



THE FERTILIZER ASSOCIATION OF IRELAND

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The Irish Fertiliser Industry – a review

Mr. John Leonard, Grassland Fertilisers Ltd.
Managing Director (retired)

PRESIDENTS OF THE FERTILIZER ASSOCIATION OF IRELAND

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Dr. T. Walsh	1968	Mr. P Keane	1985
Mr. W. J C Milne	1969	Dr. J F Collins	1986
Mr. G. Foley	1970	Mr. M Stanley	1987
Dr. J N Greene	1971	Mr. W. O'Brien	1988
Mr. E J Sheehy	1972	Mr. T. King	1989
Mr J C Brogan	1973	Mr. G. Leonard	1990
Mr. T James	1974	Dr. T F Gately	1991
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Mr S McCann	1976	Mr. R. Walsh	1993
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Mr. P McEnroe	1980	Dr. N. Culleton	1997
Mr. T. Fingleton	1981	Dr. P Barry	1998
Mr. J Leonard	1982	Mr. B. Barnes	1999
Mr. P Duffy	1983	Mr. C. Watson	2000
Dr. M. Ryan	1984		

BACKGROUND

About 160 years ago - just before the Great Famine - there were 8 million people living here on the island of Ireland compared to 5 million today. We were mainly a pastoral community and, by world standards at the time, we existed reasonably well on a diet consisting mainly of potatoes. Sanitary conditions were rather primitive and livestock, including horses, abounded, so I leave it to your imagination how crops received the necessary nutrients at that time.

In fact the first real burst of progress in the development of fertilisers, as we know them today, only began during the 1800's - a few years after Maltus had written his "Essay on the Principles of Population" in 1798.

The early 1800's saw the treatment of bones with Sulphuric Acid for application as fertiliser. Guano, i.e., bird droppings, from Peru and islands in the Caribbean, which was organic of course and rich in Nitrogen and Phosphate, was discovered towards the middle of that century and later Ammonium Sulphate, which was a by-product from coal gas, was widely used.

This century has seen real and rapid developments in all areas of Agriculture, not least of which were the developments and improvements in fertiliser technology.

THE PAST 50 YEARS

During the post World War II years, Ireland, in common with most developed countries, sought to replenish the nutrients in the soil which had been used up due to intensive cultivation - "compulsory tillage" they called it - during the war years. The Irish Government introduced a subsidy on Phosphate and Potassium, payable to farmers, to stimulate the usage of products containing those nutrients. Government policy was - and I quote - "To encourage farmers to use fertiliser, later on we will teach them how to use it". The subsidies were paid to the fertiliser manufacturer who passed them on to the farmer in the price of the product. By this means the Government effectively controlled what fertiliser products would be marketed as the manufacturer had to obtain a licence for each product formula from the Department of Agriculture. This is the reason why we have so many "standard formulae" in the Irish market today.

In the immediate post-war years fertiliser products were in powder form. Mainly Sulphate of Ammonia, Single Superphosphate and Potash were used either as straights or in compound form. The principle compounds were ON 5P 10K (commonly referred to as, "Potassic Super") and 5N 5P 10K (known as "Potato

Manure"). These were packed in 3-ply paper bags weighing 1Cwt (now 50Kg.) and Superphosphate was packed in 2 Cwt (100 Kg.) jute bags. All bags were manually handled - workers were big and brawny then! Palletisation was unknown.

PARTICIPANTS IN THE INDUSTRY

The main participants in the Industry at that time (i.e. *1940's/50's*) were: -

Gouldings a well-established public company. The Goulding Brothers, of Scottish origin, who were pioneers in the development of Superphosphate, had factories in Dublin and Cork as far back as the 1860's. I would suggest that "Goulding" is one of the oldest, if not "the oldest", brand names still in existence in the industry world-wide.

Richardson Brothers were also well established in Belfast since 1860, where at that time, they treated crushed bones with Sulphuric Acid.

Albatros Fertilizers in New Ross, was founded in 1953 as a private limited company. 49.9% of the equity was held by Irish shareholders - mainly the Stafford and Dowley merchant families, the remainder was held by Urie Van Kunstmestfabrieken (U.K.F.), of The Netherlands.

Shamrock Fertilizers Limited was also founded in the 1950's, by a Belgian family named Van den Bergh, who settled in Ireland after the War. It had factories in Wicklow Town and Foynes as well as Distribution Depots in Cork, Dublin, Drogheda and Kilkenny, where it also mixed and bagged Powder Compounds. These were the forerunners of the modern-day Blending Plants. Incidentally, the family home of the Van den Bergh's and the Head Office of Shamrock Fertilizers were located in Woodstock Estate, Kilcoole, Co. Wicklow, which is today the internationally famed Druid's Glen Golf Club.

In addition to Superphosphate production and Powder Fertiliser facilities all four of the above built Steam Granulation Plants during the 1950's. This was the latest technology from The Tennessee Valley Authority Research Centre (TVA) in the United States.

McDonoghs, an old established merchant family, also had a Superphosphate Plant in Galway City at that time.

The *1960's* saw rapid developments and change in the industry: -

Nitrigin Eireann Teoranta (NET) was incorporated in October 1961 to seek tenders for the erection of a Nitrogenous fertiliser factory in Arklow, Co. Wicklow. This followed the recommendation in the Report on the "Survey of the Fertiliser Industry" by the Committee on Industrial Organisation. Mr Jack Hynes was the Secretary to this Committee and he later became the first Managing Director of NET. In 1962, a consortium of firms was commissioned to construct a plant to

produce Ammonia, Sulphuric Acid, Nitric Acid, Ammonium Sulphate and Calcium Ammonium Nitrate. Subsequently Phosphoric Acid and Compound Fertiliser Plants were commissioned.

Shamrock Fertilizers was taken over jointly by its main competitors, Goulding and Albatros, in 1963 following a failed joint venture with a German company (Ruhr Stickstoff) and was finally closed down in the following year.

Grassland Fertilizers Limited was started by the Walsh Merchant family in Kilkenny in 1963. It bought out some of the assets of Shamrock Fertilizers and subsequently employed some of the redundant workers and staff. It commenced mixing Powder Compounds and, in 1965, opened a factory on Dock Road, Limerick, where a Steam Granulation Plant was installed in 1966. Also in 1966, a German family, named Suhr, bought a controlling interest in Grassland Fertilizers and encouraged its expansion and development.

Meanwhile Goulding, Albatros and Richardsons were carrying out extensive renovations during the years 1963 to 1967 and all three erected state-of-the-art chemically based Concentrated Compound Fertiliser (CCF) Plants. ICI had acquired a majority shareholding in Richardsons in 1960.

I should mention that The Anglo/Irish Free Trade Agreement was signed in the mid-1960's, and gave rise to imports of fertilisers from the UK in addition to Calcium Ammonium Nitrate from Europe. Understandably, these imports - mainly by Grassland and McDonoghs - caused headaches for the major producers (who, as we have seen had recently invested in expensive chemical plants) and were the subject of many Anti-Dumping complaints for a number of years.

Before leaving the 1960's, I should also mention that Powder Compounds had been phased out with the advent of Granular products; 1Cwt (50 Kilo) Plastic (i.e. PVC) bags had replaced the old Paper and Jute sacks; Charles Haughey had been Minister for Agriculture and, in 1968, The Fertiliser Association of Ireland was formed.

The *1970's*: -

I suppose it could be said that the years 1972 to '74 saw the Irish fertiliser Industry "at the height of its glory". Fertiliser usage reached record levels in 1972/3. It is of note that, although the total tonnage of fertiliser sold in that year was only some 50% higher than in 1964/5, the amount of nutrient tons was well over double that available in the '64/5 Season because of the greater concentration of nutrients in CCF and PK-Compounds. Of course confidence - and expectations - were high on Ireland joining the EEC.

At this stage NET had increased its production capacity at Arklow and employment exceeded 1,000 in 1974, compared with 300 originally envisaged.

In 1972, Goulding Chemicals Limited, as it was now known, was acquired by

Fitzwilton Limited (Tony O'Reilly's Irish public holding company). Gouldings had a marketing division and operated eight distribution depots throughout the country in addition to manufacturing complexes in Dublin and Cork. Employment was about 1,000 personnel. In 1976 50% of the equity was sold to Agrico Chemicals Company in the United States.

The Irish interest in Albatros Fertilisers was sold to U.K.F. in 1971. Apart from its production facilities in New Ross it operated depots in Dublin, and Limerick and employed some 360 persons. Cork Fertilizer Distributors (C.F.D) had an exclusive selling agency for Albatros in the Cork/Kerry area.

Grassland Fertilizers had also expanded. It had a (much revamped) steam granulating plant (not CCF) and a blending plant in Limerick also blending plants in Kilkenny and Cork, the latter opened in 1971. It also operated depots in Slane, Wicklow and Foynes. Employment was about 150 persons at peak. Grassland had developed a unique system whereby "custom made" granular NPK "bases" were produced in the Limerick granulating plant for blending with imported "intermediates", such as DAP. By this means it could effectively compete, both in quality and price, with the more "sophisticated" and relatively costly CCF products of its competitors.

McDonoghs, in Galway, had closed down its Superphosphate production since the mid 1960's and now operated a blending plant. It had a technical service agreement with Fisons in UK from whom it also purchased intermediates.

T. & J. Farrington Limited, had a blending plant in Rathcoffey, Co. Kildare, and operated a bulk delivery and spreading service direct to farmers as part of a general agricultural business.

Co-operative Agricultural Purchases Limited (CAP), commenced general agricultural business in 1966, and opened a fertiliser blending plant in Waterford in 1973. Its share capital was owned entirely by co-operatives to whom it sold exclusively. Its stated policy was to sell fertilisers at £5 to £6 per ton below the price charged by the other Irish manufacturers. Early in 1975 CAP had drawn up plans to construct an ammonia and urea plant in Cork, using naphtha as a raw material.

Richardsons Fertilisers upgraded its plant in 1974 and imported High Nitrogen Compound fertilisers into the Republic for the first time. ICI acquired the entire share capital the following year, 1975.

By 1974 palletisation of bagged products had been introduced and CIE, whom NET and Gouldings used for transport of their fertilisers to a large extent, invested in a change-over from bulk-carrying of fertilisers to carrying of bagged fertiliser on pallets, together with handling equipment and storage facilities at railhead depots.

CRISES!

However, in the mid-1970's, the fertiliser industry in Ireland (and indeed in the rest of the world) ran into serious difficulties. For many years the home demand for fertilisers had been increasing steadily. In addition, in 1973 and 1974, there was substantial export demand for fertilisers at high prices, and most of the Irish manufacturers availed of the opportunity to create valuable export profits, which enjoyed tax free status.

This favourable situation disappeared after the substantial increase in raw material prices, which followed the rise in oil prices after the 1973 Middle East War. Between 1973 and 1975 crude oil prices rose by about 300%, liquid ammonia prices by about 200%, rock phosphate prices by around 600%, and potash prices by well over 100%. Domestic labour costs also rose and sterling (to which the Irish was linked) was devalued. These substantial and rapid increases resulted in an approximate doubling of the manufacturer's selling prices.

Such price increases on their own would have been expected to exert downward influence upon fertiliser consumption. They coincided, however, with a period when farm incomes fell substantially, largely due to the recession in the cattle trade, and the confidence of farmers was severely depressed.

In 1974, in response to persistent allegations by farming bodies, the Government set up the Fertilisers Prices Advisory Body to enquire generally into the industry in Ireland. That report was published in July 1976, by which time conditions had substantially altered.

The late 1970's saw considerable losses followed by radical upheaval and restructuring in the industry. For example, Goldings closed down the plant in Dublin in June 1976, with the loss of 365 jobs and scaled down operations in Cork. In that year it reported a loss of £3 million. Albatross and Grassland also closed down their production facilities for several months and a number of employees were made redundant. CAP was put into liquidation with a loss of over £1 million. Grassland, although its profits were somewhat reduced, did not suffer as much owing to its relatively low-cost operation.

By 1979, some little confidence was returning. Northern Ireland Services (NIS) opened a blending plant in Hillsboro, Co. Down; IAWS had opened a blending plant in Askeaton, Co. Limerick; Grassland Fertilizers opened their fourth blending facility in Slane and NET commissioned the new Ammonia and Urea plants at Marino Point in Cork. (Officially opened by the then Taoiseach, Jack Lynch on 5th October 1979).

Albatros, meanwhile, had discontinued its agency agreement with CFD and the latter formed a new company - Emerald Fertilizers Limited - which commissioned its own blending plant in Cork (also opened by the Taoiseach, Jack Lynch in June 1979) and which went into liquidation a few years later.

THE 1980'S

By 1983 all the Granulating Plants (both steam based and CCF) in the Republic had closed down, there was considerable rationalisation in the industry and the manufacturers had followed Grassland's lead into relatively low-cost blending. Quality of imported raw material and intermediates had also improved considerably.

The 500Kg ("Big") Bag was introduced into the Irish market where, today, it is marketed as the "conventional" 2-ton unit load i.e. four 500Kg bags palletised and shrink-wrapped.

The late 1980's saw a period of mergers and acquisitions: -

Goulding was acquired by IAWS; NIS was acquired by Kemira; Albatros was acquired by McDonoghs; Suhr acquired 100% shareholding in Grassland and a controlling interest was jointly acquired by Avonmore/Waterford Co-operatives (now Glanbia) in Grassland's Killkenny blending plant and of course, NET merged with Richardsons/ICI to form the new North/South Company - IFI.

To complete the picture, in 1991 Grassland was acquired by Irish Sugar Company - now Greencore.

THE 1990'S

So after all that "turbulence", the 1990's have been relatively quiet. Obviously the participants have continued with programmes of modernising and rationalisation and may now be considered "slim and efficient". There the picture remains today.

THE FUTURE?

In the writer's opinion further amalgamations and/or acquisitions will and must take place. The fertiliser industry is really a "distribution industry" where economics of scale and economics of transport based on sound study of the underlying logistics is essential to continued profitability and even viability. Let that be the thought for the 2000's !!

IN CONCLUSION!

When one is part of change it is imperceptible - it is only when one looks back over a period of 30/40 years that one realises the magnitude of the changes that have occurred.

Nitrogen Mobility – a review

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INTRODUCTION

Following the weary, hungry years of the Second World War, agricultural research from the late 1940s to the 1960s had a simple goal, to increase agricultural production at almost any cost. As plant breeders introduced new cultivars of grass and arable crops with ever increasing yield potential and agrochemicals to control weeds, pests and diseases became available, it was possible to justify larger inputs of plant nutrients, especially nitrogen (N).

Today the goal is not quite so simple for two reasons. First, for some years it has been accepted that all agricultural systems should have minimum adverse environmental impact. Second and more recently it has become more difficult for farmers to achieve economically viable production. One aspect of satisfying both goals will be the efficient use of all inputs including plant nutrients. Agriculture, however, irrespective of the level of intensity, will always have some environmental impact when it seeks to produce on a given area of land, a larger quantity of food for humankind or feed for animals than it can produce in its natural state. Thus achieving the goals of efficient production and minimum adverse environmental impact requires skill in matching annual inputs to any shortfall in the outputs from the complex interactions between the biological, chemical and physical properties of soil within the constraints of seasonal climatic conditions.

Provided that those properties related to soil fertility, including freedom from pests, weeds and diseases, soil structure, soil acidity and the phosphorus (P) and potassium (K) status are optimum, then N is the key element which drives production in both arable and grassland farming systems. This N can come from the biological decomposition of soil organic matter and organic manures, from fertilizers added to soil and from aerial inputs.

This paper considers some aspects of N use. Because mineralisation of organic matter is a biological process it is both difficult to control and to predict when and how much nitrate (NO₃) will be released. This makes it difficult to advise on how much N to apply to achieve optimum economic yields. It also makes more difficult attempts to lessen the environmental impact of ammonia or nitrous oxide lost to the atmosphere or nitrate lost to water when these forms of N can derive more from soil organic matter or organic manures than from fertilizers.

NITROGEN CYCLES

In the 1990s it is not readily appreciated that only 160 years ago there was still uncertainty about the source of N for plants. It required the large scale field

experiments started by Lawes and Gilbert from 1843 at Rothamsted to prove conclusively that plants, other than legumes, required a supply of N as NO₃ or ammonium (NH₄) in the soil solution. The experiments also showed that both these forms of combined N could be supplied by fertilizers or farmyard manure (FYM).

In 1840, Liebig in the first edition of his book, *Organic Chemistry in its Application to Agriculture and Physiology* (Liebig, 1840) proposed a very simple N cycle. The decomposition of plant and animal debris on or in the soil produced ammonia which was released to the atmosphere. Subsequently the ammonia dissolved in rain and was returned to the soil to be used again by plants. Today, there are many examples of very much more complex diagrams of the global N cycle. Within the global framework there are detailed N cycles for the soil-plant-animal system with storage pools and flow pathways between them. Quantifying the pools and pathways is not easy. Any description of the N cycle must recognise that a gain at any point must be accompanied by loss at another. For example, zero grazing may decrease N losses in the field but with the risk of increased losses from a number of sources including the cattle shed, slurry tank and slurry applied to the field.

A major problem is still to apportion losses between the various possible loss pathways which have been identified. For example, the N cycle has been studied extensively under the comparatively simple continuous wheat cropping on Broadbalk at Rothamsted. After 150 years of the different fertilizer and manure treatments, the soil organic matter levels are now relatively stable and Jenkinson and Parry (1989) have published the N cycle shown in Fig. 1. The annual N loss amounted to some 70 kg/ha but the authors could not apportion this loss between gaseous loss to the atmosphere and NO₃ leaching. Subsequently, Addiscott and Powlson (1992) showed that the proportion of loss going to the atmosphere and to leaching depended on rainfall.

In the soil-plant-animal system by far the largest part of the N is in soil organic matter (SOM), see for example Fig. 1. But SOM is not an infinite sink for N. In any farming system, SOM reaches an equilibrium value which depends on the annual input of organic matter and its rate of decomposition, the rate of breakdown of existing SOM, soil texture and climate (for examples see Johnston 1986, 1991). On the silty clay loam at Rothamsted, when an arable soil with about 1.7% SOM, its equilibrium level, was put down to permanent grass, it took 100 years for the SOM to increase to about 5.0%, a level characteristic of permanent grassland on this soil type under the prevailing climatic conditions. Because the relationship between the increase in SOM and time is exponential, it took about 25 years to reach the SOM level halfway between the two extremes (Johnston, 1991).

As SOM increases the soil frequently contains more NO₃ at risk to loss by leaching. Fig. 2 shows for the period September to April, the NO₃ concentration in two soils, one given 35 t/ha FYM, the other NPK fertilizers (48 kg/ha N)

annually since 1856 in an experiment at Rothamsted. The FYM- and fertilizer-treated soil contained, on average, 130 and 50 kg/ha inorganic N throughout the winter period to a depth of 110 cm.

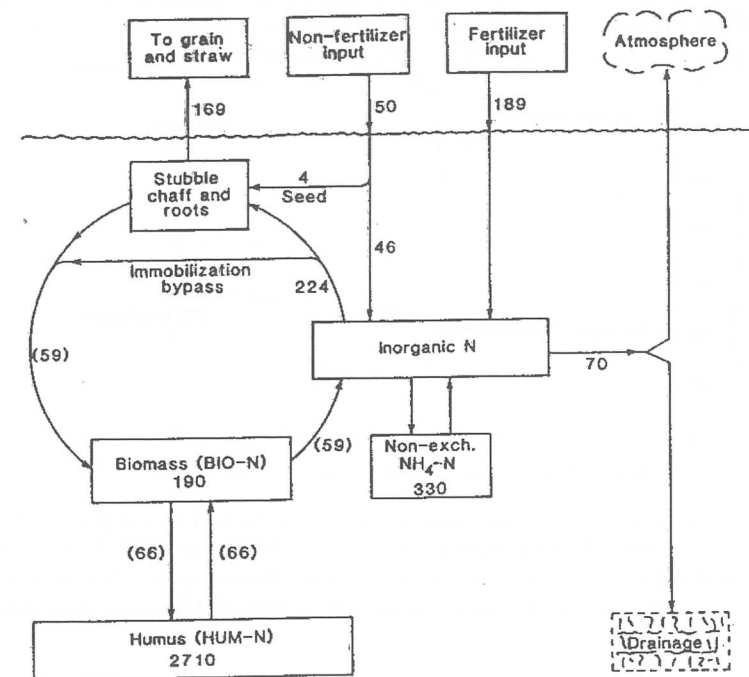


Fig. 1. Nitrogen cycle under continuous winter wheat grown in the Broadbalk experiment, Rothamsted and receiving 192 kg N ha⁻¹ each year since 1968. All N transformations are assumed to take place in the plough layer (0-23 cm). Many of the figures were derived from ¹⁵N-labelled fertilizer experiments made between 1980 and 1983; figures within boxes are kg N ha⁻¹ (mean of all four years); figures between boxes are the means of 1980 and 1981; figures in parentheses are calculated from the model described by Jenkinson and Parry (1989).

NITROGEN USE EFFICIENCY

To achieve economically viable crop yields it is frequently necessary to supplement the supply of plant available N from the soil with N applied in fertilizers or organic manures. In part, this is because the mineralisation of SOM rarely coincides in time or amount with crop demand. But for the applied N to be used efficiently all other soil factors must be optimum. Fig. 3 shows the yields of spring barley given three amounts of N on soils with different amounts of Olsen P and exchangeable K. Only when P and K were optimum was it justified to give the largest amount of N.

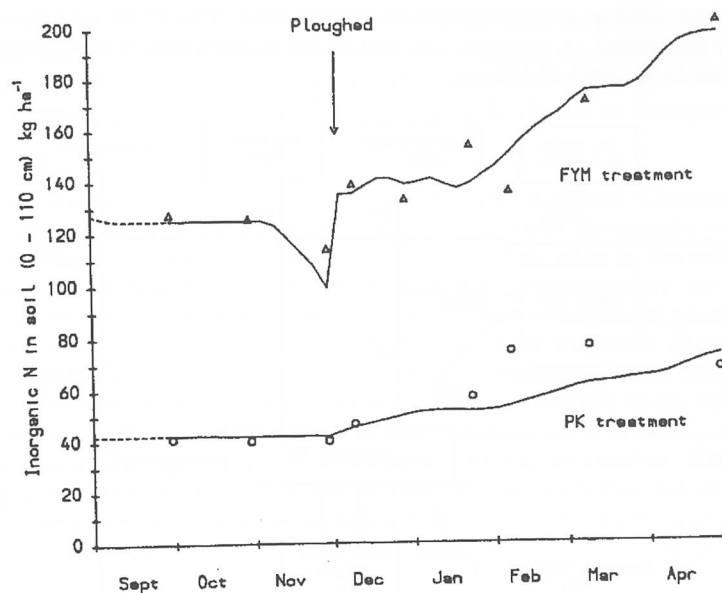


Fig. 2. Inorganic nitrogen (ammonium + nitrate) in soil to a depth of 110 cm in soils treated annually with farmyard manure (FYM) or NPK fertilizers since 1856, Hoosfield Continuous Barley experiment, Rothamsted. Measured values (data points) or simulated (lines) using the model of Addiscott and Whitmore (1987).

The experimental estimation of fertilizer N use efficiency is frequently assessed by the difference method:

$$\% \text{ recovery} = \frac{\text{uptake by crop given N} - \text{uptake by crop without N}}{\text{N applied}} \times 100$$

To get meaningful results it is essential that the amount of available soil N is the same on both the control and N fertilized plots.

A much more robust assessment can be got by labelling the N in a fertilizer with its heavy isotope ^{15}N and following the fate of this labelled N. Table 1 shows data for four years when labelled N was applied to actively growing winter wheat on Broadbalk. On average, about 20% of the labelled N remained in the soil and about 20% could not be accounted for. Of the ^{15}N in the soil, the proportions in stubble, SOM, biomass and mineral N (mainly NO_3) were approximately 9, 69, 17 and 5% respectively. This data shows that when the appropriate amount of N is applied to actively growing cereals at the correct time then very little remains as NO_3 in soil in autumn at risk to loss by leaching. The nitrate that does accumulate in soil following cereal harvest comes almost entirely from the mineralisation of SOM (see Macdonald et al., 1997 and the references therein). More recently Pilbeam (1997) has reviewed all readily available data from ^{15}N

experiments done globally on rainfed winter wheat. Rainfall had a major effect on yield and, as would be expected, on the proportion of labelled N in the crop and in the soil at harvest. But, on average, 20% (range 10-30%) of the applied N was not accounted for. Determining the pathway of loss of this N and then finding ways of decreasing it would have a major financial benefit for the farmer as well as minimising possible adverse environmental effects.

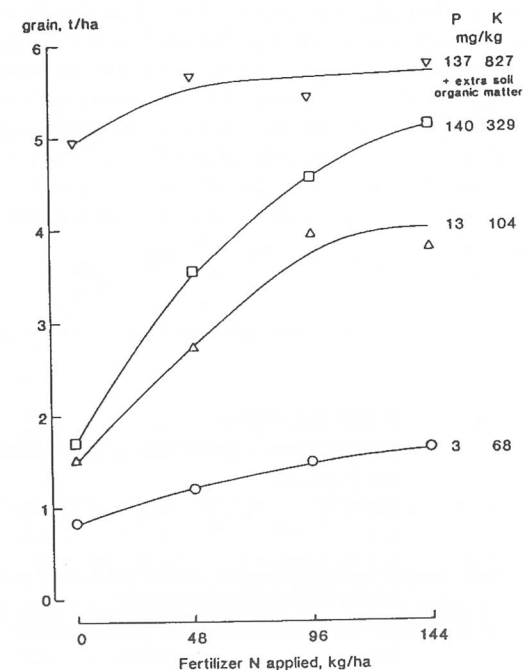


Fig. 3. Response by spring barley, cv Georgie, to nitrogen on soils with different concentrations of Olsen P and exchangeable K and with extra soil organic matter (4.6 v 1.8%) Hoosfield, Rothamsted (from Johnston, 1994).

Table 1. Percentage distribution at harvest of fertilizer-derived nitrogen applied at 144 kg N ha⁻¹ labelled with ^{15}N , Broadbalk, Rothamsted. (Adapted from Powlson et al., 1986).

Year	% fertilizer nitrogen in			
	Grain	Straw	Soil	Unaccounted for
1980	55	13	17	15
1981	37	16	20	27
1982	45	23	24	8
1983	44	13	16	27
Mean	45	16	19	19

NITROGEN AND GRASSLAND

– Nitrogen interactions with phosphorus and potassium

The interaction between N and P and N and K on the yield of permanent grassland are well illustrated by data from Rothamsted where rainfall frequently limits maximum yield to about 12 t/ha dry matter.

Table 2 shows the yields given by 40 and 80 kg/ha N applied for each cut of grass on soils with little or adequate amounts of Olsen P and with a test on both soils of 34 kg P/ha applied each year in spring. Where P was not applied to a soil with a low P status, the yields were small (5 t/ha) and similar with both amounts of N. This implies that much of the 40 kg/ha increment in N was liable to have remained in the soil as NO₃ at risk to loss by leaching during the winter. The results also show that on soils with little Olsen P applying P fertilizer increased yield but not to the level on the soil with adequate Olsen P. Only on soils with adequate P it was justified to apply 80 kg N/ha for each grass harvest.

Table 2. Interaction of nitrogen and phosphorus on the yields of permanent grassland, t/ha dry matter.

Soil P status	N per cut, kg/ha		
	40	80	Increase
	No P added		
Low	5.0	5.2	0.2
Adequate	9.1	11.7	2.6
Effect of soil P	4.1	6.5	
	34 kg P/ha added annually		
Low	7.1	9.0	1.9
Adequate	8.9	12.1	3.2
Effect of soil P	1.8	3.1	

Defining inadequate soil P status requires experiments in which yields are measured on soils with a range of P values. Fig. 4 shows that this can be done for grassland as well as for arable crops. Below the soil P value at which the yield response flattens, the critical value, yields are severely decreased, a financial penalty for the farmer. Above the critical P value there is no financial incentive to further increase the soil P values. There is also a greater risk of P polluting surface waters if excessively P enriched soil is eroded into the water or more P is leached from such soils.

Table 3 shows that there are similar interactions between N and K on the yields of grassland as there are for N and P. As for P, adding K to a soil with less than adequate exchangeable K did not increase yields to those on a soil with adequate K at either of the two amounts of N tested.

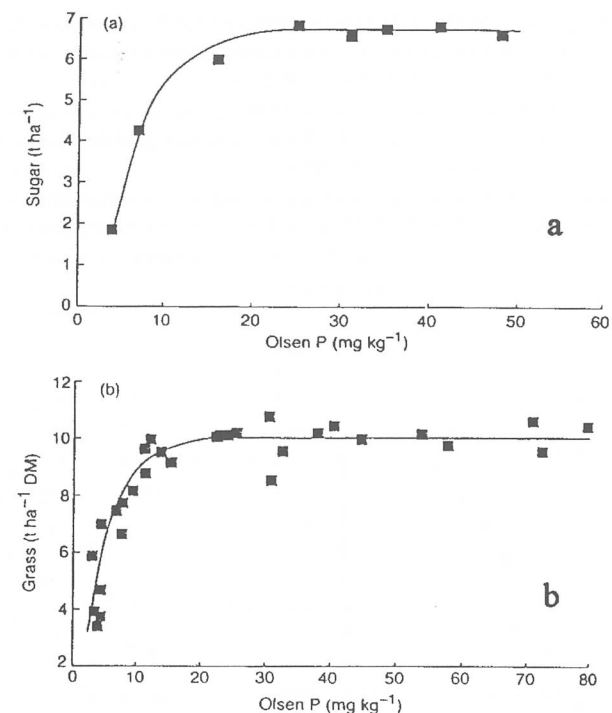


Fig. 4. Relationship between Olsen P and yield of sugar (from sugar beet) (Fig. 4a) and grass on a silty clay loam soil (Fig. 4b), Rothamsted (from Poulton et al., 1997).

Table 3. Interaction of nitrogen and potassium on the yields of permanent grassland, t/ha dry matter.

Soil K status	N per cut, kg/ha		
	40	80	Increase
	No K added		
Low	5.8	6.5	0.7
Adequate	8.5	11.8	3.8
Effect of soil K	2.7	5.3	
	112 kg K/ha added annually		
Low	6.9	8.3	1.4
Adequate	9.0	12.0	3.0
Effect of soil K	2.1	3.7	

Fig. 5a shows that the offtake of K in herbage increases linearly with yield while Fig. 5b shows that more K than N is removed in the harvested crop. Both sets of data imply that the soil must be able to supply large amounts of K. Currently we assess the ability of a soil to supply K to the soil solution on the basis of exchangeable K. But there is evidence that as K is removed from the soil solution by plant uptake it is replenished from exchangeable K and this in turn is replenished by non-exchangeable K. The available evidence shows that there is a good relationship between exchangeable and non-exchangeable K on some soils (Johnston and Mitchell, 1974). Research to determine similar relationships for a wide range of soils would be well justified because it would give greater confidence in deciding critical soil K values.

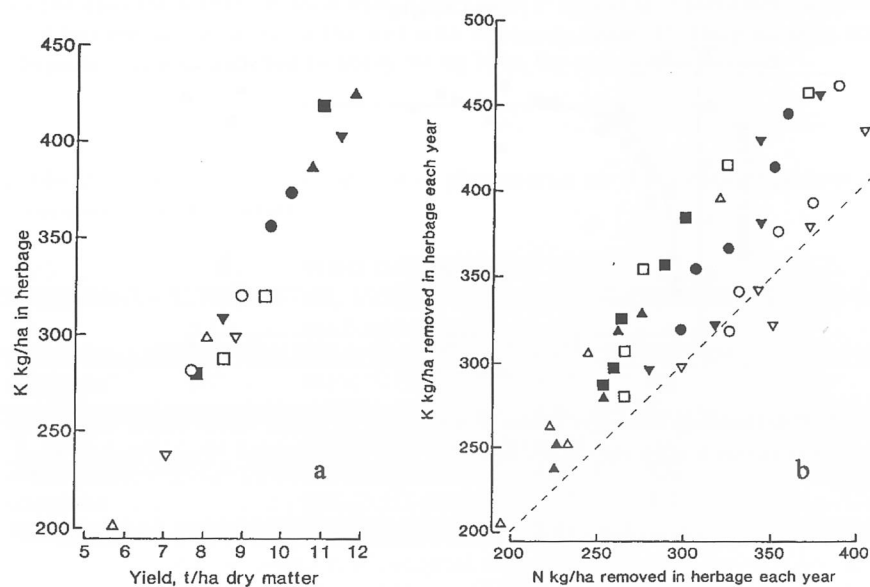


Fig. 5. Relationship between potassium in herbage and yield (Fig. 5a) and potassium and nitrogen in herbage (Fig. 5b).

In the 1950s and 1960s much was written about luxury K uptake by grass (see for example Cooke, 1967). Luxury K uptake was defined as increasing concentrations of K in grass dry matter without a commensurate increase in yield. However, much of the K taken up by plants is used to control cell turgor (a biophysical function). In general larger, rather than smaller plant cells will have a larger green surface to photosynthesise. But larger cells will contain more water and therefore require more K to maintain turgor.

Some work with cereals (Leigh and Johnston, 1983) and later with grass (Barraclough and Leigh, 1993) suggested that if K concentrations were expressed on a tissue water basis rather than on a dry matter basis then there was a near constant level of solution K throughout the period of active growth. Also K sufficient plants had a greater concentration of solution K than did K deficient plants. This suggests that there is no luxury uptake. Rather the cells need K to maintain turgor and that it is the relationship between dry matter production and water use which is important. If the K concentration in dry matter increases this suggests that the plant has taken up more water than it used effectively in the production of dry matter.

– Nitrogen responses and recoveries

It is probable that there will be differences between N recoveries by permanent grassland and grass leys grown in rotation with arable crops depending on the level of soil organic matter and the amount of N applied. When grass leys are grown on soils with little organic matter then some N may be sequestered to SOM. On permanent grassland at its equilibrium level of SOM there will be no net change in total soil organic N.

Table 4 shows the total annual yield of herbage from four cuts of permanent grass testing six amounts of N and the % recovery of N determined by the difference method. In this experiment the legumes in the sward were killed by selective herbicides to determine the yield and N uptake by other components of the sward. This explains why the % recoveries of N exceeded 100% where a total of 75 and 150 kgN/ha was divided equally between the four cuts of grass. These small amounts of fertilizer N produced insufficient growth of the other component species of the sward to eliminate the legumes. There were excellent recoveries of applied fertilizer N up to 300 kg/ha. Even with 375 kg N/ha, % recovery was very much better than would be achieved with arable crops. In an experiment with ^{15}N on this site, labelled fertilizer N was applied in spring of year 1 and its fate followed over that and the following year. At the end of two years, 60% of the labelled N had been removed in the harvested crops, 30% remained in the soil and 10% was unaccounted for (Jenkinson et al., 1983). The latter was a little less than in the corresponding experiment with winter wheat.

Table 4. Effect of nitrogen on the total annual yield of herbage from a permanent grass sward and the recovery of the fertilizer nitrogen.

	Total N applied, kg/ha per year						
	0	75	150	225	300	375	450
Yield							
t/ha dry matter	1.8	6.1	8.3	10.0	11.8	12.0	12.4

Table 5 shows the yield, N removed in the harvested crop and the % recovery of the N applied to irrigated, short term, all-grass swards newly established on soils which had long been in arable cropping. The experiment was duplicated on the silty clay loam at Rothamsted and the sandy loam at Woburn. The total annual application of N was divided equally for each of the six harvests, and the yields shown are averages for the four years 1978-81. Where the applied N was in the range 100 to 300 kg/ha, % recoveries of the N were less than those on permanent grass (cf Tables 5 and 4). This suggests, as noted previously, that some of the fertilizer N had been sequestered into SOM where leys followed a period of arable cropping. The yield data suggest that it was not justified to apply N in excess of 400 kg/ha at Rothamsted and 500 kg/ha at Woburn when the grass was cut for conservation and there was no water stress. But, with these large amounts of applied N apparently good recoveries of about 75% still left large quantities of N unaccounted for. Any environmental impact of this N will depend on how much N has been stored in SOM.

Table 5. Effect of nitrogen on the total annual yield of herbage from a newly established, irrigated grass sward, the offtake of nitrogen and the recovery of the fertilizer nitrogen. (Adapted from McEwen et al., 1989).

		Total N applied, kg/ha per year						
Site*		0	100	200	300	400	500	600
Yield								
t/ha	R	2.0	3.6	7.8	10.0	13.4	13.7	13.9
dry matter	W	1.4	3.8	6.5	10.8	13.0	14.7	14.3
N								
offtake	R	40	70	160	210	340	390	450
kg/ha	W	20	70	130	230	310	400	420
%	R	-	30	60	57	75	70	68
recovery	W	-	50	55	70	72	76	67

* R = silty clay loam, Rothamsted; W = sandy loam, Woburn.

In the same experiment to that described immediately above, similar tests of N were made on newly established grass-clover leys. Again these leys were irrigated and cut six times each year but N was tested only up to 400 kg/ha, again equally divided for each harvest. Table 6 shows that in the absence of applied N, yields from the grass-clover leys were, on average, six times larger than those from all-grass leys (cf Tables 6 and 5). With extra fertilizer N, maximum yields from both the grass-clover and all-grass leys were very similar. However, Table 6 shows that although the fertilizer N increased yields there was little or no extra N in the harvested crops so that in many cases none of the extra fertilizer N was recovered. It is most unlikely that all of this extra N was stored in extra SOM and there could have been large losses to the environment.

Table 6. Effect of nitrogen on the total annual yield of herbage from a newly established, irrigated grass clover sward, the offtake of nitrogen and the recovery of fertilizer nitrogen. (Adapted from McEwen et al., 1989).

		Total N applied, kg/ha per year				
Site*		0	100	200	300	400
Yield						
t/ha dry	R	9.7	10.9	11.5	12.3	13.3
matter	W	10.7	10.9	11.5	11.5	14.0
N offtake	R	358	380	355	356	426
kg/ha	W	389	371	340	336	382
%	R	-	2	0	0	17
recovery	W	-	0	-	-	0

* R = silty clay loam, Rothamsted; W = sandy loam, Woburn.

- Losses of nitrogen on ploughing grassland

There can be large losses of N when grassland is ploughed due to the mineralisation of the large stock of soil organic matter. For example, when old grassland on the silty clay loam at Rothamsted was ploughed in November the loss of N amounted to about 500 kg/ha even when the soil was cultivated and resown to grass in March (diArifat and Warren, 1960).

An experiment on the sandy loam soil at Woburn tested the effect of one-to-six-year old grass clover leys on the yields of the following arable crops the first of which was winter wheat. The leys were ploughed on 17 July and the wheat drilled on 25 September. Nevertheless there were large losses of N which increased linearly from 110 to 250 kg/ha as ley duration increased from one to six years. This led to computed values of NO₃ in the through drainage that year which ranged from 180 to 400 mg NO₃/l (McEwen et al., 1989). Water with such large concentrations of NO₃ would need to be diluted many times before it reached the upper limit of 50 mg NO₃/l in water intended for human consumption.

Nitrogen losses in grazed grassland are frequently even larger than in grassland cut for conservation. Garrett et al. (1992) gave an excellent overview of the N economy of grazed grasslands. They showed that the relationship between total N loss, kg/ha each year, by leaching, denitrification and volatilisation and the N consumed by the animal was curvilinear. Total losses were about 40 kg N/ha when 100 kg N/ha was consumed increasing to about 250 kg N/ha lost when 400 kg/ha was consumed. These authors also gave an excellent example, Fig. 6, of the linear relationship between N losses by leaching and denitrification showing that as losses by one pathway decrease those by another increase.

There is still much uncertainty about the relationship between NO₃ leached and N applied to grazed grassland. Fig. 7 shows four NO₃ leaching curves derived from different studies. For example, from curve 4 leaching losses with 800 kg

N/ha are about 100 kg N/ha while from curve 1 leaching losses are 150 kg N/ha with less than 400 kg N/ha applied. If all four curves are correct then it is difficult to suggest upper limits for N applications to grazed grassland which might be imposed to limit the risk of NO₃ leaching. If all four studies are correct it also suggests that any limits which are imposed will have to be restricted to small regions where soil types and farming management are similar.

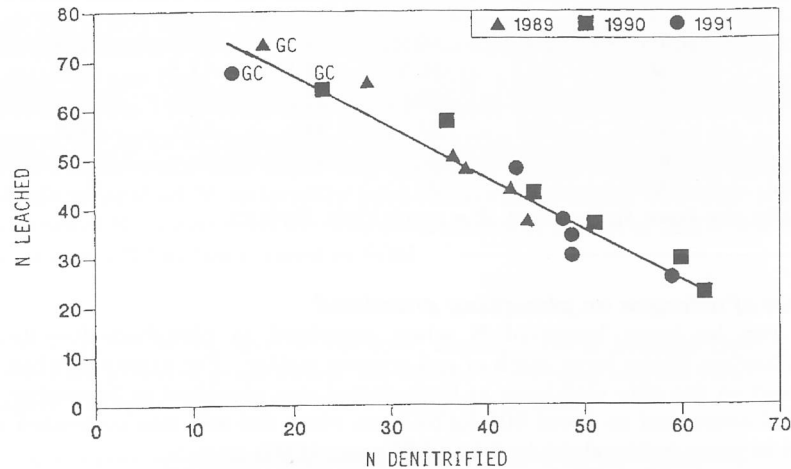


Fig. 6. Relationship between leaching and denitrification for grazed grassland in Northern Ireland receiving different rates of nitrogen fertilizer and for a grass-clover (CG) system (from Garrett et al., 1992).

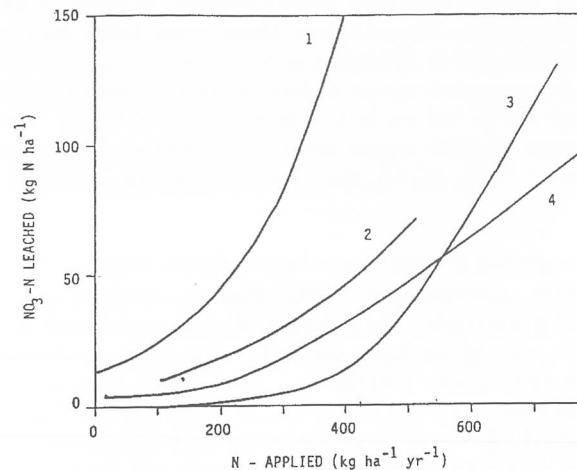


Fig. 7. Nitrate leaching curves for grassland systems derived from the following studies: Curve 1 in the Netherlands with grazing management (van der Meer and Meeuwissen, 1989); Curve 2 from Fig. 5 CENIT Project Northern Ireland (see Garrett et al., 1992); Curve 3 in England with grazing (Barracough et al., 1992); Curve 4 in Germany and the Netherlands (Kolenbrander, 1981).

CONCLUSIONS

To obtain maximum benefit from applied N requires considerable managerial skill in ensuring that all appropriate factors like soil biological, chemical and physical properties are optimum. In agricultural systems in temperate regions there are considerable amounts of organic nitrogen in soil organic matter and where there are livestock, in organic manures also. The amount and rate of release of this organic nitrogen is difficult to predict because it is a biological process. Because of the variability in the mineralisation process it is never easy to give site specific recommendations for fertilizer N applications. Seeking to minimise losses of N from agricultural systems must consider the whole system, paying special regard to the turnover of N through organic materials, and recognising that the successful decrease in lessening losses by one pathway may increase losses by another. Seeking a balance between an economically viable agriculture and its minimum environmental impact will never be easy. The imposition of any control on the use of N must consider not only differences between individual farming systems but also the probable effects on the economy of the farm and the peripheral industries dependent on viable farming enterprises.

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Potash – The Cinderella Nutrient

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Whilst potassium (K) is clearly identified as one of the three major nutrients for plant growth, there are a number of practical reasons why it tends to receive less attention than nitrogen or phosphorus. There is evidence that this is now leading to adverse effects on production efficiency and long term fertility in Irish agriculture.

WHY POTASH RECEIVES LESS ATTENTION THAN IT SHOULD

There are a number of highly practical reasons why potash may not command the attention it should at a farm level. Firstly there is rarely clear, unequivocal visual evidence of K shortage. Soil fertility of course cannot be seen and although everyone would accept this, there is still too little use made of soil analysis to provide factual measurements. K deficiency in the plant can be clearly described in theory, but in practice the same symptoms may well be caused by many other factors and be unrelated to K nutrition. Even where correct visual diagnosis of K deficiency is made it may be too late to fully rectify the situation.

It might be argued that the relatively low cost of potash compared with other nutrients should encourage adequate use but perhaps perversely it appears to add to its low priority.

	Irish £ per unit nutrient
N	3.50 – 4.20
P	8.50
K	2.60

The functions of potash are not as clearly understood by many farmers as are the functions of nitrogen (increasing the rate of growth and yield) or phosphate (root development). If the reasons why an adequate supply are not clear there is less incentive to use the input, especially when there are strong pressures to try and reduce costs overall. In particular, the lack of understanding as to what potash does, results in frequent under-estimate of the large quantities of K that are needed. The fact that peak uptake of potash is frequently greater than the peak uptake of nitrogen and that for cut swards the amount of potash to be replaced is equal to the amount of nitrogen applied, is often met with disbelief by farmers.

The considerable research programme looking at environmental aspects involving nitrogen and phosphate also draws more attention to these nutrients and away from potassium which has no such R & D justification because it provides no risks to environment or health.

ENVIRONMENTAL ISSUES

Concerns over phosphate impact on the environment have resulted in more careful and responsible use of this nutrient in Ireland over the last few years and because of the practical linkage between P & K in compound fertilisers this has had a marked knock-on effect on potash use. In the early and mid 1990s P & K use was relatively static but from 1995/6 onwards there has been a reduction of around 17% in both nutrients largely as a result of environmental pressures on P. See Table 1.

Table 1 Nutrient Usage in Ireland

'000t	N	P	K
1989/90	379	65	158
1990/1	375	63	153
1991/2	358	59	148
1992/3	337	59	146
1993/4*	405	60	145
1994/5	429	62	151
1995/6	417	62	152
1996/7	379	54	132
1997/8	432	50	124
1998/9	443	49	121

Source: Dept of Agr

*Change to Oct/Sep basis from calendar year

Not surprisingly with continuing high levels of production and potash removal over this period, there has been a reduction in soil K reserves as shown in Table 2

Table 2 Mean soil K levels

mg/l (index)	1990	1997	1998
Grazing	124 (3)	128 (3)	123 (3)
Silage	105 (3)	96 (2)	94 (2)
Cropping	114 (3)	116 (3)	113 (3)

Source: IFA Paper 'Caution 33% drop in potash' N Culleton, P Blagden, S McCormack, TEAGASC

Soil K levels under grazing tend to be higher and to have altered very little because a large % of potash is simply re-cycled through the grazing animal back into the soil. This contrasts markedly with cutting areas where large quantities of K are removed and would appear to have been inadequately replaced over this period resulting in declining reserves. The changes in reserves under cropping show no definite trend at present but would be expected to follow a decline if levels of use continue to fall.

SOIL FERTILITY LEVELS

The distribution of soils in each K index band also gives rise to some concern. The index banding of soil K concentrations was devised to represent the following:-

Index 1	Deficient
Index 2	Low
Index 3	Satisfactory (target level)
Index 4	High (some opportunity for economy)

As shown in Table 3 around 65% of cut grass and winter wheat soils and 45-50% of grazing and spring barley soils are below the satisfactory target level for K reserves (index 3). These appear much higher proportions of low K soils compared to UK soils adjusted to a comparable index system. This suggests that there is little scope to allow Irish soil K levels to generally decline further.

Table 3 % of soils in each index band for soil K

% of soils	Soil K index			
	1	2	3	4
Grazing	10	35	30	25
Cutting	20	45	20	15
UK all grass	5	40	45	10
Sp Barley	15	35	25	25
W Wheat	20	45	20	15
UK all cropping	5	20	55	20

Source: 'Soil Fertility in Ireland' P A Blagden TEAGASC Food & Farm Research Feb 1989

POTASH YIELD RESPONSES AND PENALTIES

Silage trials in the UK have indicated substantial yield responses at the equivalent of Irish soil K index 1 and 2 as shown in Table 4.

Table 4 Yield and value response to potash

	Irish soil K index	
	1	2
% yield response at optimum K	65%	28%
Value of extra grass £/ha	415	298
Cost of potash £/ha	67	67
Profit from potash £/ha	348	239

Source: PDA

A simple plot comparison – Table 5 - illustrates the penalties which can result from inadequate replacement of potash removed in a demanding silage cutting regime (3 cuts p.a.) resulting in reduced soil reserves and a radical drop in yields. In this particular study on a sandy loam soil with a soil K value of 93 mg/l (index 2) at the start, soil reserves were quickly reduced to less than 60 mg/l (index 1). Years 2 & 3 were associated with dry summer growing conditions which placed the crop under much stress, and in the absence of adequate K levels, silage yield was much more seriously affected than where potash levels had been maintained.

Table 5 Silage yield penalties where inadequate K replacement results in falling soil K

Yield index	Year 1	Year 2	Year 3	Year 4
Yield with K replacement	100%	100%	100%	100%
Yield with nil K	87%	74%	51%	47%
Yield penalty	13%	26%	49%	53%

Source: PDA

Of course not all soils would perform in the same manner – the greatest penalties would be expected on lighter soils with smaller reserves of K. Heavier soils would be able to sustain satisfactory yields for longer but would be much more difficult to restore to satisfactory soil K once levels had been run-down. An inadequate supply of K for grassland is also associated with other penalties besides yield, including deterioration of sward composition and loss of productive species and clover, decline in sward density, reduced frost, drought and stress tolerance.

THE N:K PARTNERSHIP

There is a strong inter-relationship between nitrogen and potash. Where potash levels are limiting, nitrogen fertiliser will neither be taken up by roots so readily nor synthesised in the plant so effectively. This may result in surplus N remaining in the soil increasing the risk of leaching, lower total protein yields in the crop and higher levels of simple N compounds in the silage leading to poorer fermentation and feeding quality. It is salutary to examine the change in the N:K ratio of use indicated by the national figures in Table 1. The widening of the N:K balance of use in the light of the considerable proportion of soils with modest or low levels of K reserves must be viewed as extremely worrying in terms of sustainability of future yields and soil fertility.

Table 6 N:K ratio of use

	N:K ratio
1989/90	2.40 : 1
1990/1	2.45 : 1
1991/2	2.42 : 1
1992/3	2.31 : 1
1993/4	2.79 : 1
1994/5	2.84 : 1
1995/6	2.74 : 1
1996/7	2.87 : 1
1997/8	3.48 : 1
1998/9	3.52 : 1

Source: Dept of Agr

PRINCIPLES OF POTASH MANURING

Soils maintained at adequate fertility levels by past manuring practice are more efficient and productive than impoverished soils which receive larger amounts of fresh fertiliser in order to compensate. The aim therefore is to maintain soils at a satisfactory level of reserve (the target is index 3) by replacing nutrient removed in the crop. Potash removal in silage is considerable, 3.5 – 4.0 kg K per tonne of silage, and is often under-estimated especially with high yielding modern short term ley mixtures which are cut several times in a season.

Grassland fertilisation is complicated by the return of FYM or slurry usually in un-measured quantities with varying dilution of slurries and uncertain nutrients contents in manures. More careful estimation of this nutrient contribution must be made, but the long term practical test is that if soil analysis reveals that soil K levels are falling, the overall balance in the rotation is negative and fertiliser additions must be increased.

A relevant analogy is to compare potash in the soil to the oil in a car engine and the measurement of soil K to the dip-stick – see figure 1. As with oil in an engine, it is appropriate to maintain soil K at a specific level which is determined by soil type and cropping system. To drop below the normal mark indicates a risk that the engine/plant will not operate as efficiently and at some stage will completely fail. Thus potash should not be applied in order to achieve a direct yield response in the same way as other inputs. It should be applied simply to replace that taken-off in the crop in order to maintain the same level on the dipstick. At this level soil reserves will provide the needs of the crop and ensure full potential yields. Where levels have been depleted, fertiliser additions need to be greater than removal whilst for soils at high levels of fertility, additions may be reduced or omitted. This should be the basis for practical fertiliser policy.

POTASH LEACHING ?

Whilst virtually all forms of potash are water soluble, the nutrient is held by the clay minerals so that potash does not move through the soil and become lost if it is not taken up by the crop as is the case with nitrogen. On lighter soils particularly where there is little depth and therefore less volume of soil to absorb K, potash will move further and fertiliser policy should follow the rule of little and often. However for the great majority of soils it is misleading to suggest that potash leaches - measurements in the UK indicate that only 1kg/ha of K is lost beyond rooting depth for every 100mm of through drainage. Thus the maintenance of target levels of K in the soil is a sustainable and effective policy.

PRACTICAL ISSUES

Current potash recommendations for single cut silage systems look about right in terms of replacing average removal and improving low K soils, but for multi-cut intensive systems producing high yields, current recommendations may not make sufficient allowance for offtake. Of greatest importance is the question as to whether recommendations are actually being followed in practice. For all the reasons given above there is a tendency for potash requirements to be overlooked especially where there is the need to reduce phosphate levels.

In practice this suggests the need for wider ratio P:K products which are more in line with the balance of P:K offtake which for silage is 1 : 6.5 and are matched to soil P needs. The popular 0:7:30 may still be applying more phosphate than needed in some cases and a move to straight muriate of potash (50% K) could be highly worthwhile - achieving a reduction in costs, addressing the environmental concerns and maintaining future yields and fertility. The same principles may also apply in some situations to typical 18:6:12 product use, where a switch to a simple N:K product may again save money and provide a better technical solution.

CONCLUSION

Whilst this article deals with general issues, best fertiliser practice must operate on a site specific basis and it is essential to calculate fertiliser needs for each particular situation on an individual basis and use the support of a well informed advisor or technical salesman.

Decline in Lime Usage

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The usage of lime has declined in recent years. In 1995, there were slightly over 1.1 million tonnes sold, while in this year it is reckoned that lime usage will be done to approximately 750,000 tonnes. This decline is reflected in the lime requirements in the soils analysed at Johnstown Castle laboratories in recent years. In 1995, the mean LR for the country was 5.3 tonnes/ha, while in 1997 the LR was 6.1t/ha. The soils of the country have become a little more acid.

It is now widely accepted that the availability of most nutrients to plants is seriously reduced in acidic conditions. Phosphorus, which is the most expensive major nutrient, is significantly less available to plants at low soil pH than at high pH. Similarly, when soils are above pH 6, the micro-organisms in the soil recycle nutrients rapidly and considerable quantities of nitrogen are released from the soil to become available to plants.

In a time where there is (a) great emphasis on reducing P inputs and (b) restrictions on N usage in the Rural Environmental Protection Scheme (REPS) it is surely highly advisable that lime be applied to soils to meet the lime requirement of crops. The amounts of lime required can only be determined accurately by a soil test.

Lime in Irish Agriculture

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The main function of liming soils is to correct soil acidity. In addition to reducing Al and Mn to sub-toxic levels, liming alters the capacity of the soils to retain cations and anions (Coleman and Thomas, 1976) and changes the availability of most plants nutrients (Jackson, 1967).

(1) INFLUENCE OF LIME IN SOIL

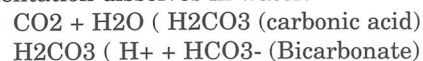
Lime has many benefits in the soil and is a vital factor in soil fertility. The importance of lime can be considered in relation to:

- Soil Acidity Control
- Soil micro-organism activity
- Soil structural development and maintenance
- Nutrient availability
- Crops and Livestock

(1) Soil Acidity

Soil acidification is a natural process, caused by a range of phenomena: preferential leaching of bases, acid rain, organic matter decomposition, crop off-takes, fertiliser use and differential uptake of cations and anions.

Soils become acid because of prolonged recurrent leaching coupled with the inputs of acids (Substances capable of releasing H⁺). While water itself is a weak acid, soil water contains stronger acids, mostly of biological origin. Carbonic acid is the most abundant and is formed when CO₂ gas from respiration and fermentation dissolves in water:



Even as rainfall drops through unpolluted air, it absorbs enough CO₂ to lower its pH from 7.0 to about 5.5. In soils, microbes and roots greatly increase the CO₂ pressure and concentration of carbonic acid. Nitric and sulphuric acids both occur in air polluted by burning of vegetation and fuels, and even more of them is produced in the soil by the biological oxidation of ammonium ions and sulphur. Finally, roots and soil microbes release organic acids or their anions.

However, acid input alone does not explain cumulative acidification. With every addition of acid to soil some H⁺ is adsorbed onto soil colloids by its attachment to pH dependant sites, or by the exchange of H⁺ with Ca, Mg, K or Na. The retention of H⁺ is aided when leaching removes the anions of the acids along with the displaced Ca, Mg, Na and K that would otherwise compete with H⁺ for attachment to the colloids.

This mechanism explains why acid soils develop mostly under conditions of vigorous leaching and biological activity. It also explains why soil acidity develops more readily on parent material that contain little Ca, Mg, Na and K. As a natural process, acidification is favoured by high rainfall, low evaporation, free drainage, ample oxidative biological activity that produces acids. Acidification is accelerated by certain agricultural practices e.g. some selectively promote H⁺ producing processes in the cycling of N and other plant nutrients.

The most important of these processes are nitrification

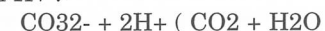


and the excessive removal of cationic plant nutrients NH₄⁺, K⁺, Ca²⁺ and Mg²⁺ for which the plant exchanges H⁺ into the soil. Practices that promote these acidifying processes include the production and removal of heavy harvests, the accumulation of soil organic matter, and the inputs of large amounts of N by means of ammonium fertilisers or biological nitrogen fixation.

Acid soils normally develop high levels of dissolved and exchangeable aluminium. As its concentration rises Al displaces H⁺ and other exchangeable cations, occupying much of the exchange capacity. More than 15-20% of the exchange capacity occupied by AL spells trouble for many crops species. Manganese toxicity is likewise connected with soil acidity.

Acidity itself, even lower than 5.5 does not necessarily cause crop problems. The pH effect is compounded by Al and Mn toxicity. Roots are commonly the first organism to show injury owing to acidity and/or Al toxicity. Stunted roots have difficulty getting immobile nutrients (e.g. P) which are frequently deficient in acid soils. Because of poor root growth and reactions between Al and P, Al toxicity in plants resembles P deficiency and the correction of Al toxicity can reduce the need for fertiliser P (Singer and Munns, 1991).

The use of lime to correct acidity has been practiced for centuries (Johnston et al., 1986). Its mode of action has been discussed extensively (Gallagher, 1930, a,b; Walsh, 1942; Walsh and Golden, 1952; Johnston and Whinham, 1980; and Archer, 1985) and it is not proposed to deal in detail with the soil chemistry here. When lime is applied many things happen, primarily the base carbonate reacts with H⁺ :-



As H⁺ is reacted, the pH rises. The higher concentration of OH⁻ immobilises free Al, by precipitation of aluminium hydroxide. The H⁺ and Al³⁺ ions in the soil solution are important because they directly influence roots etc., but their quantity is relatively negligible in comparison to the amounts of acidity that the soil solid phase can release as the soil pH is raised. The solid phase reserve acidity acts as a pH buffer system. The capacity to release and take up Al and H is the soils buffering capacity which determines the amount of lime needed to bring about a desired shift in pH.

In general, an acid soil is better pH buffered, if it has considerable clay and humus and if these colloids have high reactivity, cation exchange capacity and pH dependent change. Well buffered soils need larger but less frequent additions than weakly buffered soils; and a lime quantity suitable for a well buffered soil would overlime a weakly buffered soil.

(2) Soil Organism Activity

The soil is inhabited by vast numbers of microscopic organisms - bacteria, fungi, algae and protozoa. The breaking down of plant and animal residues leading to formation of humus and the mineralisation of simple plant nutrients in available form is dependent on their activities. These organisms are influenced by soil acidity and liming.

The addition of fresh organic matter to the soil causes a great increase in the number of micro-organisms when soil conditions are favourable. In the course of the resulting decomposition, carbonic acid and other acids are formed. Soil acidity increases until the growth and activity of the micro-organisms is interfered with, even though these may still be some fresh organic matter remaining in the soil. The addition of lime, by reducing acidity, encourages the soil organisms and tends to permit decomposition to proceed to completion, with the accompanying liberation of nutrients.

The development of a mat of undecomposed litter on grassland under acid conditions is a good illustration of the relationship between soil, lime and the activities of soil organisms. In grassland, worms play a part in the removal and digestion of old dead herbage (Foth, 1990); the beneficial bacteria continue the process and, ultimately, release plant nutrients. Under acid conditions, the activity of worms and bacteria is reduced, dead herbage accumulates, soil nutrients become locked up in undecayed organic matter, aeration suffers and as a result, a surface mat builds up and the sward rapidly deteriorates. Liming combined with other renovation treatments points the way to improved fertility and better quality herbage.

Activity/virulence of many pests and diseases of crops is also affected by pH status of the soil. For example, Johnston and Whinham (1980) noted that some pathogenic fungi only survive in acid soils, or are more damaging at acid pH values. *Plasmodiophora brassicae* which causes finger and toe or club root tolerates acidity better than its host plant and so causes more damage on acid soils. On the other hand, *Ophiobolus graminis* (take-all in cereals) usually occurs on soils well supplied with lime. Similarly, liming immediately before potato cropping should be avoided because it exacerbates Common Scab, caused by *Streptomyces scabies*.

Soil pH will affect the adsorption, stability and mobility of pesticides. A decrease in the pH of soil particles increases the adsorption of most surface acting herbicides (Archer, 1983). This may result in poorer weed control or may require larger application rates.

(3) Soil Structure

It is widely accepted by farmers that liming improves the structure of heavy soils, reduces stickiness, lightens cultivations and makes it easier to break down clods to obtain a satisfactory tilth. Johnston and Whinham (1980) reported that liming light soils prevents crusting or capping, while liming heavy soils improves friability and eases cultivation, reducing drawbar pull and increasing tractor speed.

Many of the beneficial effects of lime on soil structure are indirect. For example, the addition of lime to an acid soil increases the population of bacteria responsible for breaking down organic matter. The decomposition of organic matter helps soil crumb formation.

On the other hand lime has the effect of making heavy wet grassland soils more liable to poaching because of the more rapid breakdown of the surface layer of undecomposed organic matter at or near neutral pH. There is therefore a conflict between the benefits of liming in terms of improved yield, nutrient efficiency and N release and the disimprovement in utilisation of the sward for grazing.

(4) Nutrient availability

Liming affects the availability and uptake by crops of both major and trace elements. It may also affect the toxicity to plants of some of these elements. The pH influences nutrient availability by causing deficiency or toxicity. The ideal pH achieves a balance between these extremes. Nutrient uptake is influenced by pH in terms of cation vs. anion uptake. Curtin and Smillie (1983) showed that liming dramatically changes the composition of the soil solution in ways which must influence plant composition and yield. The general relationship between availability of plant nutrients under the influence of soil pH is illustrated in Table 1.

Table 1: Effect of pH on availability of plant nutrients - Gardiner and Garner (1953)

Nutrient	pH below 6	pH 6 to 7.5	pH 7.5 upwards
Nitrogen	Falls gradually	Steady	Possibly falls slightly
Phosphorus	Falls rapidly	Steady	Falls considerably
Potassium	Possibly falls slightly	Steady	Falls considerably
Calcium Magnesium	Falls steadily	Steady	Remains high
Manganese	Rises rapidly as pH falls	Falls rapidly if much organic matter	
Iron Aluminium	Rises rapidly	Falls fairly rapidly and is very low at 8.5	
Boron	Steady until high		
Copper	Acidity when it falls	Falls steadily 7.0 up to 8.5	
Zinc			
Molybdenum	Falls	Increases rapidly as pH rises	

With some elements, these effects are mainly associated with changes in availability due to conversion to more soluble forms e.g. manganese become more available as soil acidity increases, even to the extent of becoming toxic to crops under extreme conditions. Others become toxic when acid conditions are associated with poor aeration e.g. iron. Molybdenum becomes more available as alkaline conditions increase. Phosphates are converted into less soluble compounds of iron and aluminium as acidity increases. In alkaline conditions phosphates are again rendered less available with the formation of relatively insoluble dicalcium phosphate etc.

Thus, the pH for maximum availability of nutrients for crop use is not the same for all nutrients. This is shown by data in Table 2 (Foth, 1990) and refers to the pH values at which the availability of the individual nutrient is maximal: generally pH values in the range 6.5-7.0 is taken to be the optimum value for soil pH.

Table 2: Optimum soil pH values for maximal availability of the major and most important micro-nutrients.

N	P	K + S	Ca + Mg	Fe	Mn	B, Cu + Zn	Mo
6-8	6.5-7.5	>6	7-8.5	<6	5-6.5	5-7	>7

It is generally accepted that pH *per se* is not a major cause of poor plant growth in acid soils but rather that low pH causes changes in the soil which affects growth. Thus, Arnon et al. (1942) showed that many plants grow satisfactorily in water culture at a pH as low as 4. Also, vegetables will give high yields in peats at pH values of around 5.

One of the characteristics of acid soils is the risk of aluminium toxicity. Acid solutions cause the breakdown of clay minerals releasing aluminium and these ions are adsorbed onto the surface of the remaining clay particles where it is available to plants as a toxic element. The physiology of aluminium in soil solution is complex; very few plants appear to require it (apart from the tea plant), some plants are stimulated by Al in low concentrations but in general Al in solution retards the growth of roots and prevents or inhibits the uptake of phosphorus and its translocation to the rest of the plant (Fleming, 1980).

Manganese is also found in excess in acid soils. It accumulates in all tissues and interferes with the metabolism of the plant. This problem is best diagnosed by plant analysis. Foy and Brown (1964) reported Mn toxicity symptoms in Lucerne at Mn level of 1,000 ppm in the plant. To be available to plants, Mn must be in a divalent state. For this reason, the toxicity of Mn is affected by the oxidation state of the soil. Drying a very acid soil results in large increases in divalent Mn and hence Mn toxicity. It is, therefore, difficult to predict Mn toxicity by soil analysis. Generally toxicity from Al and Mn occur together and both are ameliorated by liming.

Nitrogen:- Soil acidity affects the supply of available nitrogen from sources in the soil and from added manures and fertilisers (Curtin and Smilie, 1986a). Nitrogen from organic matter, either from applied organic nitrogenous manures or from plant residues, is converted into forms available to plants by the activities of micro-organisms. The organisms responsible for the conversion of organic N to ammonium show a marked tolerance to acidity. On the other hand, the bacteria responsible for the conversion of ammonium to nitrates cannot work efficiently in acid soils and ammonium salts applied as mineral fertilisers remain near the surface and are only slowly converted to nitrates. The application of lime stimulates nitrification. The most favourable reaction range for nitrification lies between pH 6 and 8 (Goulding and Annis 1998).

The process of fixation of atmospheric nitrogen by rhizobia in the roots of leguminous plants is greatly retarded both under strongly acid and strong alkaline conditions. A pH of about 6.3-6.5 is generally considered most favourable for nitrogen fixation by white clover.

Lime x Nitrogen Interactions

Liming stimulates the release of nitrogen from soil organic matter and may also increase nitrogen supply by increasing clover growth. The lime x nitrogen interaction was investigated in a trial set up at Johnstown Castle from 1970 to 1974 (Gately, unpublished data). The trial was conducted on a newly established perennial ryegrass sward and treatments ranging from 0 to 20 t lime/ha were used. The yield of herbage DM was higher for the 20 t lime/ha compared to the zero lime treatment at all levels of nitrogen except the highest level. If one interprets the lime effect simply as affecting nitrogen supply; then for any particular yield of dry matter between 8,000 and 13,000 kg/ha approximately 50-70 kg/ha more nitrogen was required for the zero treatment than for the 20 t/ha treatment. This can be taken as an indication of the amount of nitrogen released. Both lime treatments produced the same yield at 300 kg N/ha, indicating that there was no restricting factor on the zero lime treatment other than nitrogen deficiency. It has already been shown that grass can grow grass at a pH as low as 4.0. It is solubility of elements like aluminium and manganese at these low pH that cause toxicity to plants. At the higher pH, growth is aided by the release of nitrogen from organic matter breakdown. The ideal pH for grass growth and N release is, as already shown believe 6.0 and 7.0.

Murphy and Culleton (1992) reported similar findings in a trial conducted in Kerry in 1990-1992. There was a strong response to lime, especially at the zero nitrogen treatments. Clover made an increased contribution in the limed plots.

Phosphorus:- P fixation occurs through adsorption and precipitation. Adsorption is the dominant process and is largely independent of pH. Precipitation, white less dominant, is very dependent on pH. The most favourable conditions for phosphorus availability is when the pH lies between 6.0 and 7.0. When phosphatic fertilisers are applied to the soil, the phosphate reacts to form either Ca phosphate at high pH levels or Al/Fe phosphate if the soil pH is low. Ca

phosphate is somewhat soluble and available to the plant over time, but al-phosphate is not soluble and hence the P is fixed and unavailable. Liming can make the soil P more available.

Potassium:- The supply of exchangeable potassium in the soil is often low in acid soils, due to the formation of soluble K salt by soil acids and their loss by leaching from the soil. The availability of K begins to fall below a pH of 6.0.

Calcium:- Lime is composed of calcium carbonate. Calcium is an important nutrient for plants and animals but even in acid soils there is usually sufficient calcium present and the supply of calcium is not a major function of the use of lime in Irish soils.

Manganese:- Manganese occurs in several states of chemical combination in soils depending largely on the degree of acidity, aeration of the soil and organic matter. In acid soils, the availability of soil manganese increases rapidly when the pH falls below 6.5, and under very acid conditions may reach toxic levels. At pH values above 6.5 the amount of soluble manganese available for crop growth falls rapidly and under alkaline conditions soon becomes a limiting factor in crop growth in some soils, especially with such susceptible crops as oats and sugar beet. Mn availability is further reduced when the soil is dry. So that Mn deficiency is most common in excessively drained high pH soils.

Iron:- The availability of Iron increases in much the same way as manganese in acid soils, and iron toxicity due to excess of ferrous iron occurs under conditions of poor aeration from impeded drainage.

Boron:- High pH values in soils leads to boron deficiency in susceptible crops such as sugar beet and swedes. In some soils, the content of available boron is so low that even a normal dressing of lime may cause boron deficiency and thus reduce crop yield. When this occurs, the application borax to the soil or chelated boron to the crop will remedy the conditions and at the same time make it possible to meet the lime requirement of crops which need alkaline conditions for normal growth. Boron is needed only in small amounts and excess leads to boron toxicity, especially in very susceptible crops like potatoes. For this reason, boron should only be applied when there is a proven deficiency.

Copper and Zinc:- deficiencies of these in crops have been reported in cases of over-liming.

Molybdenum:- Unlike other micro-nutrients, molybdenum availability increases with increasing pH. Thus, liming a soil already high in available Mo leads to high levels in grasses and can lead to Mo toxicity in grazing animals. Areas known to have this problem have been delineated and liming of such areas must be done with discretion (Section under recommendations). It must be said that not all farms in high Mo areas have the problem. Similarly some farms in low Mo areas have a high Mo problems due to excessive liming.

(5) *Crops and Livestock*

It is clear that the response of crops to liming is complex. However, the bottom line is that there must be obvious crop yield increases before lime can be justified.

In the case of tillage crops, it is generally accepted that lime is essential in order to maintain pH and optimum nutrient levels. Archer (1995) summarised the results of the long term liming trials at Rothamsted and Woburn Farms, and yield penalties for barley for dropping one pH unit below the recommended pH was about 2 t/ha. The critical pH for the range of crops is given in the section under lime requirements.

Cutting trials carried out between 1952 and 1974 have shown that response to liming on grassland approximate to increases of 1500 kg DM/ha on the old pasture and between 3,000 and 4,000 kg/ha on new pastures (Gately, unpublished data). In some instances there were also effects on quality, in the new pastures; ryegrasses fail to establish on the acid plots and poorer species e.g. creeping softgrass (*Holcus mollis*) can grow instead. Curtin and Smillie (1986b) showed that ryegrass was apparently much less tolerant of Al than was bentgrass.

A trial was instigated by Johnstown that ran between 1967 to 1971 to study the response of a range of crops to lime, N, P and K (Murphy, Priv. Communication). Only five sites had an initial pH below six and for the first three years of the trial a high rate of nitrogen was applied across all lime treatments. No responses to lime were observed. The application of nitrogen was discontinued in 1970 and the responses to lime on three out of five sites were observed on grassland (Table 3).

Table 3: Herbage D.M. yields (kg/ha) at different sites and lime rates (t/ha) after withdrawal of N fertiliser.

Site	pH	Rate of Lime t/ha		
		0	5	15
Limerick	5.4	5300	5200	4800
Laois	5.2	5400	5800	5600
Wexford	5.5	3700	5300	4300
Kilkenny	5.4	5300	6500	6900
Louth	5.2	3700	4500	4900
Mean	5.4	4700	5500	5500

Because a considerable amount of nitrogen is recycled through the animal under grazing, it was thought that this might replace the lime effect and that cutting trials might exaggerate the benefits from lime. An experiment was started in 1976 to examine the effects of liming old pasture on the performance of grazing Freisian bullocks (275 kg). The soil had an initial pH of 5.2 and the sward was of mixed species dominated by common bent grass (*Agrostis tenuis*).

The liming treatments and the liveweight gains are summarised in Table 4. The limed treatments were approximately 20% better than the control, but there were no differences between the two lime treatments.

Table 4: Effects of lime on liveweight gain per animal per day (5 animals/ha)

Lime (t/ha)	0	7.5	15
Liveweight gain (kg/ha/day)	0.55	0.65	0.67

The amount of grass on offer when the animals entered various grazing cycles was measured with the following results (Table 5).

Table 5: Grass on offer at different grazing periods.

DM (kg/ha)		
Lime (t/ha)	0	7.5
First cycle	2369	2787
Second cycle	2899	3744
Third cycle	2688	3656

This shows that animals had 18-36% more herbage available on the limed plots. The digestibility and the clover content was higher in the limed plots (Table 6).

Table 6: Digestibility of herbage (May) and %clover (July) in limed and unlimed plots.

Lime t/ha	0	7.5
Digestibility %	66.5	69.2
%Clover	4.7	14.0

(2) LIME, SOILS AND SOIL TESTS

Soil pH is a measure of the H⁺ ion activity in soil solution. In most soils, the soil pH is buffered by several components of the solid phase, including hydroxyaluminium monomers and polymers, the soil organic matter, and (in alkaline soils) undissolved carbonate compounds (Coulter, 1969). An equilibrium condition exists between these components and the soil solution such that when acid or base is added to the solution, the buffering agents may absorb the addition and/or release acid or base to maintain the initial equilibrium. Thus, a change in soil pH due to the addition of a base (lime) is usually much less than predicted by neutralisation, based only on the quantity of acid or base present in the soil solution (as given by the soil pH). Lime requirement tests for soils, which

generate recommendations for effecting relatively long term changes in soil pH, are designed to take account of the buffering power of soils which is usually related to soil texture and organic matter content.

pH is useful as a measure of the degree of acidity/alkalinity of a soil while the lime requirement is an estimate of the amount of lime required to alter the pH in the soil to a target pH.

The pH of the soil can be taken by pH indicators or by pH meters. pH indicators are organic dyes in solution in ethyl alcohol. They change colour depending on pH. A wide pH range can be determined by using a mixture of dyes. These are useful tools for analysis in the field but are restricted in application. They can be helpful in diagnosing the cause of crop failure by checking near the roots of diseased and healthy plants for acidity. They may also be used to decide quickly whether a soil needs lime or not. If the soil is acid a sample should be sent to the laboratory for a precise estimate of lime requirement. They can be used to determine the uniformity of an area before taking soil samples.

The disadvantages of the indicator are :-

- A very small sample must be used and it can not therefore be representative.
- The indicators are not affected by the buffering capacity of the soil so lime requirement based on pH will be inaccurate.
- Indicators are colour tests and yet four per cent of the population are colour blind.
- Soil colour can mask the colour of the indicator.
- It is not possible to accurately estimate L.R. from the pH. pH does not measure the buffering capacity of the soil. Using pH to determine how much lime to use can lead to overliming in some soils and underliming in other soils.

pH can also be determined potentiometrically in a slurry system using an electronic pH meter (McLean, 1982). There are many different types of these around the world (McLean 1982) and specific instructions are provided with individual units. When used carefully, they are more reliable than indicators as the sample is larger and therefore more representative. They measure the pH and should not be used for making lime recommendations as they do not measure the buffering capacity of the soil.

The lime requirement of soils in Ireland is estimated using the Shoemaker-McLean-Pratt Method (SMP) buffer method. Over the years, it has been found to be reasonably accurate for most Irish soils and has been calibrated in experiments in which lime incubated with different soils over long periods. Some studies have suggested that it is less accurate in poorly buffered, sandy soils, in soils with organic matter greater than 10% or in soils with a predominance of Kaolinite and aluminium (McLean 1966). Nonetheless, this buffer method has worked well in Ireland for many years. The lime requirement for peats will be discussed in the recommendations section.

To know the actual quantity of ground limestone to recommend involves the following laboratory procedures on each soil sample, 1. Drying; 2. Sieving; 3. Mixing; 4. Use of buffer test. You can with confidence take responsibility for lime recommendations where each of these steps has been followed carefully on correctly taken soil samples.

Other Methods

A rapid 'Quick Test' method was suggested by Bailey et al. (1989), in which titratable acidity was shown to relate closely to soil organic matter and the latter to soil density; a measure of bulk density by a simple scoop method and of the initial pH was combined in a regression model to calculate the lime requirement. This method has not gained widespread acceptance. Currently, in Britain a series of look-up tables to determine lime requirement (ADAS, 1986). This followed the analysis of many years data that showed a linear relationship between soil pH and lime requirement, with a different relationship for each textural class. However, the use of this method involves assessment of soil texture and organic matter content. Rothamsted have been working on a lime requirement model that uses empirical lime loss under arable and grassland system. It is eventually hoped to extend this model into other soil types. Curtin and Smillie (1995) have suggested that a simple method of predicting cation ratios in the soil solution in itself may have diagnostic value in plant nutritional problems. At the moment, in Ireland there are no plans to change from the buffer method currently being used.

All lime requirement estimations are based on soil samples. It is critical that the soil sample be representative of the area being sampled. The sampling procedures for one similar to those required for sampling for P and K.

(3) LIME LOSSES

Lime is constantly lost from soil through a series of mechanisms

- Crop losses
- Drainage losses
- Air pollution
- Fertiliser/manures

Crop Losses

Since Ca is an essential plant nutrient, it enters into the composition of all crops and the removal of these crops, either directly, or through the feeding of livestock, leads to depletion of the soil's lime reserves. With crops like cereals, very little, if any of this Ca is returned to the soil. With crops utilised for stock feeding much of it is returned. Johnston and Whinham (1980) reported offtakes of 3 kg/ha of calcium for potatoes, while Wild (1988) quotes Johnston and Whinham (1980) give removals of 65 kg/ha of Ca in grass, although much of this

is returned either directly or via the slurry. Gately (unpublished data) calculated that the losses via crop or animal are probably less than 100 kg limestone equivalent per hectare per year.

Drainage Losses

Rain and soil water are charged with carbon dioxide (Carbonic acid), which dissolves the lime contained in the soil. Some of this dissolved lime finds its way down into the drainage system thus being lost from the soil. The rate of loss depends on the rainfall, the texture of the soil and the amount of calcium in the soil. In the U.K. losses equivalent to 400 kg limestone equivalent per ha per annum have been measured in drainage water. Long term studies in Ireland indicated losses in the range 250-500 kg/ha/annum (Gately, unpublished data).

Air Pollution

Air pollution contributes to losses via the drainage mechanism. The lime losses in drainage are even greater when rain water contains other acids besides carbonic acid e.g. sulphur and nitrogen dioxide arising from combustion of fuels can be washed into the soil by rain. This can greatly increase the lime loss. SO₂ is the main ingredient of acid rain.

Fertilisers

One of the causes of soil acidification on agricultural land is the application of ammonia N fertiliser. Kennedy (1992) calculated that in the order of 400-1000 kg of limestone is required annually in grassland systems based on using ammonium nitrate. Ammonium salts create acidic conditions. In the nitrification process H⁺ ions are created and this leads to acidity. The most common form of N fertiliser used in Ireland is CAN. This contains 20% of ground limestone as filler and this neutralises at least some of the acid generated.

(4) LIME RECOMMENDATIONS

Crops differ in their sensitivity to pH. In addition, the optimum use of fertilisers containing nitrogen and phosphorus is obtained when the soil pH is between 6.2 and 7.2. The availability of some trace elements, especially manganese and boron is decreased when pH is above seven. A deficiency of manganese is quite common in cereals which follow sugar beet in the rotation due to the over use of lime for the beet.

Although potatoes and oats can grow very well below pH 6.0 it is necessary to maintain the soil at a pH suitable for the rotation. The pH levels to aim for in mineral soils are as follows:

pH 6.3	Grass
pH 6.5	Cereals
pH 7.0	Beets, Beans, Peas

The target pH for grassland in the UK is 6.0 for mineral soils. One of the reasons for the slightly higher Irish figure is that clover is deemed to be very important

in Irish conditions and it is reckoned that clover persistency require a higher pH than grass (MAFF 1994). In general terms a high pH at the establishment phase is important in three respects.

- Both grasses and clovers require a higher pH at the establishment phase
- Of all the elements, phosphorus is most important for seedling growth, and it is most readily available at around pH 6.5.
- In minimum cultivation techniques there can be considerable quantities of organic matter on the surface (decaying grass etc.). These can exude organic acids in the decomposition process that are harmful to the seedlings. Lime neutralises these acids.

Having established a target pH in the soil for crops, there is a necessity to maintain it at that pH. This is an area that merits some consideration. There are different approaches that can be adopted.

The current methodology is to raise the pH to 6.8 for grassland. The reason for this is that if the lime status is brought to that level, lime need not be applied for a further 8-12 years i.e. it will take up to 8-12 years for the pH to drop to below 6.0. A simpler approach to liming would be to do a soil test every 4-5 years and apply lime when required. It would be adequate to aim for a pH of 6.5 if this approach was adopted.

Surface acidity (top 5 cm) often occurs in grassland due to our high rainfall and the use of nitrogenous fertiliser. This reduces the availability of fertiliser phosphorus. For this reason it is better to have frequent small application of lime than one large application at irregular intervals. M. Murphy at Johnstown Castle has suggested that a yearly application of lime and sulphur could be used to meet the sulphur requirements and minimise surface acidity. The lime requirement to bring the soil to 6.5 is based on the premise that optimum production is required. In today's agriculture, optimum production is not always required. For instance in REPS no lime need be applied allowed if nitrogen usage is less than 20 kg/ha. Similarly, if less than optimum stocking rates are required, the amount of lime spread is at the discretion of the advisor.

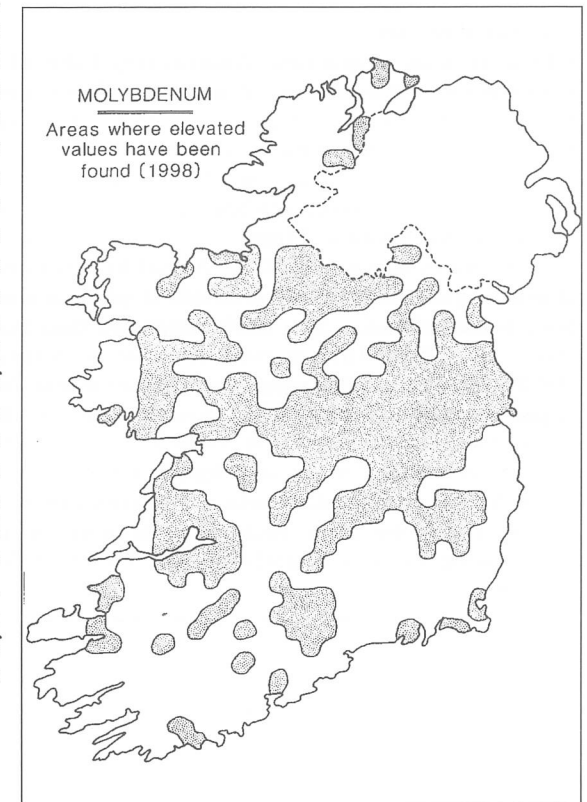
There are some areas where general lime recommendations do not apply i.e. in peats, on soils in high Mo areas and an acid soils of marginal/high Mo content, where more liming for grass/clover growth may increase Mo levels to toxic levels.

Peats:- In the very high rainfall areas (1500 mm or higher) on the hills in the West of Ireland the leaching of calcium by rainfall becomes very intense. Iron and aluminium are washed down from the top soil and deposit again up to 500 mm below the surface. They form a layer or iron pan which is impenetrable to water causing the whole soil to become water logged. Plant remains fail to decay under these conditions and peats develop. These peats are very acid but because they contain very little mineral matter and very low levels of aluminium or manganese a pH of approximately 5.5 is considered acceptable for most crops

compared to 6.5 on mineral soils. However, when these peats are limed and drained the organic matter at the surface is broken down more quickly by soil microbes and the surface of the peat can shrink and disappear over a few decades.

Basin peats can be strongly acid, with pH as low as 3.5 at the surface but quite high in pH (6.0-7.0) near the base of the peat layer. Peat harvesting operations may complicate this pattern as the top peat maybe returned to the floor after most of the peat has been removed. The floor of midland bogs may have high molybdenum and a naturally high pH, while the peats may have low copper, so ploughing up sub-soil with peat can lead to acute molybdenum excess.

(2) *High Molybdenum soils.* When the level of molybdenum in herbage exceeds 1.5 mg/kg it may interfere with copper metabolism in the animal consuming it and cause illthrift and more specific disorders. If soil molybdenum is high, liming will usually increase Mo uptake by grass or clover, so such soils must be treated very carefully. A general recommendation is not to increase the soil pH above 6.0. To achieve this, the lime recommendation suggested by the lime test should be reduced by 7.5 t/ha. This is particularly important for old pasture where even relatively light dressings may increase the pH in the top 25 mm of soil and thereby increase molybdenum uptake. The presence or absence of clover may be more important than soil pH, as clover may contain significantly more molybdenum than that found in grasses. High rates of N fertiliser will tend to discourage clover and therefore reduce the risk of problems caused by high molybdenum. Fig. 1 shows areas of the country when high Mo content of pastures is most common. Not all fields or farms in those areas have high Mo. Similarly not all fields or farms in the remainder of the country are free from this Mo problem.



(5) SOURCES OF LIMING MATERIALS

Ground limestone is generally a mixture of calcium carbonate (CaCO_3) and dolomite ($\text{CaCO}_3 - \text{MgCO}_3$) that has been crushed sufficiently finely that it will react with acid soils. The quality of limestone is measured by its purity, its fineness of grinding and sometimes the proportion of dolomite or magnesium in the material. Pure calcium carbonate (calcite) contain 60% of carbonate and pure dolomite i.e. 40% $\text{MgCO}_3 + 60\% \text{CaCO}_3$ contains 64.5% carbonate. Thus, in its pure state dolomite has more neutralising value than calcite. Although it is slower to react than limestone it is rarely used unless magnesium deficiency is encountered.

All producers of ground limestone must hold a licence from the Department of Agriculture. Before issuing such a licence the Department must be satisfied that the rock deposit being quarried is of the required standard and that the machinery being used is capable of producing ground limestone conforming to statutory requirements. Samples are drawn regularly at each licensed quarry and analysed to ensure that standards are complied with.

The standards are

- Product must have a Total Neutralising Value of not less than 90 per cent.
- All the product must pass through a 3.35 mm sieve.
- Not less than 35% must pass through a 150 (m sieve).
- The moisture content must be less than 3.0%.

There are many forms of lime:

(1) *Ground limestone (CaCO_3)*. A trial by Myer and Volk (1952) on the fineness of grinding showed the effectiveness of particle size on the yield of Lucerne and Soya bean (Table 7). The work suggested that limestone sized from 60 to 100 mesh (i.e. 250-150 (n) was most effective in increasing yield. Work from ADAS (1992) showed a similar result with winter wheat Total Neutralising Value (TNV) of pure limestone is 100.

Some limestone deposits contain a percentage of Magnesium carbonate. The ground limestone from such deposits may be brownish in colour, and its neutralising value is slightly higher than that from deposits of pure ground limestone.

Table 7: Effects of particle size of limestone on yield of Lucerne and Soya beans (Meyer and Volk, 1952)

Particle Size (mesh)	Plant Yield (oven dry wt per pot mg)	
	Lucerne	Soya Beans
5-8	5.3	7.8
8-20	5.6	-
20-30	7.5	10.8
30-40	8.0	-
40-50	8.2	12.2
50-60	8.8	-
60-80	9.5	13.3
80-100	9.5	-
<100	9.5	11.9
No Lime	4.6	-

Calcium Oxide Burnt Lime or Quicklime (CaO): This can act somewhat more rapidly than ground limestone. The TNV is 178 and 560 kg of CaO is equivalent to 1 ton of ground limestone.

Hydrated lime, Slaked lime Ca(OH)_2 . This reacts very rapidly and has a TNV of 135, thus 740 kg of slacked lime is equivalent to one ton of ground limestone i.e. the TNV = 135.

Other materials can be used for liming soils. Lime rich sea sand has been used on the west coast. The TNV is very variable and the particle size is generally large and therefore it is slow acting.

Calcified sea weed is also used. The TNV is somewhat similar to ground limestone and is often finely ground before use. Grinding helps the distribution in the soil.

Sugar factory sludge is usually has large amounts of water (up to half its weight) and about 30-40% calcium carbonate. It is an effective liming material and contains useful amounts of nitrogen and phosphorus as well. It can be difficult to spread evenly.

(6) LIME USE SURVEY

Approximately 70,000 soil samples are delivered annually to Johnstown Castle for lime requirement analysis. The percentage of soils with various lime requirements are summarised in Table 8.

Table 8: Percentage soils with varying lime requirements

L.R. (t/ha)	0	0.1-5.0	5.1-10.0	10.1-15	15.1-20	20.1-25	>25
1997	11	31	34	18	4	1	1
1989	17	40	29	11	3	0	0

This table suggests that soils have become more acid in the last 10 years. In 1997, some 42% of soils had a L.R. at or below 5 t/ha. In 1989, some 57% of soils had a LR below 5 t/ha. It is difficult to determine how much can be taken from this table. There is no way of ensuring that the samples taken represent the L.R. of the country. For instance in 1997, there were less tillage samples than in 1989 (The total area under tillage declined from 1989 to 1997). A breakdown of the L.R. for tillage and grassland in 1997 is given in Table 9. Mean lime requirements since 1991 are summarised in Figure 2. Total L.R. has increased slightly, as has L.R. for both grassland and tillage.

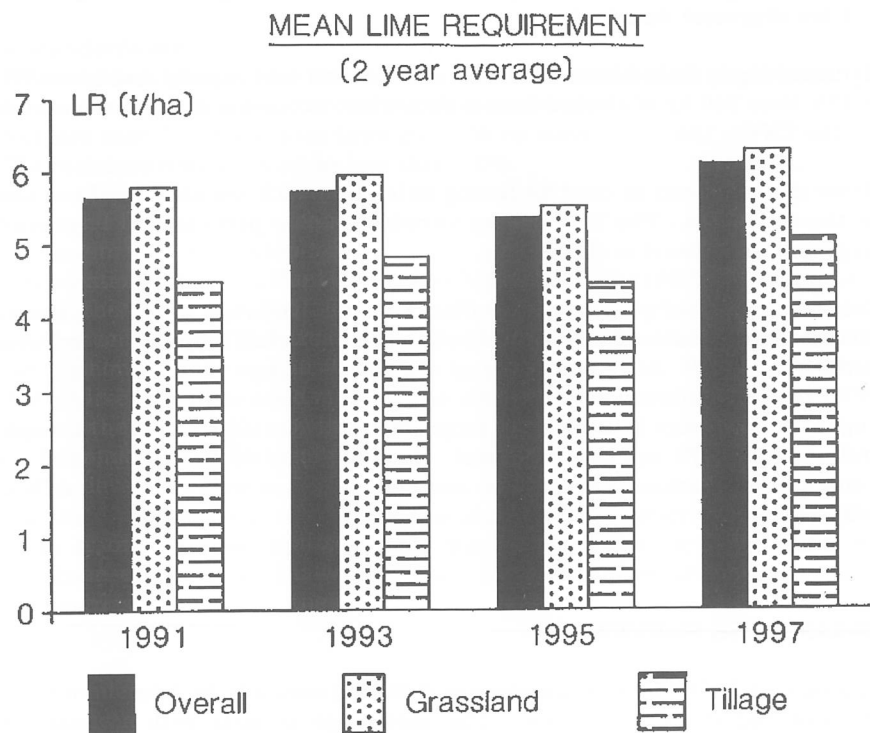


Table 9: The L.R. for grassland and for tillage crops in 1997

LR (t/ha)	0	0.1-5.0	5.1-10	10.1-15	15.1-20	21.5-25	>25
Grassland	10	29	36	19	5	0.5	0.5
Tillage	17	50	24	4	4	0.5	0.5

Some 67% of the tillage samples had a L.R. of 5.0 or less t/ha, while in grassland only 39% had a L.R. of this magnitude. Only 9% of tillage soils had a L.R. greater than 10t/ha while in grassland some 25% of samples had a L.R. greater than 10 t/ha.

The actual lime used on a yearly basis since 1989 is given in Table 10. This shows a marked decline lime usage since 1996. There are no data on the amount of lime being applied to different crops. But the previous data suggests that there is less lime being used on grassland than on tillage crops. There are 3.4 m hectares of good agricultural land in the country and we estimate that an annual ground limestone (calcium carbonate) usage of approximately 1.5 million tonnes would be needed to maintain a satisfactory level status on these soils. Consumption is falling significantly below optimum usage. Surely, in a time when nitrogen usage is under scrutiny, the use of lime should be increasing, rather than decreasing.

Table 10: Lime usage (1988-1998)

Calendar Year	Tonnes
1998	750,000*
1997	962,471
1996	1,100,076
1995	1,124,080
1994	612,821
1993	812,045
1992	580,911
1991	716,239
1990	806,900
1989	940,616
1988	885,559

* This is an estimated figure

Table 11 summarises the usage of lime in the differing counties. Some eight counties have a L.R. greater than 10 t/ha.

Table 11 1997 Survey of Lime Requirement (t/ha) on a county basis.

	0	0.1-5	5.1-10	10.1-15	15.1-20	20.1-25	>25	No. of Samples	Mean
Clare	10	13	23	32	16	5	1	2539	9.9
Dublin	22	30	32	14	2	0	0	1137	4.7
Carlow	15	44	30	9	1	0	0	2821	4.4
Donegal	3	23	34	29	8	2	1	1340	8.7
Meath	13	35	37	13	1	1	0	2359	5.3
Longford	4	18	39	29	7	2	1	545	8.7
Galway	17	28	36	13	4	1	1	3832	5.7
Westmeath	9	23	40	23	3	1	1	1743	7.1
Kildare	24	34	22	8	1	1	0	1991	2.9
Monaghan	2	25	39	27	5	1	1	1184	8.0
Kerry	8	23	34	24	8	2	1	5890	8.2
Laois	25	38	29	7	1	0	0	1985	3.4
Mayo	6	16	29	32	11	4	2	2145	9.8
Kilkenny	14	42	32	10	1	1	0	2705	4.5
Cork	8	38	35	15	3	1	0	11553	6.0
Tipperary	18	34	33	12	1	1	0	6003	5.0
Leitrim	3	9	24	41	17	4	1	195	11.6
Roscommon	8	22	37	26	5	1	1	1683	7.8
Sligo	3	10	26	45	12	3	1	828	10.9
Waterford	7	36	40	13	2	1	1	2365	5.9
Louth	7	40	38	13	1	1	0	1269	5.7
Cavan	2	20	35	29	11	1	0	1107	9.1
Wicklow	4	31	46	15	2	1	1	1369	6.6
Wexford	9	47	35	8	1	1	0	5188	4.9
Offaly	34	34	24	5	2	1	0	2009	2.7
Limerick	9	23	30	27	8	2	1	3517	7.9
Mean	17	40	29	11	2	0	0	69302	6.2

(7) CONCLUSIONS

- Lime applied at the correct rates is beneficial for all crops.
- All crops have their own optimum pH, grassland is 6.3, cereals 6.5 and beans, peas and beet 7.0.
- Liming strategy must be to maintain soil at the desirable pH by frequent applications of lime. The amount of lime to be applied must be determined by soil testing. If liming is carried out in frequently to grassland apply lime to bring pH to 6.8. If liming is applied at 4-5 year intervals maintain pH at 6.5.
- pH is useful as a diagnostic tool, i.e. to immediately identify if acidity is the cause of poor growth. It cannot be used to determine lime requirement. The

lime required to change the pH can only be done by a lime requirement test.

- Trends derived from soil samples analysed at Johnstown Castle indicate that lime requirement of grassland is increasing. This is reflected in the decline in usage. In the light of nitrogen restrictions caused by REPS and reducing P usage this is very undesirable.

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the invaluable advice offered by Dr. Austin Morgan (U.C.D.). His help was invaluable. The advice of Dr. George Smillie (U.C.D.) is also greatly appreciated. The help of Eleanor Spillane in preparing the manuscript is gratefully acknowledged.

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Transboundary Pollutants and Measures to Control Them

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The pollutants are comprised of compounds of nitrogen and sulphur as well as volatile organics (VOCs). In addition to causing damage in the country of origin, these pollutants cross national frontiers resulting in damage to both health and the environment in other countries. Despite ongoing improvements in air quality as a result of the implementation of national / EU legislation and various international protocols, the amounts of such pollutants are still far too high. Besides, emissions of some of these compounds have increased dramatically during recent decades notably in the industrial and transport sectors. The pollutants involved are :-

(a) *Sulphur Dioxide (SO₂)* : This comes mainly from the combustion of coal and residual fuel oil, i.e. fuels which contain sulphur and which are used in power stations, industry and other stationary combustion activities.

(b) *Nitrogen Oxides (NO_x)* : The dominant sources are mobile combustion associated with transportation, electric power generation and residual heating. The biggest single source is road traffic.

(c) *Ammonia (NH₃)* : This is derived principally from agricultural activities, namely from the production and management of animal manures and to a lesser extent from the production and use of artificial fertilisers.

(d) *Volatile Organic Carbons (VOCs)* : They come from solvents, paints, adhesives, glues, etc., e.g. benzene.

TYPES OF DAMAGE RESULTING FROM EXCESSIVE LEVELS OF THESE POLLUTANTS

- A secondary pollutant, namely tropospheric or ground-level ozone (O₃), is formed by the photochemical reaction of precursors such as NO_x and VOC in the presence of sunlight. This is a widespread transboundary problem in Europe where ambient concentrations are now three to four times greater than in pre-industrial times, with the result that thresholds set for humans and sensitive plants are frequently overstepped. This gas impairs lung functioning and causes respiratory problems in children and asthmatics. It damages sensitive plants, e.g. agricultural crops and trees.
- Eutrophication due to excess nitrogen (N) deposition in terrestrial and aquatic ecosystems resulting in algal growths and oxygen (O₂) depletion. The eutrophying effect of N also leads to a reduction of plant species. Depositions from NH₃ and NO_x gases constitute the N load in this case.
- Acidification due to deposits of SO₂, NO_x and NH₃, either singly or in

combination. The effects of this deposition vary geographically and depend on a combination of two factors :-

- (a) magnitude and form in which deposition takes place;
- (b) the natural sensitivity of the recovery media (soil and water).

The effects of acidification can be diverse and may be classified as follows :-

- effects on soils, forests and related ecosystems (soil acidification is often a prerequisite to water acidification). In forests, defoliation and loss of vitality in trees are normally recognised as symptoms.
- effects on surface waters, groundwaters and related aquatic ecosystems can mean widespread damage to plant and animal life.
- leaching of plant nutrients and hence reduced fertility in soils.
- deterioration of building materials including objects of cultural heritage, mainly damaged by SO₂ gas.

The relationship between the pollutants and damage caused is illustrated in Figure 1

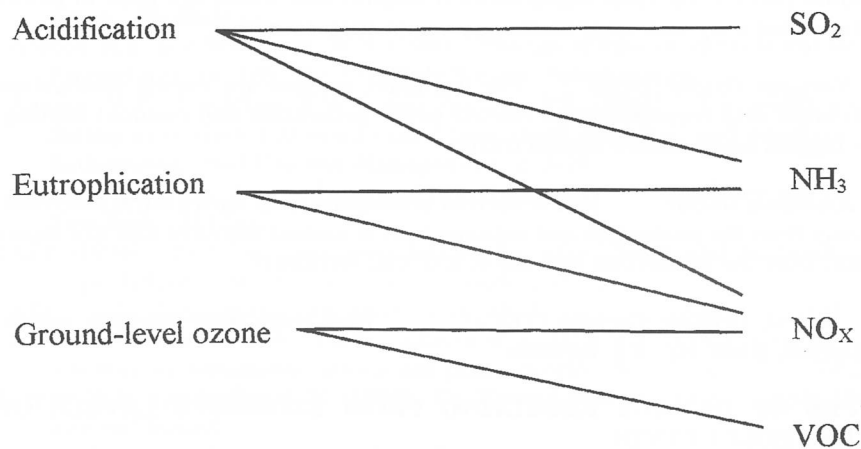


Figure 1: Inter-linked problems and pollutants

TRANSPORT AND DEPOSITION OF POLLUTANTS

Pollutants in the atmosphere can return to the earth's surface in two different ways :

1. directly, either as dry deposition on vegetation or other surface elements, or as wet deposition attached to falling precipitation.
2. indirectly, in a wet or dry form following chemical transformation. Sulphur dioxide and NO_x may combine with water molecules in the atmosphere to form H₂SO₄ and HNO₃ there or following deposition, while NH₃ may lead to

acidification after it reaches the soil where it is transformed to HNO₃. Ammonia may also react with H₂SO₄ and HNO₃ to form (NH₄)₂SO₄ and NH₄NO₃ particles. These pollutants are generally transported by winds and may be spread over thousands of kilometres. Fifty percent or greater of the nationally volatilised NH₃ is deposited within the country (ApSimon et al., 1995; Ferm, 1998; Van den Bueken, 1977,). This is in sharp contrast to emissions of SO₂ and NO_x which are transported to much greater distances by long range transport (see Figure 2). Patterns of pollutant deposition will

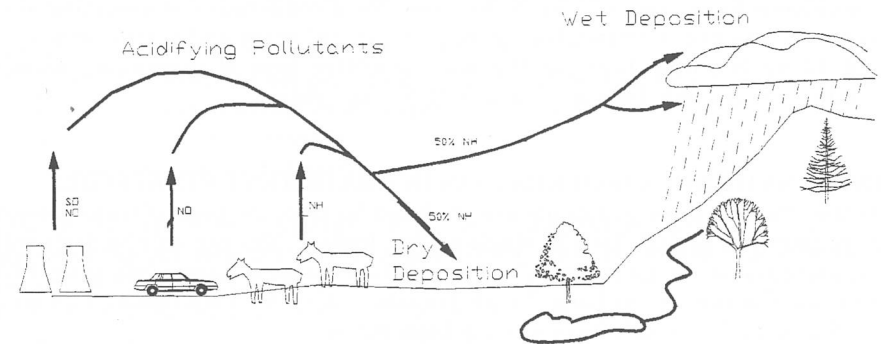


Figure 2: Deposition of Acid Pollutants

depend on both the magnitude and geographical distribution of emissions of each, and abatement of any particular species will affect each of the others. As an example, inflated NH₃ levels may increase the deposition of SO₂ (Cape et al., 1998,). The principal reason for much local deposition of NH₃ is because of its release at relatively low temperatures and adjacent to ground level. This is in contrast to the hot gaseous emissions of SO₂ and NO_x which are released from tall industrial chimneys and mobile combustion sources. These warm emissions travel upwards to the stratosphere from where they can be transported over long distances before final deposition.

The average NH₃ emission per unit land area in Western Europe is 12kg / ha / year and the highest loss in a 150 by 150 km grid is 45kg / ha / year in the Benelux countries (Kirchmann et al., 1998). The smallest emissions are found in northern Scandinavia, being (0.1 kg N /ha / year (Barret et al., 1995).

CRITICAL LOAD

This indicates the sensitivity of a particular environment by defining how much exposure to pollution it can tolerate. It was defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to our present knowledge (Nilsson and Grennfelt, 1988). Critical loads are based on data and methods arrived at through international co-operation and World Health Organisation (WHO) health issues. Each of the countries adhering to the

Convention on Long-Range Transboundary Air Pollution makes maps to show the critical loads for various areas and pollutants within its territory. Each country is also responsible for submitting data on critical loads and emissions and for checking the data on national abatement costs and potentials. Transboundary pollution is being monitored for the whole of Europe under the European Monitoring and Evaluation Programme (EMEP), with a network of some 100 stations in 25 countries. Ferm, 1998, and Kirchmann et al., 1998, estimated a number of critical figures, where a range of 5-20 kg N was given for a deciduous forest and 3-15 kg N /ha / year for a coniferous one assuming sites were well-drained. Comparable figures for natural grassland varied between 3 and 10 kg N while those for the most sensitive type of vegetation, namely heather, ranged only between 3 and 5 kg N / ha / year.

INTERNATIONAL CO-OPERATION IN ABATEMENT STRATEGIES

As the effects of these pollutants are produced far from the point of transmission, no country can protect itself by single action. Instead, this can only be dealt with by international co-operation. The prime forum for such liaison has since 1979 been the Convention on Long-Range Transboundary Air Pollution and under it the following 5 protocols have already been signed :-

- SO₂ protocols 1985, 1994
- NO_x protocol 1988
- VOC protocol 1991
- protocols on heavy metals and Persistent Organic Pollutants (POPs) 1998

The multi-effects and multi-pollutant protocol which will address transboundary gases is now being negotiated and this is a natural continuation of the earlier ones under the convention. As a result of the implementation of these protocols (part implementation in Ireland, particularly in respect of SO₂) plus EU legislation on air quality, there has been a general decrease in emissions of acidifying substances in EU countries. Between 1990 and 1994 SO₂ decreased by around 27% and NO_x by around 6% in EU states. This period also saw a shift in the major source of SO₂ emissions from industry to the energy sector and for NO_x a shift from industry to the transport sector.

PROCEDURE FOR DEVELOPMENT OF PROTOCOL

As in 1994 with the protocol for SO₂, the critical loads approach is used. In this methodology, emission reductions are negotiated according to the effects of the air pollutants rather than requiring an equal reduction in % from each country. The long-term effect, taking on board cost-effectiveness, is that critical loads will ultimately be no longer exceeded. It is recognised that because of technology, economics and other constraints, reductions may not be attainable everywhere in one step; several will therefore be required.

COVERAGE OF THE PROTOCOL AND REASONS FOR BRINGING IT INTO FORCE

The main feature will be ceilings on the emissions of NO_x, VOCs and NH₃ under which each country must have brought its emissions by the specified target year (2010). To further reduce the damage from acidification, and fully exploit the advantages of the multi-effects and multi-pollutants approach, sulphur emissions will also need to be further reduced. The environmental targets of the protocol for the year 2010, compared with the base year 1990, are to reduce :-

- health-relevant excess ozone exposure by two thirds;
- the area of ecosystems not protected against acidification by a half;
- vegetation-relevant excess ozone exposure by one third;
- excess N deposition (eutrophication) by 60%;
- additional targets for 'hot-spots'.

Some of the reductions necessary to achieve these targets are met by simply implementing all relevant existing legislation. This is termed the reference scenario (REF) or starting point. However, in order to achieve the targets set for 2010, it shall be necessary to implement a more stringent (G5/2) scenario. Emission reductions compared to 1990 plus control costs in respect of both scenarios for the 4 polluting gases are shown in Table 1.

Table 1: Results : REF and G5/2 scenarios

	Emission Reductions		Control Costs	
	(compared to 1990)		(Billion EURO/year)	
	REF	G5/2	REF	G5/2
SO ₂	-60%	-70%	14.0	+1.8
NO _x	-35%	-42%	52.6	+3.3
VOC	-37%	-45%	52.6	+3.3
NH ₃	-12%	-24%	0.7	+3.4
Total			67.3	+8.5

With respect to emission targets, analysis is carried out with the use of computer models for integrated assessment. The principal one is that known as RAINS (see Figure 3). This was developed by the International Institute for Applied Systems Analysis (IIASA). By using models, comparisons can be made of the costs and effectiveness of various strategies for the achievement of specified interim targets (those set for 2010 are only interim) for environmental quality. Moreover, when run in the so-called optimisation mode, the RAINS model is designed to be able to find the least-cost solution for Europe as a whole for attaining one or several specified targets for environmental quality. Emission ceilings (G5/2) in respect of the 4 gases for a select number of countries are shown in Tables 2, 3, 4 and 5.

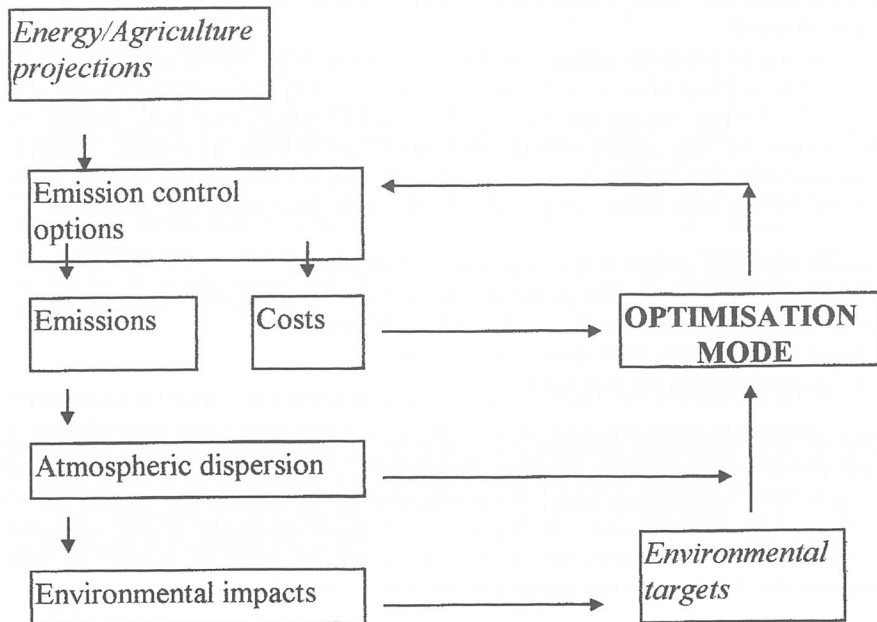


Figure 3: The RAINS Model (showing how targets were arrived at)

Table 2: Emission ceilings for NOx.

	1990 RAINS	REF		G5/2	
		kt*	Change	kt*	change
Austria	192	103	-46%	91	-53%
Denmark	274	128	-53%	113	-59%
France	1867	858	-54%	704	-62%
Germany	2662	1184	-56%	1081	-59%
Ireland	113	70	-38%	55	-51%
Netherlands	542	280	-48%	266	-51%
Portugal	208	177	-15%	144	-31%
United Kingdom	2839	1186	-58%	1181	-58%

Table 3: Emission ceilings for SO2.

	1990 RAINS	REF		G5/2	
		kt*	Change	kt*	change
Austria	93	40	-57%	35	-62%
Denmark	182	90	-51%	60	-67%
France	1250	448	-64%	219	-82%
Germany	5280	581	-89%	463	-91%
Ireland	178	66	-63%	36	-80%
Netherlands	201	73	-64%	50	-75%
Portugal	284	141	-50%	141	-50%
United Kingdom	3805	980	-74%	499	-87%

Table 4: Emission ceilings for VOC.

	1990 RAINS	REF		G5/2	
		kt*	Change	kt*	change
Austria	352	205	-42%	142	-60%
Denmark	182	85	-53%	85	-53%
France	2382	1223	-49%	989	-58%
Germany	3122	1137	-64%	995	-68%
Ireland	110	55	-50%	55	-50%
Netherlands	490	233	-52%	157	-68%
Portugal	212	144	-32%	102	-52%
United Kingdom	2667	1351	-49%	1101	-59%

Table 5: Emission ceilings for NH3

	1990 RAINS	REF		G5/2	
		kt*	Change	kt*	change
Austria	77	67	-13%	66	-14%
Denmark	77	72	-6%	69	-10%
France	807	777	-4%	642	-20%
Germany	757	571	-25%	413	-45%
Ireland	127	126	-1%	116	-9%
Netherlands	233	136	-42%	105	-55%
Portugal	71	67	-6%	65	-8%
United Kingdom	329	297	-10%	264	-20%

*1 kt (kilotonne) = 1,000 tonnes

AGRICULTURE'S CONTRIBUTION TO TRANSBOUNDARY GASES

Agricultural practices are the main contributors of NH₃ emissions, being responsible for about 95% of these. In Europe the prime source of these losses is volatilisation from animal manures, with this accounting for in excess of 80% of the emissions. Between 10 and 20% are estimated to arise from volatilisation associated with N fertiliser and fertilised crops. Losses from cultures without fertiliser are considered to be negligible. Losses also arise from the fertiliser industry, composting plants, sewage works, etc. In 1990 the highest emissions were recorded in two of the most intensive farming areas in Europe, namely the Netherlands and Italy (Po Valley), at 7 tonnes per square kilometre.

The large loss of NH₃ from livestock systems is due to the low conversion of dietary N into animal protein. Usually more than 75% of the N intake is excreted in forms that give rise to NH₃ losses (Jarvis and Pain, 1990). We are familiar with the basic difference between ruminants and monogastrics in the way they utilise dietary protein. In ruminants, essential amino acids can be synthesised in the alimentary system whereas monogastrics depend on the feed protein for their source of these. In order that a balanced system of protein can be synthesised in ruminants, there must be an adequate supply of both degradable protein and digestible carbohydrate; these should also be present in suitable ratios. Protein surplus to needs will be metabolised and the N excreted. In monogastrics, the feed should ideally have a content of crude protein that is close to that of the over-all body need for individual amino acids. Protein in excess of requirements is metabolised for energy and the N excreted. Commercial success in pig and poultry production dictates that the feed usage per unit of meat produced should be minimised. This requires that the balance of energy to amino acids be optimal. In this regard, synthetic amino acids, namely lysine, methionine and threonine are widely used to improve the balance of the amino acids in the protein.

Ammonia emission is related to the quantity of N excreted and this loss becomes greater with increased productivity and rising N levels in the feed. Data on N outputs is limited to certain livestock types and classes, with no distinction made between breeds. Differences between or indeed within the various data sources are often quite high. In the Netherlands, for example, Mandersloot et al (1992) showed that the N excretion of dairy cows could vary between 101 and 140 kg for a cow with a milk yield of 6000 kg/year. It is assumed from this that total N excretion varies by 20%. The same assumption can be made for other grazing animals. Dutch information on N excretion by pigs shows only minor variation, but this data is likely to be unsuited to Ireland because of our policy to slaughter finishers at lighter weights. There is a great scarcity of information on sheep and horses, and no data is available for these animals in the Netherlands. Dutch information on broiler fowl is assumed to contain a variation of 30% while very little data is known for laying hens. National N emissions for the Netherlands are given in Table 6.

Table 6: Emissions for Netherlands (N in kg per head/place per year)

Dairy cows	134	Sheep	34
1-2 yr. old cattle	87	Horses	50
< 1 yr.	36	Laying hens	0.766
Pigs for slaughter	13.6	Broiler fowl	0.455
Sows and boars	33.6		

Ammonia emissions for any country can be estimated/determined from the national livestock census and average N excretion per animal in respect of the main livestock classes. The NH₃ losses occur from the following sources:- livestock buildings, manure storage systems, land applied animal manures, grazed pastures and chemical fertilisers. If the emission coefficients (EF_is) are known for the N fertiliser types used and for the different phases of manure management, then the total gaseous loss can be calculated. Many emission measurements, based on experiments, are known for the Netherlands, Germany and the UK, and EF_is can be determined from this data. If there is no data or just a limited amount available for other countries, then the emission information from these 3 countries mentioned may be used as a basis for the estimate.

AMMONIA EMISSIONS FROM LIVESTOCK HOUSING

There is a wide range of livestock house types employed within the UN/ECE region and a correspondingly wide variation in volumes of gas emitted. The potential for NH₃ loss increases with the following factors (Fabry, 1992) :-

- Increasing residence time of manures /slurries within buildings prior to their removal. Beauchamp and Burton, 1985 showed that residence times of 1 hour, 1 day and 1 week gave NH₃ losses expressed as a percentage of total N of 5, 21 and 27% respectively;
- Increasing the surface area of the exposed manures / slurries;
- Increasing temperature and humidity simulating conditions that would occur with high stocking densities;
- Increasing ventilation rates;
- Increasing manure exposure during the collection and removal phases.

Many of the measures available for reducing NH₃ emissions are only appropriate to newly constructed buildings. Otherwise, costly modifications would be required to existing structures. For these reasons it is generally a much cheaper option to abate emissions during the storage and land application phases of manure management. Besides, assessing net emission reductions from new or structurally modified buildings in comparison with losses from existing units is extremely difficult. This is because most livestock buildings are naturally ventilated and it is very difficult to measure losses from these houses due to continuous fluctuation in volumes of outlet air.

HOUSING SYSTEMS FOR DAIRY AND BEEF CATTLE

The system on which most information is available is the slatted shed where emissions are released from both the store underneath the floor and from slurry adhering to slats or lying on solid floor parts. Abatement systems include flushing, addition of acid, dilution, use of smooth and /or sloping floors. Most of these systems are impractical, however.

HOUSING SYSTEMS FOR PIGS

Ammonia emissions from pig buildings arise from the slurry under the floor and from that adhering to slats and solid floors. Emissions are influenced by the ratio of slats to solid floor area, and are highest in fully slatted units. Part slatted floors reduce emissions and more particularly where the slats are metal or plastic coated, i.e. with low resistance to retain the manure, permitting it to fall into the pit more rapidly and completely. Emission from solid floor sections can be reduced by inclining the floor or giving it a smooth finish. Additional reductions can be achieved by appropriate siting of feeding and watering facilities and by good air control. Further emission reductions can be achieved by reducing the surface area of the underground tank. This is made possible by installing channels in the floor to direct the slurry into the tank. Using straw bedding on solid floors appears to give losses as high as for fully slatted floors. This is probably because of the larger area involved.

HOUSING SYSTEMS FOR POULTRY**(a) Laying Hens**

The deep pit into which manure from battery caged birds falls directly, is the highest gaseous emitter for intensive laying hens. These emissions are halved if the excreta is collected on manure belts underneath the cages and subsequently removed to covered storage. A much more effective abating system is to dry the manure on the belts to in excess of 70% DM so as to prevent NH₃ formation, and subsequently store it under cover.

(b) Broilers

These are traditionally reared on solid floors which are covered with litter. The bedding material should be kept as dry as possible to minimise atmospheric losses. Emissions can be reduced fivefold if a floating floor is installed in the building and air is then forced up through the manure and litter from underneath the floor. This system, however, being very energy intensive, approximately doubles the normal heating costs of a unit.

AMMONIA LOSSES FROM MANURES IN STORAGE

There is very limited information available on emissions from solid manures in storage and currently there are no proven technologies for reducing such losses. However, it is known that losses can be large where manure DM is high. For this reason it is crucial that NH₃ conserved during the housing phase, e.g. in broiler litter, be protected while in storage.

In the case of slurries, the storage method used influences the extent of the emissions. Potential losses can be reduced by a number of options, e.g.:-

- Decreasing air flow across open pit surfaces;
- Permitting the formation of a natural crust (cattle slurries);
- Reducing the surface area per unit volume;
- Installing a cover.

Emission reductions achievable, relative to losses from an uncovered slurry tank, for a number of abatement techniques (UNECE, 1999) are as follows:-

Rigid lid or roof	80%
Flexible cover or floating sheet	40%
Low technology covers e.g. straw	40%
Natural crust	35-50%

The manner and duration of manure storage influences NH₃ emissions. These increase with increasing temperature, rising pH and increasing exposure to air. Storing manures under anaerobic conditions will exclude / minimise losses while composting will greatly inflate them.

AMMONIA EMISSIONS FOLLOWING MANURE APPLICATION

This phase of manure management gives rise to the greatest, but also the most variable, single source of NH₃ volatilisation. A major loss of nutrient N can occur, particularly where the manure is applied to the surface of the soil. When livestock slurries are applied in this manner, emissions are affected by ambient temperature, soil properties, application technique, slurry characteristics and type of animal that produced the manure (Pain, 1991). Soil properties such as infiltration potential, cation exchange capacity, the pH value and the buffer capacity have a significant effect on NH₃ losses when slurry is applied (Stevens et al., 1989). Ammonia losses became greater as the dry matter of the slurry increased (Sommer and Olesen 1991). Gaseous loss will be higher where NH₃ has already been conserved during the housing and storage phases of manure management. Hence, volatilisation loss at this stage can undo the savings made by earlier abatement strategies.

Emissions from slurry occur in two stages, namely during and following its application to land.

- During application, the contact time between slurry droplets is small and so only a small fraction of the NH₃ is lost {1-4%} (Pain et al., 1989, Jarvis and Pain 1990).
- Following application, the major emission arises from slow evaporation on the soil surface where losses are influenced by factors already outlined plus the effects of wind speed and air humidity (Sommer et al., 1991).

There are a number of options available for applying animal manures to land. These range from broadcasting on the surface to incorporation in the soil. Some of the methods are more effective than others at reducing gaseous emissions. However, all of these techniques have certain limitations. Some may temporarily reduce crop yields, especially grass, by causing physical damage to the sward. There is also a potential for increasing N losses through other pathways, e.g. nitrate (NO₃) leaching to groundwater or nitrous oxide (N₂O) gas to the atmosphere.

The traditional method of spreading slurry in many countries is by the splashplate technique which broadcasts the manure onto the surface of the soil. This method of application results in the highest level of NH₃ emission and is environmentally the most unfriendly. Newer techniques are now being investigated and these have improved efficiencies relative to the splashplate system. However, a number of factors must be considered when determining the applicability of each of these techniques. These include soil type and condition, e.g. depth and presence / absence of stones. Other important characteristics are :- topography, manure composition, manure type / viscosity and whether the land is in tillage or permanent grassland. In the case of solid manures, the least efficient abatement strategy is to broadcast it on the soil surface and leave it exposed for 1 week or longer.

The newer techniques to reduce NH₃ emissions are based on methods which either minimise the exposed surface area of applied slurries or aim to prevent losses almost entirely by incorporating slurries / solid manures within the soil. The newer application options may be summarised as follows :-

Bandspreading

This is where slurry is discharged from a machine through a series of flexible hoses on to the soil surface. The system is applicable to both tillage and permanent grassland, and abatements of around 30% are achievable when compared with the splashplate method. Reductions will be less where the grass cover is below 10cm high. To achieve full potential, the slurry should be of a sufficiently high dry matter for it to remain within the bands. Dilute slurries will result in lateral surface flow, so increasing the potential for NH₃ losses. On the otherhand, this system is not suitable for applying viscous slurries because of blockage problems. Effective technology for bandspreading is now available and this includes a pump and macerator for handling fibrous materials such as straw. This is a specific area of manure management in Ireland where an opportunity for NH₃ abatement exists. Slurries suitable for bandspreading are likely to come from slatted tanks and separate covered tanks associated with cattle units. All pig and poultry layer slurries can also be considered suitable

Trailing Shoe

This applicator may be termed a refinement of the bandspreader. The machine contains a network of tubes which direct the slurry through shoe attachments on to the soil surface. The system is mainly used in grassland in which case the shoe

separates the stems of grass and places the slurry in strips under the canopy. For this technique to be effective, the grass should be at least 8 cm high. Abatement in these circumstances can have an efficiency of 40% in comparison with the splashplate system. Adoption of this technique would create certain difficulties for the farmer, the more important one being the fact that slurry is not traditionally applied to grassland until the second silage cut has been removed. The reason for the deferral being to avoid possible contamination of the conserved fodder. Despite assurances to the contrary with this system, that worry would remain if spreading were to take place prior to cutting the crop. Applying slurry for the first silage cut would be very difficult in any case because of the poor traffic-carrying capacity of soils at this time. The application of slurry after the first silage cut is harvested would have to be deferred for some 2 to 3 weeks until the regrowth of grass reached 8 cm in height. Such a delay would mean depriving the crop of valuable slurry nutrients at a time when it most needs them and would thus likely delay harvesting of the second silage cut.

Slurry Injection

This is where slurry is inserted into the soil in bands which are spaced 300 mm apart. The liquid is injected to a depth of about 50mm via a series of tines and as the manure is/should be totally covered in the process, ammonia abatement is high being of the order of about 80%. Injection is best suited to arable land because of the risk of sward damage and consequently reduced herbage yield potential in the case of grassland. The system in its current state of development has limited application in Ireland because (a) of the low percentage of our land under tillage (b) in the case of grassland it is commonly not possible to achieve either adequate or uniform depth penetration because of the heterogeneous nature of our soils.

Incorporation

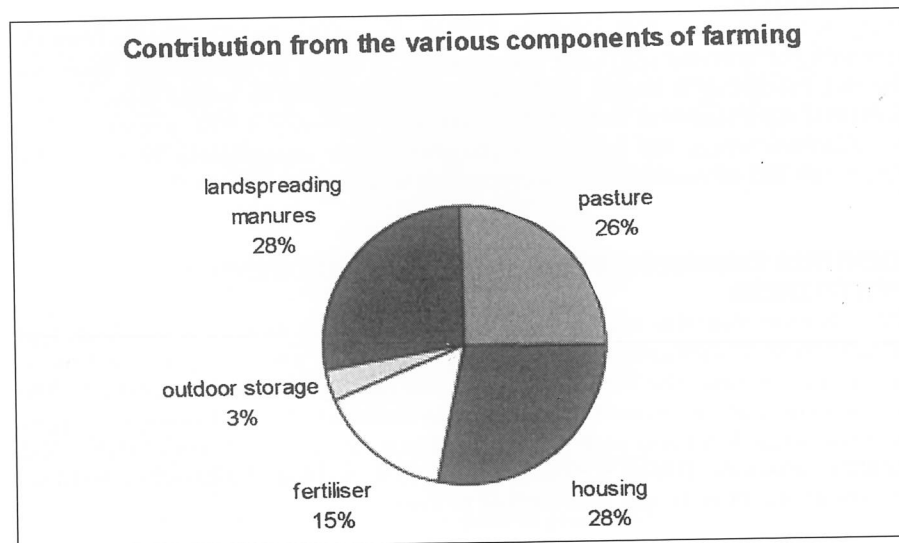
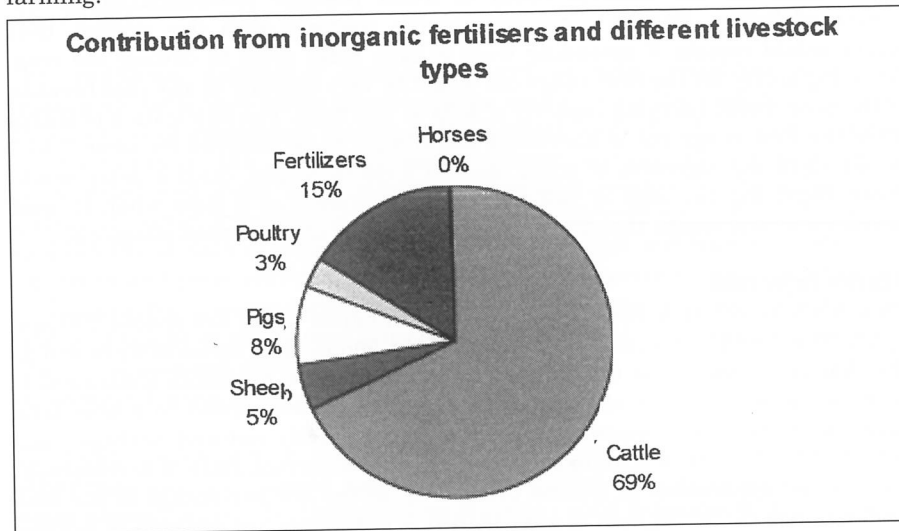
Malgeryd 1998 showed that the most effective way to reduce emissions from the spreading of (slurries and) solid manures was to (inject or) incorporate them into the soil. Ploughing is mainly applicable to solid manures on arable soils, hence it is of little significance in Ireland. An abatement efficiency of 80% is commonplace in situations where the manure is ploughed under immediately, however, this figure can fall substantially if incorporation is delayed for more than 24 hours.

AMMONIA EMISSIONS FROM N-CONTAINING CHEMICAL FERTILISERS

Volatilisation from this source depends on factors such as kind of fertiliser, type of soil, time of application and weather conditions prevailing at the time of spreading. Of these, the kind of fertiliser used has a particularly important effect on the extent of the losses (Whitehead and Raistrick, 1990). Losses are largest for urea, while fertilisers such as CAN (Calcium Ammonium Nitrate) show much smaller emissions. Hence, a potentially effective method of controlling fertiliser emissions would be to use alternatives to urea.

COMPONENTS OF AMMONIA EMISSIONS FROM AGRICULTURE IN IRELAND

These are displayed in two separate formats in the attached pie charts. Number 1 shows the contributions from inorganic fertilisers and the different livestock types while Number 2 shows the contributions from the various components of farming.



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Grassland Management – effect on herd performance

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INTRODUCTION

Current changes in agricultural policy and future expected changes will continue to remove the relatively high level of protection engaged by the EU countries. Market forces are likely to determine producers returns much more in the future. Therefore in the future with probably a lower milk price and the possibility of increased milk production (no-quotas) Irish dairy farmers will have to become more efficient producers of milk. Grazing grass in situ at a reasonable level of utilisation will remain the simplest and most efficient method of milk production. With good grazing management we can have a long grazing season with high quality feed available at low cost. A research programme was set up in Moorepark in the Autumn of 1995 to investigate if increased measurement at farm level could influence the performance being obtained from grazed grass. The farms selected were intensive dairy farms which were already achieving above average performance. The increased performance would result in improved financial returns. The measurements that would have most influence on performance were:-

- Pasture cover.
- Post grazing sward height.
- Pasture quality.

Other measurements which were already being monitored on these farms included milk yield, milk composition, cow fertility performance, concentrate input and silage quality and yield. Thirteen dairy herds were initially selected for this project. All herds were visited twice monthly from March to September and once monthly for the remainder of the year. All four measurements were taken on each visit. The grazing management practices of these farms have now being monitored for two and a half years. The questions being asked in the project are:-

- What major deficiencies in terms of grazing management have been identified on these farms.
- Has the use of more measurement being a benefit in correcting these deficiencies.
- What are the recommendations coming from these measurements.

1. PASTURE COVER

Pasture cover is defined as the total supply of available grass (>4cm) on all the paddocks which are available for grazing. Paddocks closed for silage are not included. Four main areas were identified where a knowledge of pasture cover was of significant benefit.

(a) **Closing cover in late November/early December.** Figure 1 shows closing average farm covers for six Spring calving herds over the last 3 years (1995-1997). The figure clearly shows large increases in closing cover over the past 3 years. The benefit seen at farm level of an increased closing cover is a much increased Spring grass supply. Increasing opening Spring cover demands a higher level of utilisation by earlier turnout and making more grass available during the first cycle. The results also showed that grazing very large covers (>2800 kgs DM/ha) in the last grazing rotation were detrimental for perennial ryegrass survival and grass supply the following Spring.

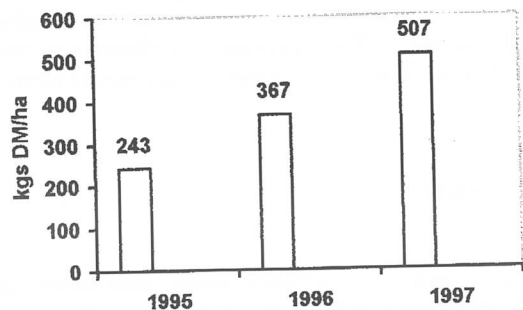


Figure 1. Average pasture cover at closing in Autumn for six Spring Calving Herds 1995-1997

Therefore the main findings concerning cover were;

- Farm grass cover should be >350kgs DM/ha with a range in paddock cover of 200-800 kgs DM/ha.
- The farm should be closed in rotation, with the first paddock closed between the 10-15th of October.
- By the end of the first week of November 60% of the farm should be closed and all grazing should cease by late November.
- Large covers >2000kgs DM/ha should be avoided on the last grazing rotation.

(b) **Opening pasture cover in the Spring.** The benefit of grazed grass as part of the diet in early lactation with Spring calving dairy cows has long been identified. It is not possible to suggest one turnout date for all dairy farms. This will very much depend on grass supply, stocking rate, calving pattern, soil type and the implication of other enterprises on the farm. It also has implications on target Mean Calving Date. The project has identified that a knowledge of pasture cover can be used to make maximum use of grazed grass from mid February to late April. Figure 2 shows the average turnout cover on six Spring calving herds for the last 3 years.

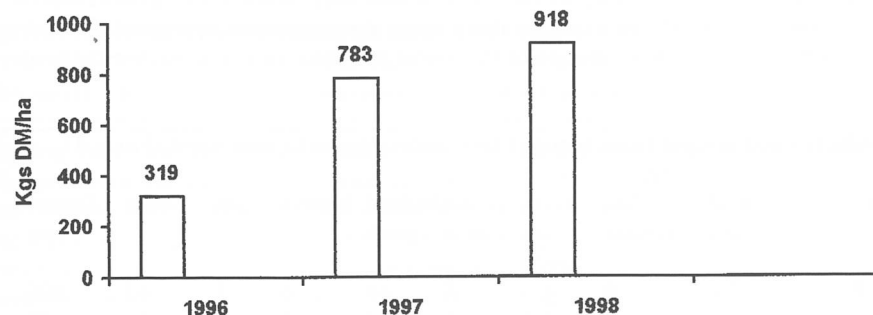


Figure 2: Average cover at turnout for six Spring Calving herds 1996-1998

It is evident from the data that considerable improvement has taken place on these farms with regard to pasture cover at turnout in late February/early March. Figure 3 shows how turnout with very low pasture cover can actually reduce the amount of grass utilized over the Spring. Whereas if turnout takes place at the proper cover the grass available can be maximized in the cows diet. However, over the past two Springs the former has been the situation on some dairy farms where turnout was too late and optimized use of Spring grass was not achieved.

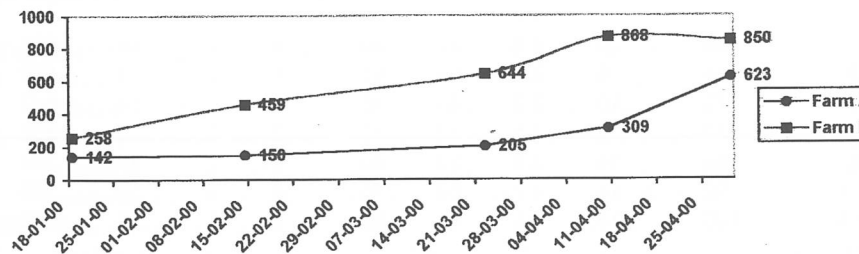


Figure 3: The effect of two levels of pasture cover at turnout on subsequent Spring cover

Table 1 and 2 show feed budgets for two contrasting farms. For the purpose of comparison the two farms were 100 cow herds with similar calving patterns. Farm 1 has access to 40ha (100 acres) of grazing area, while Farm 2 has access to 22 ha (54 acres). Both farms have a turnout cover of 600kgs DM/ha. The farms have different turnout dates and turnout only occurs when the cows can be allowed 6kgs DM/cow. Both of these farms have a target cover of 800 kgs DM/ha on the grazing area in mid April at similar stocking rates. Because of the larger grazing area, a lot more grass can be allocated to the cows in Farm 1, Farm 2 cannot turnout as early or allow the same level of grass because of the grazing area constraint. From turnout until mid April Farm 1 is able to allow a total of 1.0t grass/DM/Cow, while Farm 2 can only allow 0.62t grass/DM/cow. This shows the benefit of using pasture cover measurement to exploit the extra grass which is available because of the lower stocking rate and earlier turnout.

Table 1: Feed budget from turnout late February until mid April (Farm 1)

Date	No of Cows	Grass allowance	Stocking rate cows/ha	Demand per ha	Predicted growth	Depletion	Days	Decline	Expected Cover
21/2	52	6	1.3	8	14	6	7	43	600
28/2	59	8	1.5	12	17	5	7	36	680
6/3	62	12	1.6	19	20	1	7	10	690
13/3	66	14	1.7	23	25	2	7	13	703
20/3	73	16	1.8	29	35	6	7	41	744
27/3	79	18	2.0	35	45	10	7	67	810
3/4	84	20	2.1	42	60	18	7	126	936
10/4	92	20	4.5	90	75	-15	7	-105	831
17/4	100	20	4.5	90	85	-5	7	-35	796

Table 2: Feed budget from turnout early March until mid April (farm 2)

Date	No of Cows	Grass allowance	Stocking rate cows/ha	Demand per ha	Predicted growth	Depletion	Days	Decline	Expected Cover
6/3	62	6	2.8	17	20	3	7	22	622
13/3	66	8	3.0	24	25	1	7	7	629
20/3	73	10	3.3	33	35	2	7	14	643
27/3	79	12	3.6	43	45	2	7	13	656
3/4	84	14	3.8	53	60	7	7	48	704
10/4	92	16	4.2	67	75	8	7	55	758
17/4	100	18	4.5	81	85	4	7	28	786

The main finding regarding turnout date and budgeting of the feed :

- i Turnout should begin with a pasture cover of 550-600 kgs DM/ha at 2.75 cows/ha, lower turnout covers are possible at lower stocking rates.
- ii The available feed should then be budgeted, and the first rotation should finish between the 10-20th April (the day grass supply equals grass demand). This date can vary from year to year. The precise date to finish the round can only be found by careful monitoring of pasture supply.
- iii Pasture cover target on the 20th April should be 750-800 kgs DM/ha at a stocking rate of 4.5 cows/ha on the grazing area.

IDENTIFICATION OF SURPLUSES AND DEFICITS.

The results from the study have shown that cow performance can be influenced by early identification of a surplus or a deficit grass supply with the use of pasture cover measurement. An extremely steep wedge pattern of grass supply (going from 350 to 300kgs DM/ha) indicates an oversupply of grass. Grazing large covers during the main grazing season (>2500 kgs DM/ha) will often result in reduced milk production or necessitate topping large residuals. In the lead up to a period of a grass shortage pre cutting some paddocks would facilitate better utilisation of large pre grazing yields especially in dry weather conditions. The reaction on most dairy farms to large pre grazing yields of grass was to remove the surplus grass as silage. If silage harvesting was delayed then it resulted in (a) reduced the pasture cover (b) increased stocking rate on the grazing area. Farms that delayed harvesting these surplus paddocks generally had a grass shortage in the next rotation. Using pasture cover in conjunction with grass DM available per cow and a forecast of future grass growth rates over the following 7 to 10 days will allow better management decisions to be made.

If grass growth rates are below normal and/or stocking rate too high a less pronounced wedge shaped grass supply pattern will result. Cows will be going into paddocks with low covers (<1500kgs DM/ha). Running covers down to very low levels will result in even more reduced grass growth rates at farm level and will generally result in the under feeding of the cows. Pasture cover measurements will identify a future problems with grass supply before pre grazing yield will. Therefore the use of pasture cover measurement will allow management decisions to be put in place at an earlier stage i.e. stocking rate can be adjusted or supplements can be introduced.

The main findings regarding identification of surplus/deficits are;

- i Pasture cover should be maintained at 900-950 kgs DM/ha or 200 kgs DM/cow on the grazing area during the main grazing season.
- ii If pasture cover increases, to greater than 1000 kgs DM/ha from mid April to mid July the surplus grass should be removed as silage. The surplus paddocks should be harvested as silage at day 21 to 25 in the rotation.
- iii With a decreasing pasture cover, the herd should be supplemented or the grazing area should be increased by including some silage paddocks. This should be introduced early enough so as not to let the pasture cover drop below 700kgs DM/ha.

(d) Obtaining high performance. Figure 4 shows the average daily allowance of grass for 6 Spring calving herds over the grazing season of 1997. The data indicates that the lowest allowance of grass occurred in the late April to early June period. This is the period of peak milk production and also coincides with the breeding season. Figure 5 shows the milk production profile for the six Spring calving herds. In 1997, average milk production in kgs milk/cow/day is 28.0, 25.3, 24.2, 23.1, 19.5, 16.9 for the months of April, May, June, July, August and September respectively. The average reduction in milk yield from April to May (2.7kg milk/cow), May to June (1.1kg milk/cow), June to July (1.1kg milk/cow), July to August (3.6kg milk/cow), August to September (2.6kg milk/cow), September to October (3.3kg milk/cow), October to November (4.5kg milk/cow). The mean calving date for these herds was March 1st. Therefore, peak milk production should occur in May. The milk production data shows a large milk yield reduction in May. This reflects inadequate feeding which can be seen in figure 4 with the low grass allowance and the use of very little supplement. The factor that will create the largest pressure on grass supply in this period is the stocking rate on the grazing area. Stocking rates of 5 cows/ha or greater are too high unless large levels of supplement are been fed. Some farms on the study were at very high stocking rates during this period and were feeding very little supplements. Table 3 shows the daily allowance of grass and the availability of grass per cow (kgs DM/cow = Pasture cover/stocking rate) at varying stocking rate using average Moorepark grass growth rates (1990-1996) from April 22 to May 27th.

Table 3: Effect of stocking rate on daily grass allowance and DM available per cow.

Stocking rate (cows/ha)	6.0	5.5	5.0	4.5	4.0
Grass Allowance (Kgs DM/cow)	15.3	16.7	18.4	20.4	23
DM available (kg/cow)	150	164	180	200	225

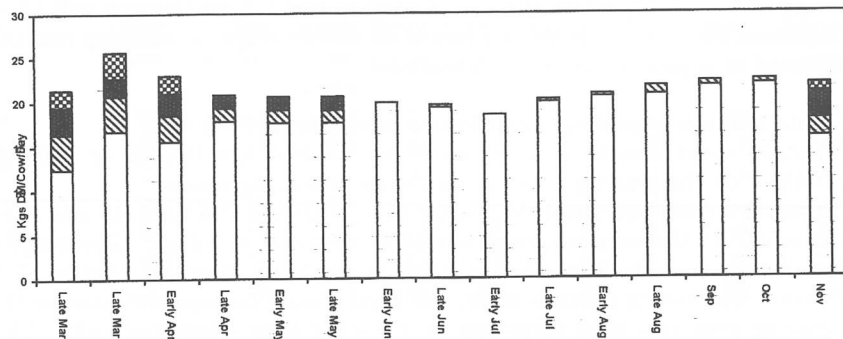


Figure 4: Average daily feed allowance for six Spring calving herds 1997

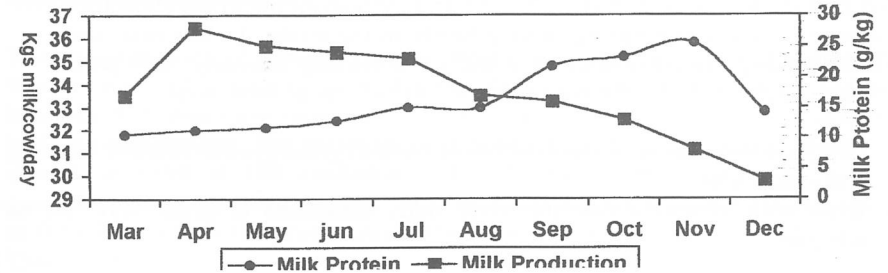


Figure 5: Average Milk Yield and Milk Protein production for six Spring calving herds 1997.

The major finds with regard to obtaining high performance from grazed grass:

- i A stocking rate of 4.5 cows/ha from mid April to early June is sufficient to maintain the correct balance of pasture supply and grass allowance to adequately feed cows at pasture.
- ii Very high stocking rates (>5 cows/ha) from mid April to June will result in inadequate grass supply and result in underfeeding of cows unless large levels of supplements are fed.

2. POST GRAZING SWARD HEIGHT

The degree to which any paddock is grazed is a function of grass availability versus herd requirement. Table 4 outlines the post grazing height that results from different grazing intensities. If a paddock is grazed to a post grazing height of 4cm, then the grass intake of the herd will be very much reduced. If on the other hand a pasture is grazed to a post grazing height of 8cm, intake will be high but a large level of grass will be wasted. On some farms post grazing height ranged from 4.5 to 5.5cm for a large part of the grazing season.

Table 4: Post Grazing severity score

Grazing Score	Grazing Height	Description
1	<4.5	Grossly over-grazed
2	4.5-5.5	Over-grazed
3	5.5-6.5	Good grazing
4	6.5-7.5	Under-grazed
5	>7.5	Grossly under-grazed

Figure 6 shows the post grazing height and corresponding grass allowance over the year for one of the Spring calving herds on the study. In this case, there was an inadequate grass allowance and a low grazing intensity. Low post grazing height could be the results of two situations at farm level.

- i Low pasture cover as a result of below normal grass growth rates or too high a stocking rate.
- ii Even with adequate pasture cover daily allocation of grass may not be adequate.

Both of these two situations were recorded at farm level. Low post grazing height as a result of low pasture cover generally occurred in the mid April to June period. This was mainly as a result of too high a stocking density (5 to 5.5 cows/ha) where the farmer attempted to maintain a 21 day rotation with very little supplementation. It also occurs during the main grazing season in periods of below normal grass growing conditions where no adjustment in stocking rate occurred and no supplements were fed. Low post grazing heights with adequate pasture cover also occurred. This took place generally where grass was been allocated on a 12 hour basis (after each milking) at farm level.

A 24 hour allocation may be more conducive to achieving higher intakes of grass. At farm level there was over emphasis placed on achieving extremely high grass utilisation.

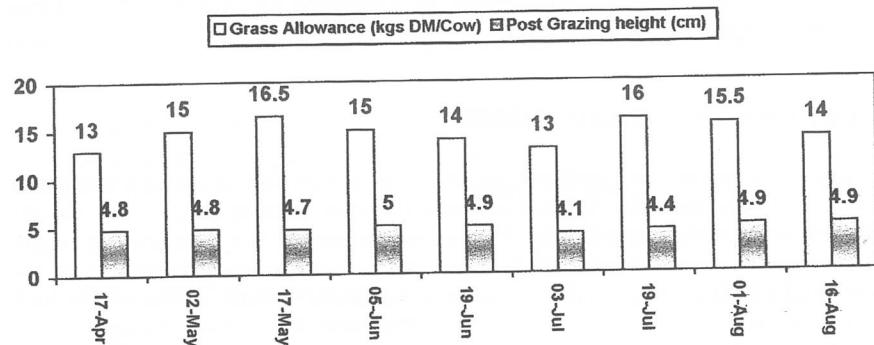


Figure 6: Low grass allowance and corresponding post grazing height

The main findings on the monitoring of post grazing sward heights were:-

- i Very low post grazing height was much more evident on the farms studied rather than high post grazing heights.
- ii The main reason for very low post grazing height was very high stocking rates with low pasture cover.
- iii Very low post grazing height also occurred with adequate pasture cover where over emphasis was placed on achieving high utilisation to the detriment of cow performance.

3. PASTURE QUALITY

The measurement of pasture quality which was used in this study was the measurement of the proportion of green leaf available in the sward (>4cm). Moorepark studies have shown a direct relationship between proportion of green leaf and digestibility. For optimum milk production the proportion of green leaf should be >65% of DM available. Most farms achieved very high quality pastures over the grazing season. However, there were a number of situations at farm level where the proportion of the sward decreased below 65% green leaf. These were:-

- i Where rotation length was in excess of 25 days in mid May/June, 30 days in July/August and 40 days in September.
- ii In periods of below normal grass growth rates and in semi drought conditions where large amounts of stem development were evident.
- iii In pastures which contained less than 50% ryegrass. These pastures had generally lower pasture quality throughout the grazing season. The greatest deterioration in quality took place mid season on these pastures. Figure 7 shows the percentage of green leaf in the grass offered to one of the Spring calving herds.

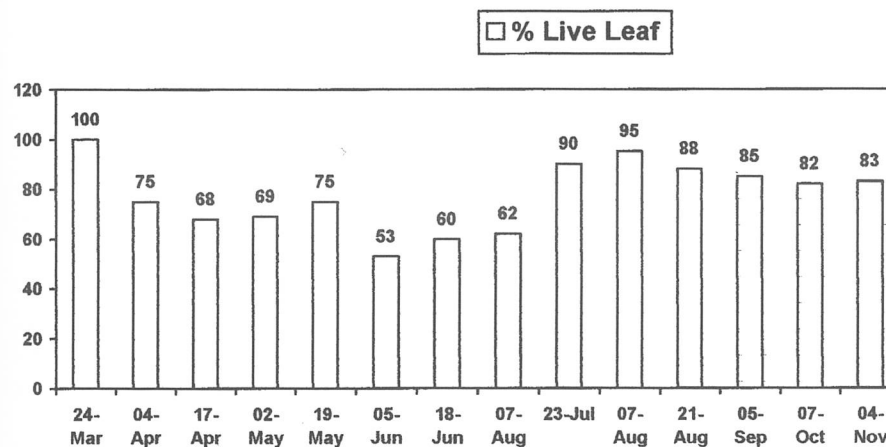


Figure 7: Percentage Live Leaf available in poor ryegrass swards

The main findings with regard to pasture quality were:-

- i Most farms maintained very high pasture quality over the grazing season. This was achieved by not leaving large residuals after the previous grazing and using pasture topping, if required.
- ii The main reason for reduced pasture quality was an extended rotation length for the time of year.

CONCLUSION

This paper clearly outlines the large benefit obtained at farm level from an increased use of measurement. It will allow dairy farmers to achieve much higher levels of performance from grazed grass. It will also allow research findings to be more readily adopted at farm level. With the increased use and focus on discussion groups as a method of technology transfer, these measurements are essential and should be an integral part of the discussions.