# Quantification of Nitrogen Sources for Grassland.

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## 1 Introduction

There is increasing pressure on agriculture to make efficient use of nitrogen (N) in order to comply with environmental legislation such as the EU Nitrates Directive (91/676/EEC). The objective of the Nitrates Directive is to reduce water pollution induced by nitrate from agriculture to acceptable levels – the nitrate in ground water, for example, may not exceed 50 mg nitrate per litre. In fulfilment of the requirements of the directive, an Action Programme has been prepared by the government. The objective of the action programme is to establish requirements such as stocking rate limits, slurry storage, non-spreading periods and best practice requirements. In addition to meeting the requirements established under environmental legislation, farmers are also faced with changes to EU agricultural policy. Under the Luxembourg Agreement premia payments are being decoupled from production. As production will no longer be premia driven, farmers are being faced with the challenge of meeting market requirements by producing quality goods at low cost, using systems of production that protect the environment.

Nitrogen use efficiency within intensive farming systems has been shown to be very low. For example, on intensive dairy farms in the Netherlands only 16% of the N inputs (feed, fertilizer etc) are captured as outputs (meat, milk etc)(Aarts *et al.,* 2000). Improved N-use efficiency within farm systems is achieved by maximising utilisation of the N circulating within the system e.g. utilising the N in organic manures, the N supplied by soil and the N supplied by biological fixation through clover etc. This leads to an increase in the amount of N removed in product (meat, milk etc) and therefore reduces N surpluses (the difference between N inputs and N outputs). Improved N-use efficiency results in increased production efficiency and profitability (due to lower costs of production) while at the same time reduces losses to the environment. The objectives of this paper are to provide a review of the availability of some of the main sources of N for grassland production and to outline ongoing work which aims to quantify some of these sources and refine fertilizer N application strategies to improve N-use efficiency.

The main sources of N inputs in a livestock-based system are fertilizers, feed and organic manures (Fig.1). In most farming systems fertilizer is the main source of N for grassland production. Average fertilizer N use on dairy farms in Ireland in 2000 was 176 kg N/ha. Use of fertilizer N on beef and sheep farms was lower i.e. 48 kg/ha (Coulter *et al.,* 2002). Fertilizer N use in Ireland increased steadily over the past number of decades to a peak of 442,916 tonnes per year in 1999 but has declined since then to 363,513 tonnes in 2002 (DAFRD, 2003).

Other sources of N include atmospheric deposition and biologically fixed N. Atmospheric depositions of ammonia-N and ammonium-N (dry and wet deposition, respectively) amount to around 12 kg ha/year in Ireland (Watson, 2001; Sherwood & Tunney, 1991). Biological fixation of atmospheric N by N-fixing bacteria (*Rhizobium* spp.) in symbiotic association with leguminous plants (e.g. white clover) can supply substantial quantities of mineral-N (100 to 300 kg N/ha/year) (Masterson and Murphy, 1983). A certain amount of N is also 'fixed' by free-living bacteria in the soil, although the quantity supplied from this source is usually small (Whitehead, 1995).

Outputs of N are found in animal products (meat, milk, wool) and as losses to water, air etc. Each transfer in the N cycle provides an opportunity for inefficiency and loss. The quantity of N lost through water or air depends on factors such as land use, soil type and climate. Measurements of N cycling and loss under various farming systems and environments have been carried out in Ireland in recent years, as described by Humphreys *et al.,* (2002) and Ryan (2002).

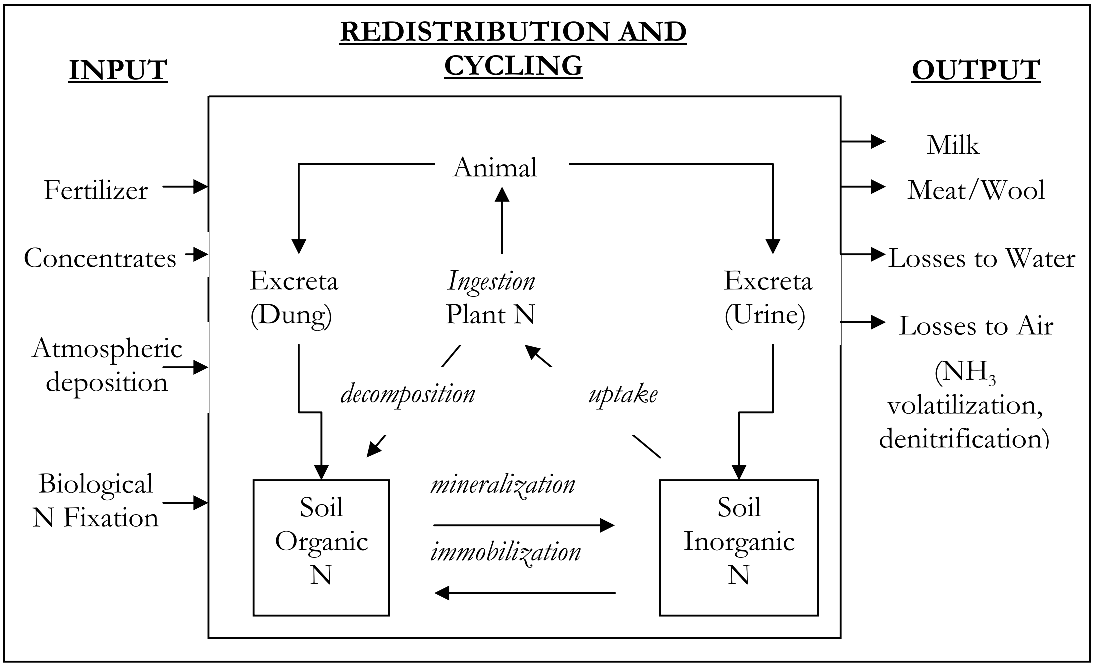


**Figure 1:** Inputs, outputs, redistribution and cycling of N in a livestock-based system (Adapted from Watson and Foy, 2001).

The various N inputs are incorporated into the soil, the grass plant and the animal and can undergo various transformations and cycling process before being removed as outputs or lost to air or water. For example, fertilizer N can contribute to the soil inorganic N component, be incorporated into the soil organic N component either directly or as decomposing plant material, be taken up by grass which then is consumed by grazing animals which either utilise it in meat or milk production or excrete it in dung or urine, or be lost to water or air. For grassland production there are three sources of available N that can be considered important. These are net mineralized soil organic matter N (SOM-N), N recycled by grazing ruminants and fertilizer N. The N in soil is in two forms: organic and inorganic fractions. Grassland soils contain large quantities of N in the soil organic matter. On average, Irish grassland soils contain an average of around 7 t N/ha in the upper 20 cm. In the upper 15 cm of soils in the UK, there can be between 3 and 10 t N/ha under grassland compared with 1 to 4 t N/ha under arable cropping (Archer, 1988). The N in the organic matter is not available for uptake by grass. Mineralization denotes the process whereby N contained in SOM is converted to inorganic N (ammonium ($NH_4^+$) or ammonia ($NH_3$), which is available for uptake by plants. This process is carried out by micro-organisms in the soil (Jansson and Persson, 1982). Nitrification is the conversion of $NH_4^+$ to nitrate ($NO_3^-$) by soil bacteria under aerobic conditions. This transformation may be considered as being part of the mineralization process (Whitehead, 1995). It is the primary route whereby $NH_4^+$ released from plant residues or added as fertilizer is converted to $NO_3^-$. It is affected by soil temperature, soil aeration, soil moisture availability and the nutrient status of the soil.

Immobilization is the reverse of mineralization, i.e. the transformation of inorganic N into organic forms. It is carried out by micro-organisms in the soil which can compete with plant roots for available N (Whitehead, 1995). Mineralization is always coupled with immobilization. The quantity of available mineral N depends primarily on the ratio of carbon (C) to N in the organic residues undergoing decomposition. Materials with a narrow C: N ratio e.g. slurry and clover residues, favour mineralization whereas material such as straw which have a low N content favour immobilisation. Under permanent grassland there is usually accumulation of SOM-N (Brogan, 1966). Ploughing exposes the SOM to oxidation resulting in an increased decomposition rate and mineralization of the SOM, and a decrease in organic C and N in the soil (Whitmore *et al.*, 1992; Vertès *et al.*, 2002).

The inorganic N (ammonium or nitrate) released through the process of mineralization (and nitrification) is an important source of N for uptake by grass swards. It is sometimes called the background release of soil-N or SOM-N. A certain amount of this background released N becomes available for uptake by the sward each year. The quantity released can be measured from swards not receiving any inputs of fertilizer, manure, fixation by clover or atmospheric deposition. The extent of release of background N is very much influenced by soil type. Soils vary greatly in their organic matter content and in their ability to retain moisture.

This influences the fate of any N present in the soil which is surplus to requirements. Clay soils have high organic matter contents so tend to accumulate N, unlike sandy soil types which have low organic matter contents. Also, sandy soils are free draining and therefore are susceptible to leaching whereas soils with high clay contents are likely to have impeded drainage and are susceptible to denitrification (the process whereby $NO_3^-$ is converted to dinitrogen ($N_2$) and nitrous oxide gases ($N_20$) by soil microbes). These factors influence the quantity and pattern in which the background soil-N is released during the year.

The second N source within the soil-plant-animal system is the N recycled by grazing animals. Grazing animals are inefficient at incorporating the N in herbage into milk or meat (Scholefield and Fisher, 2000). Of the N consumed by dairy cows only 20 to 25% is retained in milk and liveweight (Van der Meer *et al.,* 1986, Van Vuuren and Meijs, 1987). Protein consumed in the herbage is quickly converted to ammonia that can be rapidly lost from the rumen via the bloodstream. It is then converted to urea in the liver and eventually excreted in the urine (Peyraud & Astigarraga, 1998). As a result, dairy cows excrete 75 to 80% of the N they consume, the figure being higher for beef cattle at around 90 to 95% (Whitehead, 1995). Nitrogen is excreted both in the dung and in the urine. For cows the excretion in the dung tends to remain constant and is approximately 0.8g N per 100g DM consumed (Whitehead, 1995). A change in the N concentration of the diet is therefore reflected in the amount of N excreted in the urine. The proportion of excreted N partitioned into urine increases from approximately 45% for diets containing 15 g N kg/DM to 80% for diets containing 40 g N kg/DM (dairy cows) (van Vuuren and Meijs, 1987) and as outlined in Fig. 2.

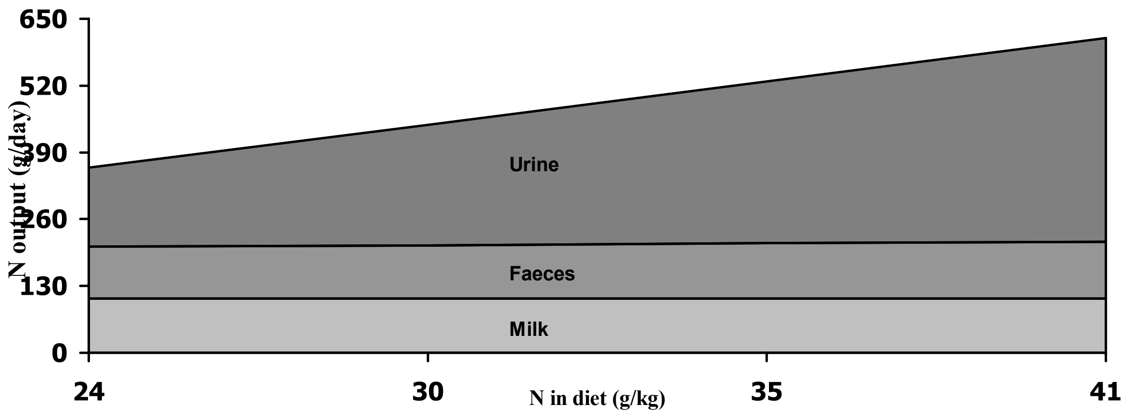


**Figure 2:** Partitioning of N output between milk, faeces and urine as influenced by N concentration of the diet (van der Meer, 1983).

The quantities of N excreted in dung and urine by grazing ruminants and the frequency of deposition are well documented (Whitehead, 1995; Haynes and Williams, 1993). For dairy cows, the frequency of excretion of both dung and urine is between 8 to 12 times per day (Lantinga *et al.,* 1987). The average volume per urination is 1.5 to 3.5 litres, resulting in the production of 12 to 42 litres of urine each day with the N concentration of urine varying from 6 to 15 g N/l (Holmes, 1989). The production of faeces ranges from about 2.5 to 5.0 kg DM/day for dairy cows. The amount produced is influenced by the amount and digestibility of the feed consumed. The daily output of faecal N would typically be between 100 and 150 g for a dairy cow of 500 kg live-weight (Whitehead, 1995; Haynes and Williams, 1993; Lantinga *et al.*, 1987).

The area affected by dung and urine during a year will depend on the type of animals grazing the sward, the stocking rate and the daily production of dung and urine. The area of pasture affected by excreta increases with increases in DM production as higher stocking rates are possible with higher herbage production (Hutchings and Kristensen, 1995). Urine deposition will affect growth of herbage beyond the area actually covered because of lateral uptake by roots (Whitehead, 1986). With cows, the area covered per urination is 0.2 to 0.5 $m^2$ (Haynes and Williams, 1993) and the area affected is about 0.5 to 0.7 $m^2$ (Lantinga *et al.,* 1987). The area affected is influenced by the volume of urine and by soil texture, porosity and moisture status (Whitehead, 1995). Thus as sandy soils have a greater infiltration rate the area affected will be smaller than with wet clay soils (Haynes and Williams, 1993). The N added in a urine patch is not distributed uniformly; because of the physical manner in which the animal urinates the centre receives more. Overlapping of urine patches also occurs during the course of the grazing season, particularly under intensive grazing (Afzal and Adams, 1992). Other factors such as wind and slope will also influence the area affected by a urination (Haynes and Williams, 1993). Herbage response to urine has been attributed to its N concentration and can last for 2 to 3 months (Ledgard *et al.,* 1982). On a freely drained brown earth soil in the UK, Cuttle and Bourne (1993) found that recoveries of urine N in herbage decreased as the growing season progressed. They attributed the seasonal pattern of herbage production as the dominant factor determining N uptake following application of urine. Unlike dung patches, which persist for several months, urine patches are avoided by the animals for a short period only. Urine-affected areas are sometimes grazed in preference after some weeks of regrowth (Norman and Green, 1958).

For dung deposits, the area covered is 0.05 $m^2$ (Haynes and Williams, 1993). Using a mathematical model that accounted for overlapping and for the non-random patterns of animal behaviour such as congregating around water troughs at gateways and beneath trees, Williams and Haynes (1995) predicted that 6% of pasture would be affected by cattle dung in any one year. The rate of disappearance of dung varies with the seasons. Weeda (1967) observed that the bulk of dung disappeared in one to two months in autumn and four to six months in late spring and summer, although extremes ranged from half a month to seventeen months. The N in dung has been shown to increase herbage production in the area surrounding the dung patch (Norman and Green, 1958). This effect may last up to 2 years. However, the increase in herbage production may not be entirely uniform. Weeda (1967) found that herbage in the zone of dung application was reduced during the first one and a half months after application due to pasture death. However, in the adjacent zone (a band 12.7cm wide around the pat) pasture growth was stronger and this compensated for the depression in the centre. In the following spring (approximately 1 year after application) herbage yields in both the patch area and the adjacent zone were significantly superior to those in an area unaffected by dung.

Annually, dung and urine deposits cover up to 20-35% of the grazing area (Whitehead, 1995). The uneven deposition of excreta (particularly urine) can lead to 'hotspots' equivalent to an application of 400 to 2000 kg N/ha in the affected areas (Jarvis *et al.,* 1995). These concentrations exceed the uptake capacity of grass and therefore increase the risk of loss, especially when plant growth and demand for N are low. The partitioning of N between dung and urine also intensifies the risk of loss as much of the N in dung is in organic forms and therefore relatively immobile, whereas much of the N in urine is in urea form. Once in soil the urea in urine is rapidly converted to mineral forms and is available for plant uptake or loss by leaching, denitrification and volatilisation (Williams and Haynes, 1994).

## 2 Study Details and Results

Recent research carried out by Teagasc aimed to measure the quantities and availability of N released from both net mineralized SOM-N and N recycled by the animal. An experiment was carried out during the grazing seasons of 2001 and 2002, in Moorepark, Co. Cork and at the Solohead Research Farm, Co. Tipperary. Moorepark has an acid brown earth soil type (5700 kg total N/ha, 210g/kg organic matter in the top 20cm) and an annual rainfall of 1040mm. Solohead has a mixture of grey-brown podzolic and gley soils (12400 kg total N/ha, 361 g/kg organic matter in the top 20cm) and an annual rainfall of 1100mm.

There were four treatments: (1) swards not receiving fertilizer and not grazed (0 Cut); (2) swards not receiving fertilizer N and grazed (0G); (3) Swards receiving 90 kg fertilizer N/ha per year split between 60 kg/ha applied in April and 30 kg/ha applied in July, and grazed (90G); and (4) swards receiving a total of 350 kg fertilizer N/ha per year, applied in ten applications at three week intervals between February and September, and grazed (350G). The objective of the 0 Cut treatment was to measure the quantity and pattern of N uptake by pasture from N released by net mineralization of SOM-N. The 0G treatment was used to determine the quantity and pattern of N uptake by pasture from mineralized SOM-N and from N recycled by the grazing cows. The objective of the 90G treatment was to measure the added impact of the application of 90 kg N/ha on the quantity and pattern of N uptake by swards receiving low inputs of fertilizer N. The objective of the 350G treatment was to measure the added impact of an input of 350 kg N/ha to the quantity and pattern of N uptake by swards. The 'difference method' was used to calculate the contribution of each treatment. For example the difference between 0 Cut and 0G gives the contribution of the N recycled by grazing cows. Soil mineral N measurements (using KCl extraction technique) were made on nine occasions during the course of the study. These reflected the quantity of available mineral N in the soil under the various N-input treatments during different periods of the growing season.

The effect of estimated N supply on herbage dry matter production, herbage N uptake during the growing season and soil mineral-N concentrations in November is outlined in Table 1. There was no significant difference between the two sites and the two years, so results have been averaged. Estimated supply equates to supply of net mineralised SOM-N and the supply from fertilizer N (i.e. 90 or 350 kg N/ha/year). The supply of net mineralized SOM-N was 124 kg N/ha/year between February and October. Uptake of N increased with increasing fertilizer N input. Annual uptake of N from the 0 Cut treatment was not significantly different from the 0G treatment. The DM yield and N concentration of grass also increased significantly with increasing N input (Table 1). However, DM production was lower under grazing than under cutting (0G versus 0 Cut). Table 1 shows that on the 90G and 350G treatments, net uptake of N in the herbage and the residual in the soil in

November were almost equal to the amount estimated to be supplied through mineralization and fertilizer N. Therefore there was no beneficial effect of recycling in these treatments.

**Table 1**. The effects of estimated N supply on grass DM production and herbage N uptake during the growing season, and soil mineral-N concentrations in November (average of two sites and two years).

| **Fertilizer Input (kg N/ha/year)** | 0 Cut | 0 G | 90 G | 350 G | Sig. | s.e.m |
|---|---|---|---|---|---|---|
| **Estimated Supply** (kg N/ha/year) (mineralization + fertilizer) | **124** | **124** | **214** | **474** | | |
| | Destination of N (kg/ha) | | | | | |
| Herbage uptake | 123.6 | 130.0 | 207.7 | 419.4 | *** | 5.1 |
| Residual in soil (0-80 cm) | 15.6 | 16.7 | 27.4 | 39.7 | ** | 4.4 |
| **Total** | **139.2** | **146.7** | **235.1** | **459.1** | *** | 5.6 |
| | Components of herbage uptake | | | | | |
| DM Yield (kg/ha) | 5371.7 | 5059.5 | 6944.5 | 10320.8 | *** | 139 |
| N concentration (g/kg/DM) | 23.0 | 25.6 | 29.8 | 40.7 | *** | 0.4 |

**Net mineralized SOM-N**

An average background N release of 124 kg N/ha was measured during the sampling period from the end of March to the end of October (Table 1). The quantity supplied on different soil types ranges from around 100 kg to as high as 330 kg N/ha/year under permanent grassland in Ireland (unpublished data; Ryan 1976). However, where management is likely to be consistent from year to year it is likely that the rates of release will not vary much from year to year. For permanent grassland sites with high SOM and total N contents the release of net mineralized SOM-N is likely to be in the region of 150 kg N/ha/year (Humphreys *et al.,* 2003). In the UK, Richards (1977) used data from 108 sites and recorded a mean background N release of 101 kg/ha ranging from some sites with very low values of less than 50 kg/ha to others releasing over 200 kg/ha. It was generally concluded that low values were associated with light, mainly arable soils and high values with long-term grassland. At 16 sites in the UK, Hopkins *et al.,* (1990) recorded mean uptake of 112 kg N/ha, ranging between 40 kg N/ha from upland sites to over 150 kg N/ha/year from more productive lowland sites. Background release of 170 kg N/ha/year under long-term grassland was recorded by Gill *et al.,* (1995). In the Netherlands, Prins (1983) recorded quantities generally in the range of 45 to 105 kg N/ha/year at three different sites. Also in the Netherlands, Hassink (1995) recorded quantities ranging between 43 and 201 kg N/ha/year on 11 sandy soils (mean = 128 kg N/ha/year) and between 45 and 233 kg N/ha/year on 10 loam and clay soils (mean = 137 kg N/ha/year).

Background N release can make a significant contribution to meeting some of the requirements of pasture for annual production, particularly during the winter and early spring when rates of DM accumulation in pastures are low. In addition to measurements of net mineralization of SOM-N for different soil types, knowledge of the pattern of mineralization would allow more precise recommendations regarding quantities and timing of fertilizer N application. The pattern of availability of net mineralized SOM-N had not been measured in the earlier mentioned studies (Ryan, 1976; Hopkins *et al.,* 1990). The pattern of supply of N from net mineralized SOM-N in Moorepark and in Solohead in 2001 is shown in Figure 3. The pattern in which this soil mineral N becomes available during the year can range from 0.2 kg N/ha/day during the winter to 0.8 kg N/ha/day during the early summer. Availability tends to peak during late April and May, and again during late August and September (see figure 3). The average requirement for soil N by intensively managed grassland is around 2.0 kg N/ha/day during the growing season (e.g. 450 kg N/ha over 225 days). Therefore, supply of net mineralization of SOM-N can make a valuable contribution to meeting the daily requirements of grassland during the growing season.

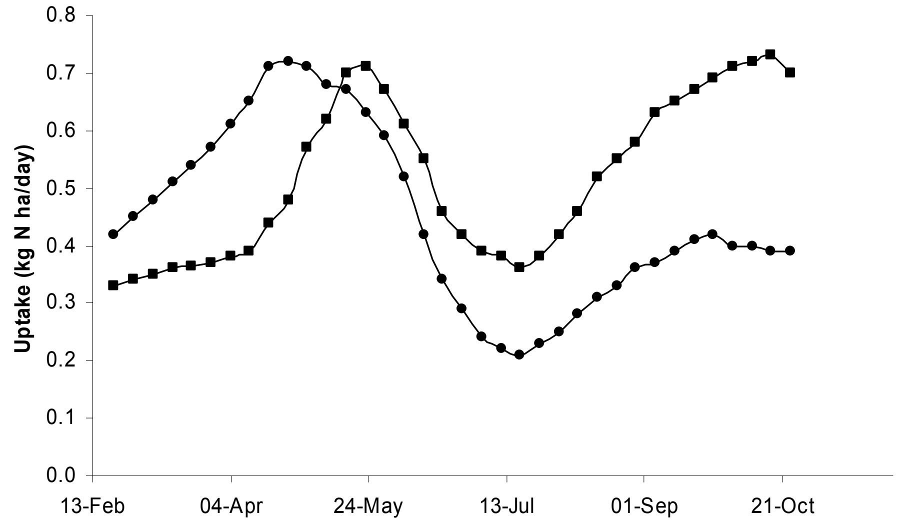


**Figure 3:** The pattern of supply of background-N made available through net mineralization of soil organic matter N at two sites (● Moorepark, Co. Cork and ■ Solohead, Co.Tipperary) in 2001.

A study involving the measurement of uptake from net mineralized SOM-N on 15 different sites around Ireland is currently underway by Teagasc. This will provide detailed information on the quantities and pattern of supply from this source of N. Fertilizer application strategies which complement this source of soil N will then be developed further.

**N Recycled by Grazing Animals**

Previous studies have emphasized the positive effects of excretal returns on herbage yields in the vicinity of the dung or urine patch e.g. Norman and Green, (1958). Because of the nature by which the N in dung and urine is deposited it can make dramatic localised impacts on the soil, plants and the subsequent grazing behaviour of animals. However, these effects are not always beneficial. The N in urine promotes herbage growth when the supply of N is less than optimum, but may reduce growth and cause death of herbage when the supply of N is excessive and when scorching occurs (Whitehead, 1995). Scorching is generally associated with dry conditions and with light soils (Richards and Wolton, 1975). Additionally, grazing animals reject herbage contaminated with dung deposits. Smell is important in affecting this grazing behaviour, initially from the fresh faeces and then from decomposition products (Whitehead, 1995, Haynes and Williams, 1993). This rejection may lead to a deterioration of herbage quality and thus the acceptability of the herbage growing in areas where it was originally rejected because of smell (Norman and Green, 1958). Tiller density in rejected areas will decrease gradually, giving rise to sward deterioration. Lantinga *et al.*, (1999) noted that under grazing on sandy soil, N aggravated sward deterioration (through a reduction in perennial ryegrass tillers) due to treading, poaching and urine scorch.

Work has shown that annual pasture production is not increased by dung and urine deposits. For example, Lantinga *et al*, (1987) studied the effect of grazing on sward quality, herbage production and utilization and concluded that grazing cattle exert both positive and negative effects on pasture production. They observed that at a fertilizer N input of 200 kg N/ha/year and above, recycled N did not significantly affect pasture production. In the current study there was no significant effect of recycling of N through dung and urine deposits on annual pasture production or N uptake. N uptake on the 0 Cut and 0G treatments did not differ significantly. The lower DM production under grazing compared with cutting (Table 1) may have been due to the adverse physical effects of animal treading and poaching. As the supply of N through net mineralization of SOM-N and fertilizer N could be accounted for in N uptake and the residual in the soil in November in both the 90G and 350G treatments it can be concluded that the positive and negative impacts of excretal returns offset each other and the net effect of the return of N through excreta was small.

In the current study, soil mineral N measurements were also used to assess the impact of the grazing animal. Measurements were made each year at the start of the grazing season in February, during the season in June and September and at the end of the grazing season in November. In addition, in June 2001, soil mineral-N concentrations beneath urine patches and areas not affected by dung or urine deposits (termed in-between areas) were measured in each treatment. The results are outlined in Table 2. The N-input level refers to the quantity of N each treatment had received up to the sampling date in June. There was no significant difference in the mineral N concentrations between the two sites, so results have been averaged.

**Table 2**. Soil mineral-N concentrations in June 2001, at four depths, beneath urine patch and in-between areas, in swards receiving varying N-inputs (average for two sites).

| Treatment | N-Input kg N/ha | Patch Type | Soil Depth (cm) 0–20 | 20-40 | 40–60 | 60–80 |
|---|---|---|---|---|---|---|
| | | | Soil mineral-N (kg N/ha) | | | |
| 0 Cut | 0 | Control | 16 | 8 | 6 | 7 |
| 0 G | 0 | In-between | 17 | 7 | 6 | 5 |
| 90 G | 60 | In-between | 17 | 10 | 7 | 7 |
| 350 G | 220 | In-between | 29 | 10 | 9 | 9 |
| 0 G | 0 | Urine | 91 | 22 | 9 | 8 |
| 90 G | 60 | Urine | 152 | 27 | 11 | 9 |
| 350 G | 220 | Urine | 334 | 50 | 15 | 11 |
| | | | N-input x patch-type x depth ($P < 0.001$) s.e.m. = 9 | | | |

The soil beneath the urine patches had substantially higher soil mineral-N concentrations ($NH_4^+$-N plus $NO_3^-$ -N) than the in-between areas, and this showed a significant ($P < 0.001$) 3-way interaction with N-input and soil depth. In the 0 to 20 cm horizon the soil mineral-N concentrations increased significantly with increasing N-input beneath the urine patches. Soil mineral-N concentrations declined with soil depth beneath both urine-patch and in-between areas. Mineral-N concentrations between treatments in the 40 to 60 and 60 to 80 cm depths did not differ significantly. However, in the 20 to 40 cm depth the mineral-N concentrations beneath the urine patches were greater than the in-between areas, and furthermore, the mineral-N concentrations in the urine patches increased with increasing N-input; the 220 kg N ha$^{-1}$ treatment being significantly higher than the 0 kg and 60 kg N ha$^{-1}$ treatments.

These high mineral-N concentrations below the effective rooting zone (0 to 20 cm) in urine patches (especially at 220 kg N ha$^{-1}$) indicate that urine patches are important potential sources for loss of N through leaching, denitrification and/or volatilization. Furthermore, the very large concentrations of mineral-N beneath urine patches, especially under the 220 kg N ha$^{-1}$ treatment (~ 400 kg N ha$^{-1}$; 0 to 80 cm) emphasise the inefficiency associated with recycling of N via urine. In a similar study, Ball and Ryden (1984) in the UK showed the accumulation of mineral N to a depth of 90 cm beneath cut and grazed ryegrass swards receiving 420 kg N/ha/year in soils sampled in November. Nitrate-N (kg/ha) concentrations were 160 kg N/ha under the grazed sward and 38 kg N/ha under the cut sward. They also recorded 920 kg N/ha below the centre of urine-affected areas and 400 kg N/ha below 'camped' areas. Cuttle *et al.*, (2001) demonstrated that most of the mineral-N beneath urine patches was subsequently lost. The earlier in the season urine is applied the higher the sward utilization of N in the urine. The largest losses of urine N occur with autumn applications (Decau *et al.,* 2003). Soil type also influences the fate of urine N with losses being higher with freely drained soil types.

In Table 1 above, soil mineral N concentrations, as measured in November, are represented as the 'residual in the soil'. The treatments that received fertilizer N (i.e. 90G and 350G) had significantly higher mineral N concentrations in November than the Cut and 0G treatments. The trend for increasing soil mineral N concentrations with fertilizer N inputs was consistent during the sampling periods of February 2002, June, September and November of 2001 and 2002 and in February 2003 (Table 3). Soil mineral N concentrations in the 350G treatment were significantly higher than the other treatments on each sampling occasion. In June higher concentrations were seen in the 0 to 20 cm depth of the soil profile. As the season progressed high mineral N concentrations were observed at lower depths in the soil profile (at 0 to 20 cm and 20 to 40 cm in Sept; 20 to 40, 40 to 60 and 60 to 80 cm in November). Higher concentrations in the 350G treatment were also observed in February 2002 and 2003 at the 40 to 60cm and 60 to 80cm depths.

The increase in soil mineral N concentrations with increasing fertilizer N input is reflected in increasing herbage N concentrations, as shown in Table 1. The N concentration in the herbage can exceed that required to meet the animal's requirements. For grazing dairy cows a threshold value of 140 g/kg crude protein in the herbage DM (22.5 g N/kg DM) has been reported by Peyraud and Astigarraga, (1998). Herbage N concentrations of 40.7 g N/kg in the 350G treatment were significantly higher than the threshold value of 22.5g N/kg. Whitehead (1995) calculated that grass harvested by cutting or grazing in a temperate environment and producing between 8 and 15 t DM/ha usually contains between 200 and 350 kg N/ha. In the current study 419 kg N/ha was taken up by the sward in which 10.3t DM was consumed by the grazing cows. The net effect of soil N concentrations and herbage N concentrations being greater than the requirements for animal and pasture production is increased amounts of N being excreted in urine and the related inefficiency associated with urine deposition as outlined in table 2.

**Table 3 :** Soil mineral N concentrations (kg N/ha) at four depths beneath cut swards receiving zero fertilizer N inputs (0 Cut), grazed swards receiving zero fertilizer N inputs (0G), grazed swards receiving 90 kg N/ha/year (90G) and grazed swards receiving 350 kg N/ha/year (350 G), on nine sampling dates.
s.e.m. = 1.78; (P≤0.001).

| **Treatment** | **0 Cut** | **0 G** | **90 G** | **350 G** | **0 Cut** | **0 G** | **90 G** | **350 G** |
|---|---|---|---|---|---|---|---|---|
| **Depth (cm)** | | **Feb-01** | | | | | | |
| 0-20 | 7.15 | 7.15 | 7.15 | 7.15 | | | | |
| 20-40 | 5.38 | 5.38 | 5.38 | 5.38 | | | | |
| 40-60 | 0.62 | 0.62 | 0.62 | 0.62 | | | | |
| 60-80 | 0.62 | 0.62 | 0.62 | 0.62 | | | | |
| | | **Jun-01** | | | | **Jun-02** | | |
| 0-20 | 16.37 | 16.58 | 16.72 | 28.08 | 10.66 | 14.65 | 17.70 | 31.57 |
| 20-40 | 7.31 | 6.09 | 9.57 | 9.12 | 6.71 | 6.57 | 9.40 | 12.87 |
| 40-60 | 5.42 | 5.28 | 6.39 | 8.07 | 3.05 | 2.52 | 4.34 | 6.85 |
| 60-80 | 5.91 | 11.87 | 6.67 | 8.51 | 2.91 | 2.87 | 4.01 | 6.46 |
| | | **Sep-01** | | | | **Sep-02** | | |
| 0-20 | 9.63 | 8.66 | 9.89 | 44.79 | 9.99 | 10.74 | 13.16 | 43.96 |
| 20-40 | 2.82 | 3.46 | 4.43 | 15.70 | 7.36 | 5.39 | 7.04 | 12.78 |
| 40-60 | 1.10 | 1.30 | 1.15 | 4.29 | 3.79 | 4.08 | 4.63 | 5.85 |
| 60-80 | 0.76 | 1.29 | 0.81 | 3.67 | 3.94 | 3.57 | 3.18 | 6.40 |
| | | **Nov-01** | | | | **Nov-02** | | |
| 0-20 | 6.98 | 6.07 | 10.46 | 11.71 | 8.65 | 8.08 | 11.81 | 11.05 |
| 20-40 | 3.01 | 3.08 | 6.07 | 12.68 | 5.96 | 5.66 | 10.17 | 9.25 |
| 40-60 | 0.53 | 1.99 | 2.55 | 11.22 | 2.76 | 3.59 | 6.73 | 8.85 |
| 60-80 | 0.79 | 1.27 | 2.58 | 5.13 | 2.47 | 3.71 | 4.43 | 9.48 |
| | | **Feb-02** | | | | **Feb-03** | | |
| 0-20 | 6.66 | 7.57 | 6.58 | 6.23 | 9.46 | 9.60 | 9.55 | 10.6 |
| 20-40 | 3.21 | 6.57 | 2.89 | 6.20 | 6.14 | 6.81 | 4.80 | 8.55 |
| 40-60 | 2.62 | 7.77 | 1.66 | 8.44 | 2.88 | 3.39 | 4.26 | 9.44 |
| 60-80 | 2.58 | 5.27 | 3.89 | 11.09 | 3.80 | 4.64 | 4.40 | 9.48 |

## 3 Summary & Conclusions

Farmers are being faced with the challenge of producing high quality produce at low costs of production using systems that protect the environment. In terms of N this involves making maximum use of the various inputs of N and the N cycling between the plant, the animal and the soil. The research outlined in this paper identifies the release of net mineralized SOM-N as a significant source of N for pasture production. For example the release of 124 kg N/ha during the growing season amounts to nearly one third the requirement of a sward producing 15,000 kg DM/ha/year and requiring 450 kg N/ha/year. The pattern of release of net mineralized N was also identified as important in meeting sward requirements, particularly during early spring and autumn.

The study also showed the inefficiency at which N consumed in herbage by grazing animals is returned to soil and contributes to further production. High soil mineral N concentrations and high fertilizer N inputs result in high herbage N concentrations. Excess herbage N is excreted as urinary N. The excretion of N in urine results in very high concentrations of N in the soil beneath urine patches. This N is only available to the herbage in the immediate vicinity of the urine patch and is therefore vulnerable to be leached from the soil – particularly sandy, free-draining soil types. Losses are higher during periods of low sward demand and high rainfall such as in spring and autumn. In the study the presence of the grazing animal was thought to have negated any beneficial effects of recycled N with the pasture being affected by treading, poaching, urine scorch and sod pulling. The net effect of these factors was that the contribution of recycled N was negligible. Improved N-use efficiency can be achieved by the strategic application of fertilizer N which takes account of N supply of net mineralized SOM-N and avoids excessive applications which can lead to unnecessary losses.

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