 0.05$) higher than the C content of the 6-year-old buffer. Differences in management histories are mainly expressed by differences in plant cover and in organic C content. The old unmanaged buffer strip (NOT) is not mowed so that plant residues naturally decompose at the site. This contrasts to the grassed seeded buffer (MAN) where mowed grasses are exported.

The seasonal pattern showed higher spring values (Figure 4). This trend is probably linked to the variations in soil water content, as a consequence of heavier spring rainfall. This assessment is supported by what was observed in a specific data set from July 2004: the same experiment was conducted twice in 3 weeks. Identical sampling and DEA analysis were performed in weeks 1 and 3. Dry and hot weather (20.8°C mean max.

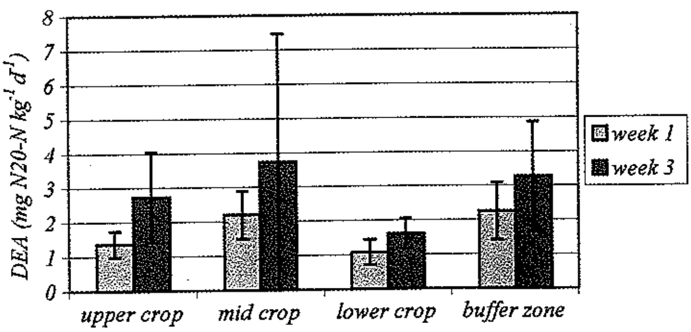

Figure 5 DEA mean values ($n = 3$) of soil samples collected within 3 weeks in July 2004. Results present separated upper, mid and lower cropped sampling area (Figure 1). Standard deviation values are indicated

temperature) occurred during week 1; weeks 2 and 3 were rainy (13 mm rainfall in week 2). The mean DEA observed in week 3 were 38% higher than in week 1 (Figure 5). N_2O emissions are known to be driven by the water-filled pore space content (Dobbie and Smith, 2001). This experiment suggests that the soil water content may be the main responsible variable for the high variation coefficients observed in denitrification activities (eg. Ambus and Christensen, 1993).

Conclusions

The nitrate removal efficiency due to the denitrification process in the studied buffer strip was higher than in the cropped field. First, the DEA in the buffer zone was significantly higher ($p < 0.005$) than in the adjacent cropped field (3.67 and 2.12 $mgNkg^{-1}d^{-1}$ respectively); and secondly, the old unknown buffer strip is potentially more efficient at the denitrification nitrate removal process than the 6-year-old seeded buffer strip. This was mainly due to the higher carbon content of the buffer, as a result of the conversion of the crop to a permanent pasture.

High temporal variability in DEA measurements may be mainly driven by short-term changes in the soil water content. This raises the question of the long-term significance of the DEA measurements.

References

Ambus, P. and Christensen, S. (1993). Denitrification variability and control in a riparian fen irrigated with agricultural drainage water. *Soil Biology and Biochemistry*, **25**(7), 915–923.

Campbell, N., D'Arcy, B., Frost, A., Novotny, V. and Sansom, A. (2004). *Diffuse Pollution: An Introduction to the Problems and Solutions*, IWA Publishing, London, UK.

Correl, D.L. (1996). Buffer zones and water quality protection: general principles. In *Buffer Zones: Their Processes and Potential in Water Protection*. The Proceedings of the International Conference on Buffer Zones September 1996. in Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (eds), Quest Environmental, UK, pp. 7–20.

Cors, M. and Tychon, B. (2003). Effects of grassed buffer strip management on potential denitrification in a Belgian agricultural watershed. Proceedings of the 7th International Specialised Conference on Diffuse Pollution and Basin Management. in Bruen, M. (ed.), Dublin, Ireland.

Dobbie, K.E. and Smith, K.A. (2001). The effects of temperature, water-filled pore space and land use on N2O emissions from an imperfectly drained gleysol. *European Journal of Soil Science*, **52**, 667–673.

Martino D., 2001. Buffer zones around protected areas: a brief literature review. *Electronic Green Journal* **15** (http://egj.lib.uidaho.edu/egj15/martino1.html).

Murray, R.E. and Knowles, R. (1999). Chloramphenicol inhibition of denitrifying enzyme activity in two agricultural soils. *Applied and Environmental Microbiology*, **65**, 3487–3492.

Parry, S., Renault, P., Chenu, C. and Lensi, R. (1999). Denitrification in pasture and cropped soil clods as affected by pore space structure. *Soil Biology and Biochemistry*, **31**, 493–501.

Puckett, L.J. (2004). Hydrogeologic controls on the transport and fate of nitrate in ground water beneath riparian buffer zones: results from thirteen studies across the United States. *Water Science and Technology*, **49**(3), 47–53.

Simek, M. and Webster, E.A. (2000). Persitence of denitrifying enzyme activity in refrigerated and air-dried cambisols. *Soil Use and Management*, **16**, 232–233.

Sotomayor, D. and Rice, C.W. (1996). Denitrification in soil profiles beneath grassland and cultivated soils. *Soil Science Society of America Journal*, **60**, 1822–1828.

Tiedje, J.M. (1994). Denitrifiers in *Methods of soil Analysis Part 2 Microbiological and Biochemical Properties.*, in Bigham, J.M. (ed.) Soil Science Society of America Bood Series 5. Madison, WI, USA.

Welsch, D.J. (1991). *Riparian Forest Buffers: Function And Design For Protection And Enhancement Of Water Resources*, USDA Forest Service, Northeastern Area, Radnor, PA, USA.