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Nitrate Leaching Losses from *Miscanthus* x *giganteus* Impact on Groundwater Quality

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Abstract: The objective of this study was to determine whether there was an increase in nitrate concentrations in soil water samples as a result of fertilizer nitrogen (N), in the form of cattle slurry, being applied at various rates to an establishing crop of *Miscanthus*; this trial was conducted during 2008/09. The crop received either no fertilizer (0-unfertilized control) or an annual application of 60, 120 or 180 kg N ha^{-1}. Soil water solution samples were collected fortnightly from porous ceramic cup samplers. Nitrate (NO_3^-) levels in these soil water samples were determined and monitored. In 2008, the soil water nitrate concentrations were high on all treatments, 14, 16 and 20 mg l^{-1}, respectively for 0, 60 and 120 kg N ha^{-1}. However, there was no significant difference between treatments. Soil water nitrate concentrations were again high (12-21 mg l^{-1}) in 2009, particularly at the 180 kg N ha^{-1} levels which showed significantly higher levels of nitrate leaching when compared to all other treatments. A high level of nitrate is seen as a threat to both public health and natural waters. Of these threats the latter is the more immediate, but the health issue has attracted more public concern, as the presence of nitrate in drinking water has been linked to a number of medical conditions such as blue baby syndrome (*methaemoglobinaemia*) in infants. The results indicate that leaching losses were closer to those recorded under arable land than extensively managed grassland; slurry application on an establishing *Miscanthus* crop does not appear to contribute adversely to levels of nitrate in groundwater when compared to other more extensive cropping systems.

Key words: Nitrate, leaching, *Miscanthus*, ceramic cup, groundwater

INTRODUCTION

Miscanthus x *giganteus* is a woody rhizomatous C_4 grass species which originated in South-East Asia and was initially imported to Europe as an ornamental plant; it is a perennial plant with an estimated productive life span of at least 10-15 years (Jones and Walsh, 2007). The remarkable adaptability of *Miscanthus* to different environments (Numata, 1974) makes it suitable for establishment and distribution under a range of European and North American climatic conditions (Lewandowski *et al*., 2000).

Energy and paper pulp production were the first end uses which were considered for *Miscanthus*, but the viability of other end uses are also being examined, such as, utilization in building material and in particular the suitability of *Miscanthus* for the bioremediation of contaminated soils; this potential use of the crop has come about as the pressures exerted on soils have increased due to intensive agriculture, industrialization, the expansion of urban areas and other factors (Visser and Pignatelli, 2007). It is argued that this contaminated land should be taken out of food production and used for production of non-food crops such as energy crops. The establishment of crops on this contaminated land can be beneficial for the reduction of aerial dispersion and runoff, the improvement of visual impacts, the supply of wildlife cover and possibly the production of an economically viable product (Wilkins and Abrutat, 1995). *Miscanthus* is a promising non-food crop, yielding high quality lingo-cellulosic material for both energy and fibre production. It is characterized by relatively high yields, low moisture content at harvest and high water and nitrogen use efficiencies (Jones and Walsh, 2007). However, little is known about the interactions between this crop and fertilizer nitrogen management. The nitrogen requirement of grassland and most arable crops has been studied at length with the impact of agronomic practices

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on nitrate leaching quantified (Thompson *et al*., 1987; Goss *et al*., 1993; Davies *et al*., 1996). However, the majority of studies on the effects of nitrogen fertilizers on *Miscanthus* (Himken *et al*., 1997; Christian and Riche, 1998; Lewandowski *et al*., 2000), focus on the effect of nitrogen on biomass yield, with fewer studies on the losses to drainage waters from this crop.

Nitrogen (N) is an indispensable input for sustainability in agriculture. The present structure and output of agricultural systems could not be maintained without the advent and widespread use of synthetic or mineral fertilizers; of the major plant nutrients N, not only provides the greatest responses in crop yield from fertilizer addition but is also the most readily lost from the agroecosystem (Merrington *et al*., 2002). Its use has increased dramatically in recent decades, but so has its losses as it cannot be fully utilized in any production system (Galloway, 1998).

Nitrogen losses have a number of environmental consequences. In particular, N loss can negatively affect the quality of soils, groundwater, surface water and the atmosphere (Schröder *et al*., 2004). In the nitrate form it is readily transported through the soil in water and it is therefore at risk from leaching (Christian and Riche, 1998). Pollution of water by nitrate contributes towards eutrophication and is therefore an environmental threat. Furthermore, much of the nitrate in groundwater and surface water is attributable to agricultural practices with concerns over the effects of nitrate on human health a significant driving force in reducing nitrate pollution (Johnson *et al*., 2002). Increased levels of nitrate in natural waters are more attributable to the increase in the area of land used for arable agriculture and the intensity with which it is farmed than the increased use of fertilizer nitrogen (Addiscott, 1996).

Over-fertilization and the inappropriate timing of fertilizer application can lead to the enrichment of soil water and result in losses of nitrate to groundwater and surface catchments. For example, grazing animals generally use only 10 to 35% of the N they ingest, with the remainder returned to the soil in urine and faeces (Bussink, 1994). Animal excreta are a valuable source of N and other nutrients for plants (Silva *et al*., 1999). However, there has been growing concern about the contribution of excreted N to the losses of N from grazed grassland. Earlier study has indicated that under grazed grassland, cattle urine is a major contributor to (NO_3^-) water contamination (Decau *et al*., 2004). Moreover, losses of nitrogen in the form of nitrate from arable systems have been well documented (Addiscott, 1996; Webster *et al*., 1999; Goulding, 2000), thus, adding to the nitrogen excess in the agroecosystem. The perceived environmental benefits of biomass energy crops, such as *Miscanthus*, could be negated if large quantities of fertilizer inputs were required for their production and consequently losses to the environment were unacceptably high. The objective of this study was to evaluate the effects of applying various rates of cattle slurry on nitrate leaching to drainage water and to measure N losses under field plots of *Miscanthus*.

MATERIALS AND METHODS

The experiment was carried out at University College Dublin, Ireland, Lyons Research Farm (53° 18' 28" N, 6° 31' 59" W). The site is relatively low lying at 80 m above sea level and is almost uniformly flat (1° slope). The soil is a silty clay loam; the previous cropping history includes the following: 2004-winter wheat (*Triticum aestivum* L.), 2005-sugar beet (*Beta vulgaris*) and 2006-spring barley (*Hordeum vulgare* L.). Following harvest of the spring barley in 2006 the site was left fallow over winter (2006/07). In May 2007 soil cultivation commenced after the site had been treated with a glyphosate based herbicide. *Miscanthus* x *giganteus* (Greef and Deuter, 1993), was established from rhizomes in May 2007. A recommended planting density of 18-20,000 rhizomes ha^{-1} was used to obtain 10,000 plants ha^{-1} or 1 plant m^{-2}. Post establishment the site was treated with a suitable sulphonyl urea based herbicide to suppress weeds. For practical reasons a conventional plot design was not possible; rather, sections of crop were divided into sub-plots and monitoring equipment (suction cup samplers) was installed in each sub-plot, i.e., 4 samplers per treatment. In 2008, the nitrogen treatments used were 0, 60 and 120 kg N ha^{-1} while in 2009 a rate of 180 kg N ha^{-1} was added to give an overall treatment programme of 0, 60, 120 and 180 kg N ha^{-1}. Nitrogen was supplied in the form of cattle slurry which was applied to the crop using a side chute attached to a vacuum tanker. By using the side chute slurry was applied without driving on the crop. The slurry was collected on Lyons Farm and was agitated immediately prior to spreading to ensure uniformity. Table 1 shows the characteristics of representative slurry samples taken from each load prior to application. A portion (50 ml) of these samples was homogenized by shaking for 10 min, in keeping with Díez *et al*. (2001) and

Table 1: Physiochemical characteristics of cattle slurry [a]

Parameters	Total amount (unit)
Dry matter	6.9 (%)
N	3.7 (kg t^{-1})
P	0.7 (kg t^{-1})
K	4.3 (kg t^{-1})

[a]Values are given as means of 10 subsamples

then analyzed in the laboratory. In January 2008, ceramic cup samplers were installed in each plot at 60 cm deep. Samplers were placed in the centre of the plot; a description of the installation and use of the ceramic cups is given in Curley *et al.* (2010). Prior to fertilizer application soil solution samples from ceramic cup samplers were extracted and samples analyzed for NO_3^- to assess baseline levels. Throughout the trial period a vacuum of -80 kPa was applied to the samplers and maintained for a period of 7-10 days (Johnson *et al.*, 2002). Samples of the soil solution were then extracted using negative pressure and NO_3^- determined for the extracted samples. Sampling took place on a fortnightly basis for four months post-fertilizer application. Samples were analyzed for NO_3^- using the zinc reduction method. All agro-meteorological data (soil moisture, drainage potential, soil moisture deficit and potential evapotranspiration) was supplied by Met Éireann for Casement Aerodrome, a synoptic weather station 6 km from Lyons farm for the duration of the experiment. In addition to this, soil moisture was measured gravimetrically each autumn and volumetric soil water content was assessed using handheld Time Domain Reflectometry (TDR) probes; vertical tensiometers (capable of measuring water pressure of 0-90 kPa) were installed according to Díez *et al.* (2001).

Statistical analysis was performed by using MINITAB 15 (Minitab Inc., 2009) software. For statistical evaluations of treatment effects and sampling dates a one-way ANOVA was used. Differences between treatments and NO_3^- levels in the soil solution samples were analyzed and compared by using Tukey simultaneous confidence intervals.

RESULTS

The years of 2008 and 2009: The occurrence of nitrate in waterways is not a new problem (Addiscott, 1996). However, what is new is the public concern about nitrate, arising mainly from the incidence of two medical conditions that have been associated with it's presence: *methaemoglobinaemia* (blue-baby syndrome) in infants and stomach cancer in adults (Addiscott, 1996); despite both being serious conditions it must be noted that these conditions are not caused directly by nitrate but rather by nitrite to which nitrate may be reduced. This study sought to evaluate the effects of applying various rates of cattle slurry on nitrate leaching to drainage waters and thus, the impact on groundwater quality.

In 2008, mean soil water nitrate concentrations were high on all treatments; 14, 16 and 20 mg l^{-1} for 0, 60 and 120 kg N ha^{-1}, respectively. As fertilizer N rates increased there was a corresponding increase in soil water nitrate concentrations with the highest soil water nitrate concentration recorded in the treatment that received 120 kg N ha^{-1}. This trend follows that documented by Christian and Riche (1998), who also recorded an increase in soil water nitrate concentrations as fertilizer nitrogen rate increased. These results would suggest that the application of nitrogen fertilizer (as slurry) increased nitrate concentrations as shown in the higher concentrations on the treatments where N was applied. Nitrate levels in soil water samples peaked at 25 mg l^{-1}, 29 days post fertilizer application (Fig. 1) before consistently decreasing.

In 2008, overall levels from all treatments were still below the acceptable limit (50 mg l^{-1}) for the production of potable water, as enforced by the European Communities (Drinking water) regulations (S.I. No. 278, 2007).

In 2009 the application of nitrogen fertilizer increased nitrate concentrations in soil water, shown in the higher concentrations on the treatments where nitrogen was applied. However, despite an increase in nitrate concentrations there was no significant difference in concentration levels between the 0, 60 and 120 kg N ha^{-1} with mean soil water nitrate concentrations of 12-14 mg l^{-1}. The 180 kg N ha^{-1} level recorded a significantly higher levels of nitrate leaching when compared to all other treatments (21 mg l^{-1}). Mean nitrate levels in soil water samples peaked 24 days post fertilizer application (Fig. 2) before decreasing steadily for the remainder of the growing season.

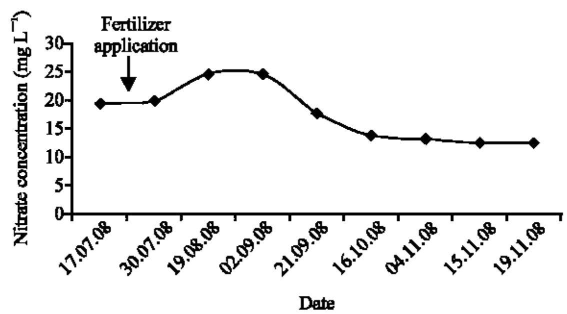

Fig. 1: Mean nitrate levels in soil water samples-2008

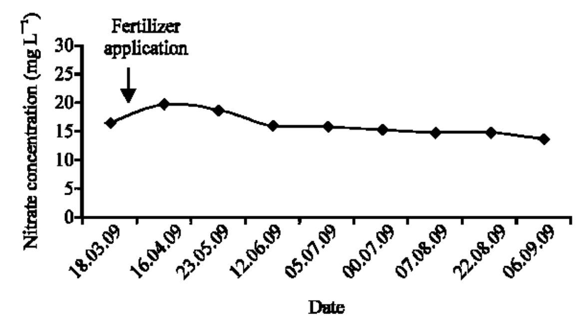

Fig. 2: Mean nitrate levels in soil water samples-2009

On the whole, levels of nitrate in the soil solution did not exceed the acceptable limit for the production of potable water in either 2008 or 2009.

DISCUSSION

Numerous leaching and drainage studies have consistently found that nitrate is the dominant form of nitrogen present in soil water (Baker *et al*., 1975; Jacinthe *et al*., 1999). Soil nitrate can be derived from both organic and inorganic nitrogen. Whether the nitrogen source is animal manure or commercial nitrogen fertilizer, over-application or ill-timed application of either source can provide too much plant-available nitrogen and increase the potential for nitrate leaching (Hatfield and Cambardella, 2001).

Nitrate contributes to surface water degradation when it flows into subsurface drainage lines that discharge into streams and lakes or when it leaches below the active plant-root zone into shallow ground water resources that connect to surface water bodies through natural processes such as baseflow (Dinnes *et al*., 2002). The purpose of this study is to investigate the effects of applying various rates of cattle slurry on the degree of nitrate leaching to drainage water under newly established *Miscanthus* grass conducted over two years (2008/09).

In 2008, the application of nitrogen fertilizer (as slurry) increased nitrate concentrations in soil water samples, shown in the higher concentrations on the treatments where nitrogen was applied. Furthermore, during the first year nitrate concentration in soil water was high partly as a result of previous agricultural practices which probably caused higher rates of nitrogen mineralization than would be usual for arable land. Over-winter fallowing and spring cultivation for planting of *Miscanthus* might also have contributed to mineralization and leaching, Christian and Riche (1998) reported similar findings. Goss *et al*. (1993) showed that fertilizer, particularly spring applied, was at risk from leaching when it as applied to soil that was close to field capacity.

In 2009, there was no significant difference in soil water nitrate concentration upto 120 kg N ha^{-1}, in addition, the mean nitrate concentrations were lower, 12-14 mg l^{-1}. *Miscanthus* x *giganteus*, as a rhizomatous perennial grass producing an annual crop of stems has the potential to translocate nutrients to the rhizomes. This minimizes nutrient off-take and the pollution resulting from combustion of nutrient-rich material, while returning nutrients to the rhizomes for the support of the next year's growth. Moreover, *Miscanthus* should have

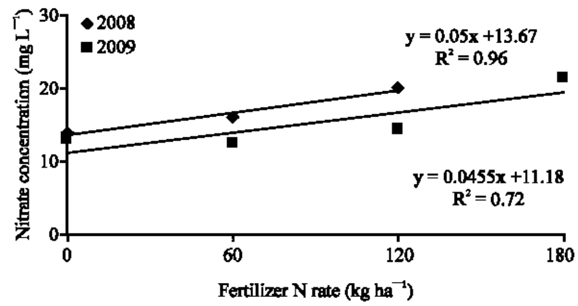

Fig. 3: The influence of fertilizer N rate on nitrate concentrations in soil water samples during 2008-09

the benefit of the higher nitrogen use efficiency which is associated with the C_4 photosynthetic pathway (Long, 1983). Simmelsgraad (1998) demonstrated that crop type was one of the most important factors affecting N loss. Thus, in year two of this trial it is assumed that soil water nitrate concentrations are lower due somewhat to the increased nutrient uptake of the crop as the total plant and root biomass increased. The lack of cultivation in the second year would have reduced mineralization of soil organic matter and therefore the change in soil management would have had a substantial effect in reducing leaching (Christian and Riche, 1998). Fertilizer application had a positive affect on nitrate concentrations in soil water samples (Fig. 3). The relationship between increasing fertilizer N rate and nitrate concentration in soil water samples in response to higher fertilizer N rates indicated a positive correlation between levels of fertilizer N and nitrate concentration with coefficient of determination (R^2) values of 0.96 and 0.72 for 2008 and 2009, respectively. Thus, the application of nitrogen fertilizer increased nitrate concentrations, shown in the higher concentrations on the treatments where N was applied, however, the overall levels of nitrate in the soil solution did not exceed the acceptable limit for the production of potable water in either of the trial years. Addiscott *et al*. (1991) pointed out that the use of fertilizer N leads to greater mineralization of soil N and this process may be partly responsible for the increase in losses from fertilized plots, although the greatest influence on leaching must have been the direct effect of amount of N applied.

These results may be beneficial to meeting the European Community's (Drinking Water) Regulations recommendations for maximum levels for nitrate (50 mg l^{-1}) in potable water and suggest that the production of *Miscanthus* would have a low or beneficial environmental impact on groundwater quality.

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