Nitrogen Losses in Relation to Soil Type

M.Ryan,
Teagasc, Johnstown Castle, Wexford

BACKGROUND

The importance of the nitrogen (N) cycle in dispersing the element through arable and grassland systems is widely recognised and while the mechanisms of N loss are fairly well understood the amounts lost in various environments through the several mechanisms encountered in the field are poorly known and so data collection continues. A threat of the imposition of nitrate vulnerable zones spurred urgent action on the research front in the late nineties since it was clear that information was lacking for grazed land with free draining soils and for many arable-cropping situations.

Research-Grassland

A joint EPA-Teagasc project, to measure nitrate leaching under semi-intensive dairying on a freely draining soil at Curtin's farm, Fermoy, in Cork, was initiated in 2000. It is a three-year project within which the effect of intensive grassland management practices on nitrate leaching at farm scale is being studied. The study measures nitrate leaching to 1 m deep from managements, which were determined to be representative of the major variables on a grassland farm. These managements are: grazing (dirty water + N fertiliser); 2 –cut silage & grazing (slurry +N fertiliser); grazing (fertiliser N) and 1-cut silage & grazing (slurry + N fertiliser). The mean N inputs to the plots in 2001 were as shown in Table 1.

Table 1. Fertiliser /organic N inputs and days (d) grazing plots, Curtin`s farm, 2001

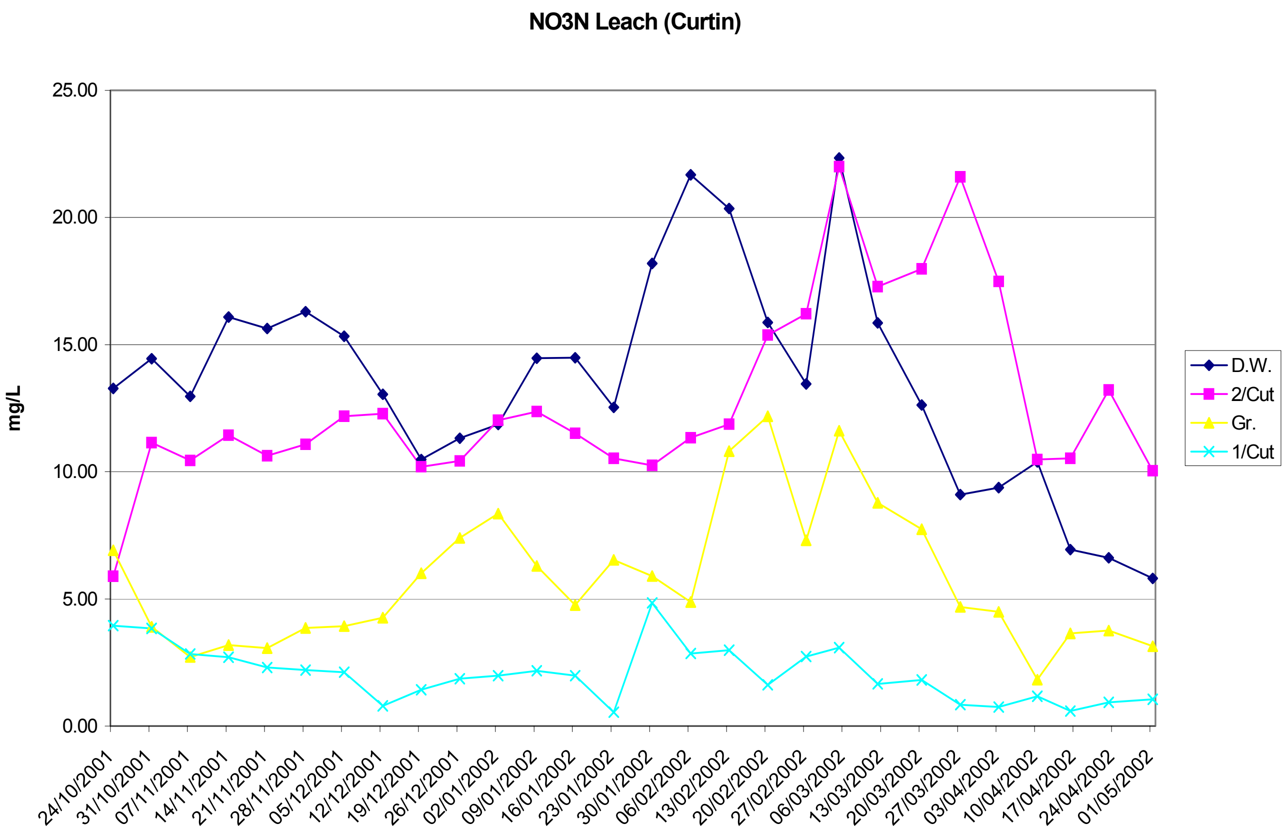
	Fert. kg/ha	Organic kg/ha	Total kg/ha	Mean d grazing/ plot
Dirty water	206	36	242	17
2 cut silage	363	44	407	6
Grazed	240	--	240	17
1 cut silage	323	?	323	11
Mean N input (Fertiliser + organic)			306	
Overall stocking rate			2.12 LU/ha	

Farm -Scale Trial at Curtin's-Preliminary Results

Water samples from 1m deep were extracted weekly from October 2001 to May 2002 and analysed for nitrate-N concentrations. Figure 1 shows nitrate – N concentrations in drainage water from the four treatments under study for the first drainage season. It must be emphasised that these results are preliminary and are presented as such. Final conclusions on the effects of the management practices on leaching must await the three years results.

The data was analysed using a SAS (1988) statistical package, which was a repeated measures analysis of variance (ANOVA) for a randomised block design. The nitrate-N

ANOVA showed significant differences between treatments on 4 dates only and the time by treatment interaction was not significant. There was no significant difference in the treatment pattern over time; there was a highly significant time effect for all treatments, however. When combined over time the treatment effects were not significant. The very high variation (CV range 29.7-135.1%) in the data makes it difficult to obtain significance in the treatment effects but the pattern of the data makes it almost certain that there are different effects present. In that sense, the dirty water and 2-cut silage data are different to those of the grazed and 1-cut silage plots. It is doubtful that the dirty water and 2-cut silage plot data are different; the dirty water data appear higher than the 2-cut silage data at certain times, similar occasionally and lower at times late in the season.



Over all dates, the mean nitrate-N concentrations (mg/l) for the treatments were: dirty water 12.0; 2-cut silage 11.7; grazed 5.2; 1-cut silage 1.9. The weighted mean value for the whole farm was 8.0 mg/l, which is satisfactorily below the EU drinking water Maximum Admissible Concentration (MAC) of 11.3mg/l, but is above the Guide Level of 5.65 mg/l. Results from the two remaining years are awaited to see if this pattern is repeated.

Beef systems

Nitrate leaching from beef systems are expected to be lower than from dairy systems due to lower N inputs and stocking rates. In the early-nineties, a 2-year monitoring of nitrate leaching, using ceramic cups at 500 mm deep, was carried out on a steer grazing trial at Grange (G. Keane, Pers. Com.). The results are shown in Table 2.

Table 2: Nitrate-N (mg/l) in drainage water from low and high N beef grazing systems.

	Year 1		Year 2		Mean of 2 years	
	57 kg N/ha	204 kg N/ha	57 kg N/ha	227 kg N/ha	57 kg N/ha	216 kg N/ha
Mean	0.4	4.5	0.8	3.0	0.5	3.9
Peak	1.3	9.9	2.2	6.2	--	--

The mean concentrations found were well below the MAC; even the peak levels at high N were below MAC. It is interesting to note that the mean nitrate-N concentration in the drainage water, where 204-227 kg N /ha were applied, was below the level recorded on the freely drained grazed plots in Cork. This result should not be surprising since the Grange soil is heavy textured and probably subject to denitrification, which would reduce nitrate-N levels.

A longer term monitoring of nitrate leaching at Grange has commenced in 2002 in which two suckler beef systems are being studied, e.g.,
A standard system-225 kg N/ha, 0.65 ha/cow unit (cow + progeny to slaughter and replacements) with grazing and 2 silage cuts
A REPS system-88 kg N/ha, plus clover-N, 0.82 ha/cow unit, grazing and 1 silage cut.
The grazing and silage treatments are being monitored within each system using 8 ceramic cups per plot at 1 m deep and three replicate plots per treatment
In addition, it is planned that shallow groundwater quality will be monitored within each treatment of each system to identify system impact on groundwater quality.

Research-Arable

From previous, limited studies in a lysimeter, on a moderately well drained, loamy Wexford soil we have information on the risks associated with cereal growing and fallow practices (Table 3).

Table 3: Annual nitrate-N leached from fallow and spring barley treatments, 3 and 11 years after ploughing.

	Fallow 0 kg N/ha		Barley 120 kg N/ha			
	kg/ha	mg/l	kg/ha	mg/l	F test	s.e.d. (kg/ha)
Year 3	232.0	26.9	88.6	11.8	***	7.1
Year11	76.3	11.9	31.8	5.3		

Fallow ground leached N for many years because of the absence of a crop. Barley too, where there is no cover crop in autumn-winter, gives rise to elevated nitrate in drainage water early in the rotation. Both reflect continued mineralisation of organic soil N. With the oncoming pressure for declaration of nitrate vulnerable zones, information on nitrate leaching from other soils and reduced inputs is urgently needed, as is the effect of sowing a cover crop. A new research initiative is tackling these information gaps.
At Teagasc, Oakpark and Johnstown Castle staff are monitoring leaching from a heavy textured, well drained soil growing continuous winter wheat and continuous spring barley. Both systems are being managed under standard and reduced inputs; there are 3 replicate plots per treatment and 6 ceramic cups at 1.5 m deep per plot.

	Continuous Winter Wheat	**Continuous Spring Barley**
Standard Inputs	223 kg N/ha	136 kg N/ha
Reduced Inputs	186 kg N/ha	104 kg N/ha

The results will indicate if reduced inputs are economically and environmentally worthwhile.

Cover Crops

Despite growing interest in cover crops, as an anti nitrate leaching practice, the development of a knowledge base for implementation is only just beginning here. Although several benefits of cover cropping may be claimed, in fact, there has been no Irish research to demonstrate these benefits, thereby restricting the selection of best management practices for the arable sector. A project looking at the effect of cover crops in minimising nitrate leaching has commenced and will be instrumented in 2003 giving results in the winter of 2003-04.

In summary, the results of the grazing leaching study at Curtin's farm, though preliminary, are encouraging in that, leaching of nitrate from semi-intensively managed grassland on free draining soil may not, on average, be likely to cause water pollution at a stocking rate of 2.12 LU/ha and a mean N input of 306 kg/ha, where collected dirty water is spread on 15% of the land area and slurry is spread only lightly in January and again in May. The same applies to previous results from beef grazing at Grange. Further development of nitrate leaching data is taking place at Curtin's farm through detailed studies on small plots, in co-operation with NUIG, and groundwater studies, in co-operation with Trinity College. The lysimeter study showed the propensity of arable land, particularly when fallow, to leach nitrate; the new investigations will show if reduced inputs and cover crops can materially limit leaching to acceptable levels.

INNOVATIONS

Variable Rate Fertiliser Strategies

A survey of fertiliser use in 2000 for grassland and arable crops (Coulter *et al.*, 2002), showed the following relationship between fertiliser N requirement and actual usage on farms:

	N Application			
Crop	Excessive	Slightly high	Correct	Low
Winter barley	√			
Spring barley			√	
Malting barley		√		
Winter wheat*	√			
Spring wheat	√			
Winter oats	√			
Spring oats				√
Sugar beet	√			
Potatoes			√	
Maize			√	

*Winter wheat N applications were appropriate for very high yielding crops but were excessive for normal crops on medium textured soils.

The use of N above crop requirements, as shown by the survey data, is wasteful while increasing the risk of N leaching. Measures to rectify this in the field are available e.g., Variable Rate Fertiliser Strategies, which have the potential to lower fertiliser inputs and reduce losses. Conventionally, fertiliser application to a field is based on the most productive soil in that field or a combination of most/least productive. Consequently, low productivity areas of that field may be over-fertilised leading to wastage and potential losses to the environment. The use of variable- rate fertiliser applicators equipped with global positioning systems (GPS) and geo-referenced soil/soil fertility maps allows nutrient applications that better match crop requirements on various soils/nutrient levels within a field. Applying fertiliser, based on yield potential associated with specific soil factors such as water-holding capacity and nutrient status, optimises yield response to fertiliser and reduces potential loss to ground and surface waters (Anderson-Cook *et al.*, 2002).

Soil-specific fertilisation may require accurate soil maps. County soil surveys often fall short of the spatial accuracy required to realise the benefits of variable rate technology. However, electromagnetic conductivity measurements can be used as a surrogate for soil properties such as soil moisture content, topsoil depth and clay content. These measurements have the potential for mapping soil zones of differing productivity potential that can further improve soil categorisation for use in precision agriculture.

Variable Rate Fertiliser Strategies are well established in the USA and are becoming so in the UK and Germany. J.O`Mahoney (Pers.Com.) reports that, on a visit to the USA in 1996, he witnessed quite a few farmers employing this method of fertilising crops. Will such applications come to Ireland and when? The system could and probably will have application here since most of the large co-operatives have the machinery and GPS technology to do so. Up to 10% of farmers also have the equipment and most new large fertiliser spreaders are equipped for following the strategy. We currently lack the maps necessary but this could be overcome using technical staff and a quad with GPS on board to survey fields for lime, P, K. Precision application of fertiliser N could also be part of this new strategy helping to curb pollution from N. Yield mapping of crops would also improve precision fertiliser applications in the following year.

Nutrient Management Planning

Surpluses of N in grassland arise because the high level of N inputs is coupled with small off-takes of added N in milk and meat. The consequent high rates of N cycling within grassland farms from grazing animal excreta, applied manure/slurry, fertiliser input and soil organic matter release, provide the opportunity for losses as nitrate and other N forms. Jarvis (1999) reported that a survey of 100 dairy farms in England and Wales revealed that application rates ranged from 100 to 689 (mean 281) kg N/ha. A crude estimate of N surpluses (N inputs minus removal in milk) on these farms indicated a range of 63 to 667 (mean 257) kg N/ha. Richards *et al.* (1998) reported similar findings (271-340 kg N/ha surplus) from a three- year study of a dairy farm in Cork resulting in nitrate-N concentrations > EU MAC in the soil drainage water. Only 22% of N inputs were removed from the farm in commercial products in the three years. Highest nitrate-N concentrations in drainage water were related to dirty water irrigation in that study. In Sweden, Swensson (2002) found that on dairy farms, mixed farming improved N efficiency – the N surplus decreased when farms, already growing grain, also grew sugar beet. N efficiency (N output in crops and milk/N inputs in fertiliser, fixation, purchased concentrate) increased from 25 to 32% on those farms**.**

Determination of the N surplus is a relatively simple desk-exercise, which can be carried out on any farm following which a nutrient management plan can be formulated. Successful nutrient management planning, i.e., integration of nutrient supply from soil and manure additions with crop requirements, reduces the amount of N fertiliser a farmer needs to buy and apply. This leads to more efficient usage of all N sources and thus reduces surpluses and losses to the environment. There are indications from Coulter *et al* (2002) that the contribution of manure to the N requirements of grass for conservation is minimal. This is supported by the fact that most farmers in this country do not get dung /slurry analysed and this is not very different to some other countries. Dou *et al* (2001) reported that only 20% of farmers in Pennsylvania had the nutrient content of manures tested. In Sweden, Swensson (2002) made the observation that it may be suspected that the farmers do not allow for the N supplied in manure thus adding to the problem of N surplus. This is in agreement with Domburg *et al.* (2000) who found little or no connection between the amount of manure given and fertiliser applied when analysing the use of fertilisers and manures in 1994 on farms in northeast Scotland.

A new farm facilities survey started by Teagasc in 2002, which is co-funded by the EPA and DAF, will disclose the shortcomings in manure storage, which need to be addressed to facilitate greater recovery of manure nutrients by ensuring they are applied at the correct time on the various soil types. Winter spreading of manure is a contributory cause of nitrate leaching in some soils (Ryan & Fanning, 1996).

Water Content and Fluxes

Field estimations of seasonal and short –term soil moisture by classical hydraulic methods are often difficult to obtain. Soil moisture status is highly variable in space and time and to obtain a reasonable estimate of this variable requires numerous measurement sites, - difficult in remote areas. Semi-automatic systems to overcome this problem in monitoring soil moisture tension have been in operation in Co. Wexford since 1995-96 (Diamond and Sills, 1998). Initially readings were taken and tensiometers were refilled with water twice weekly. The gauges were later replaced by pressure transducers, linked to a data logger, and the number of readings increased to 100 per day, showing the vastly increased data generating power of automating the method.

Electromagnetic conductivity measurements are used as a surrogate for soil properties such as soil moisture content, topsoil depth and clay content. These methods are replacing traditional ways because they are less demanding of labour, allowing much more data collection in any specified time. Data can be logged electronically and downloaded at intervals rather than manually once per day. For example, a Water Content Reflectometer is now used at Johnstown Castle (B. Hyde) to measure the water content of soil at 150mm deep at 27 sites 24 times daily, seven days per week in a denitrification experiment. If attempted manually, this would create an inordinate demand on human resources and would not be done.

The reflectometer uses Time Domain Reflectometer methodology to derive water content information from the effect of a changing dielectric constant on the propagation velocity of electromagnetic waves along a wave-guide. The resulting output is transmitted to dataloggers for storage and conversion to volumetric water content using calibration values. Two probe rods, inserted into the soil, act as wave guides. They are wired to high-speed electronic components on a circuit board configured as a bistable multivibrator. When the multivibrator switches states, the transition travels the length of the rods and is reflected by the rod ends. This reflection provides feedback to switch the state of the multivibrator. The travel time to the end of the rods and back is dependant on the apparent dielectric constant (Ka) of the material surrounding the rods. The Ka of air, soil particles and water at 20°C is 1, 2-5 and 80, respectively, which makes the measured bulk Ka predominantly dependent on the water content. Soil electrical conductivity, soil organic matter content and clay content may necessitate separate calibration relationships.

The importance of preferential flow was shown by Kung and Donohoe (1990), using ground-penetrating radar (GPR). In plot – scale experiments GPR revealed textural discontinuities, which enabled them to install suction lysimeters along preferential flow pathways. They reported that solution samples, collected from suction lysimeters located along predicted preferential flow pathways, had greater solution volumes. This suggested that samplers installed near preferential flow pathways were in a wetter region and perhaps an area of greater water flow compared with lysimeters installed outside GPR-identified flow pathways. Moreover, water samples from preferential flow pathways had chemical concentrations that were almost 400% greater than samples obtained in areas where matrix flow was expected to be the dominant subsurface flow process.

Future studies in Carlow will attempt to identify arable soils with preferential flow characteristics using tension infiltrometry. This will enable better prediction of nutrient fluxes from soil profiles. Currently, experiments are being planned in Johnstown Castle, which will examine the quantity of N lost to water and air under grazing and cutting conditions, using field-based monolith lysimeters. Three farming systems will be examined, i.e., dairy, beef and organic. Once the lysimeter technique is established it is planned to install lysimeters from a range of Irish soils on these farms to examine the effect of soil type on N, P losses under different farming systems.

Soil N Availability

A large proportion of the total soil N remains physically and chemically protected from microbial degradation in the stable soil organic matter pool and thus is unavailable for plant uptake. However, more labile fractions of soil organic matter, which are generally much smaller, remain an important source of N through mineralisation. If the contribution of soil organic N to growing crops via soil N availability indices could be predicted, then the N additions could be adjusted accordingly and so reduce loss risk. Harvested N in cut grass plots in a four-year trial on 26 sites (Ryan, 1976) give some determination of the N release from soils. On 10 major soil types, the 4-year mean N yield at zero N input ranged from 135 to 273 kg /ha with an overall mean of 219 kg/ha. Recently O'Connell and Humphreys (Pers.Com.), at the dairy research station, Solohead, Tipperary and Grange beef research centre have measured N uptake levels (kg/ha) in grass from zero N plots of 110 and 300, respectively. Peak mineralisation rates were noted in May and September with no difference showing between cut and grazed plots. The quantification of net N mineralisation and its temporal variation under grassland will be studied on the soils selected for the field lysimeter studies at Johnstown Castle with a view to fine-tuning N fertiliser advice for various systems on those soils.

Nitrification inhibitors

Nitrification inhibitors are compounds that delay the bacterial oxidation of NH4 to NO2 in the soil for a certain period of time by depressing the activities of *Nitrosomonas* bacteria in the soil. Practical advantages are significant reduction of nitrate leaching losses, a decrease in nitrous oxide emissions and better utilisation of N by plants. The currently available inhibitors, ammonium thiosulphate (ATS), dicyandiamide (DCD) and nitrapyrin, have disadvantages, e.g., ATS is unreliable in the field (Murphy, 1998), DCD is too expensive for large-scale use in agriculture and nitrapyrin is almost exclusively used with anhydrous ammonia. DMPP (3,4-Dimethylpyrazole phosphate) is a new nitrification inhibitor, apparently with highly favourable properties. In tests carried out in Germany, at low rates, 0.5-1.5 kg/ha, it inhibited nitrification over a period of 4-10 weeks. DMPP is formulated on fertiliser granules (dia 3.0-3.6 mm) of straight fertilisers and NPK fertilisers. Mineral fertilisers with DMPP contain only 1% active ingredient, based on NH4-N content (Zerulla *et al.,* 2001). It may merit study under Irish conditions.

Modelling

Many sophisticated simulation models of nitrate transport, used for predicting the potential of nitrate to leach from the root zone, have been developed during the past thirty years. N-CYCLE, developed by Scholefield *et al.* (1991) at IGER to predict losses and transformations of N in pastures grazed by beef cattle, is being adapted for use in Ireland. It will be used in conjunction with the farm–scale nitrate leaching study at Curtin's farm. The model simulates cycling of N, predicts annual live weight gain N, amounts lost through ammonia volatilisation, denitrification and leaching on the basis of fertiliser application and soil/site characteristics. It is an empirical, mass balance model, which calculates average annual fluxes of N per hectare. Schulte (Pers.Com.) at Johnstown Castle, in co-operation with Scholefield, is incorporating a grass growth sub-model into N-CYCLE, which will give grass yields, based on climatic factors, on a seasonal basis. The sub-model will separate the effects of urine and dung patches on N losses by simulation.

Application of existing and new research results together with use of the various techniques, available for environmental monitoring and enhancement are the most valuable information tools we have for achievement of better usage of farm nutrients, reduction of surpluses and minimisation of pollution.

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