Aspects of management options for pasture-based dairy production stocked at two cows per hectare.

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Abstract

White clover in association with *Rhizobium* bacteria have the capacity to fix or convent atmospheric N into plant available N. This can make a considerable contribution to sward productivity. One of the objectives of this experiment was to determine the upper carrying capacity of grass-white clover swards receiving 90 kg fertilizer N/ha. A second objective was to examine the impact of grass-clover swards on mineral-N in the soil and losses of nitrate-N from soil to drainage water during the winter. This experiment was conducted at Solohead Research Farm. There were three treatments: (i) A grass-only treatment (FN) stocked at 2.0 cows per ha in 2003 and 2.2 cows per ha during 2004, 2005 and 2006. This treatment received an average of 226 kg per ha of fertilizer N per year during these years. (ii) A grass-clover treatment (WC) stocked at the same rates as FN and received an average of 90 kg per ha of fertilizer N per year during the experiment. (iii) A grass-only treatment (CC) that was gradually converted over to grass-clover during the experiment and stocked at 2.0 cows per ha throughout the experiment. Fertilizer N input was gradually lowered from 150 kg per ha in 2003 to a target of 90 kg per ha in 2005 and 2006.

There were 24 cows per treatment. Cows were divided into four main groups on the basis of lactation number (1, 2, 3 & ≥4) and then sub-divided into sub-groups of three on the basis of calving date. From within each sub-group one cow was randomly assigned to each herd. Herds were randomly assigned to each treatment. Milk output per cow in the third week of lactation was used as covariate in analysis of variance. The aim in each treatment was to supply sufficient grass to (1) meet the cows feed requirements over 250 whole-days grazing (early Feb. to early Dec.) and (2) provide the winter (115 days) feed requirements as silage. The target quantity of silage was 1.4 t DM per cow per year. Mean calving date was 22 February. Concentrate fed averaged 473 kg DM per cow per year.

Mineral-N (nitrate-N and ammonium-N) concentrations in soil were measured in early October, late November & mid-February in four grazing plots and four silage plots within each treatment during the winters of 2003/04, 2004/05 and 2005/06. At each sampling 15 soil cores were taken to a depth of more than 1.0 m from each plot. These were subdivided and bulked at each of three depths (m): 0 to 0.3, 0.3 to 0.6 and 0.6 to 0.9, within each plot. Each sample was extracted in 400 ml of 2M KCl (1:2 w/v) and shaken continuously for 2 hours before filtering. Nitrate-N and ammonium-N concentrations were determined using automated colorimetric procedures and converted to kg N/ha using the soil bulk density at each depth. A bulked sample of water was taken once a week from four dip-wells that were installed vertically to a depth of 1 m in the soil in four grazing paddocks and four silage paddocks through each winter of the experiment. Resident water was extracted by suction and the dip-well was allowed to refill for 2 hours before sampling. The sample was then analyzed for nitrate, nitrite and ammonium.

There was no difference in milk output per cow between the treatments, which averaged 6532 kg/cow (SEM = 165). White clover based grassland receiving 90 kg per ha of fertilizer N per year

has the capacity to carry a stocking rate of around 2.0 cows per ha producing approximately 13,000 litres of milk or 1000 kg of fat & protein per ha. Uptake of N fixed in association with the white clover swards on the WC treatment averaged 127 kg/ha. The net saving in fertilizer N at 2006 prices associated with white clover in the sward was equivalent to approximately €100 per ha. On farms of 40 to 50 ha, the potential saving is between €4000 and €5000, which, in the context of average annual income on dairy farms in 2005 of approximately €35,000, can make a considerable contribution to profitability on farms.

The organic N loads on the different systems in this experiment ranged between 191 and 212 kg per ha. Median nitrate-N concentrations in water draining from these systems ranged between 3.59 and 3.79 mg per l. These low concentrations are due to the heavy soil at Solohead; a far higher proportion of losses of nitrate from the soil at Solohead is attributed to gaseous losses due to denitrification rather than as nitrate leached to groundwater. Losses of N from the white clover-based grassland (WC and CC) were similar to losses from the grassland receiving higher inputs of fertilizer N (FN). These losses were directly proportional to the amount of N circulating within the systems regardless of the original source of N; manufactured fertilizer N or biologically fixed N. From a broader environmental perspective, the white clover based swards offer the potential of lower greenhouse gas emissions at similar stocking rates to fertilized grass swards because substantially less fertilizer N is applied to the clover swards, lowering the CO_2 emissions associated with the manufacture, transport and applications of the fertilizer N.

Introduction

White clover has a number of useful attributes. *Rhizobia* bacteria live in nodules on the roots of white clover and have the capacity to fix atmospheric N and make it available in the soil for pasture production through a process known as biological N fixation. The quantity of N supplied can be as much as 150 kg per ha. Atmospheric N can also be converted into plant-available-N such as ammonium and nitrate by various industrial processes to produce artificial fertilizers such as urea (concentrated Ammonium) and CAN (Calcium Ammonium Nitrate). However, the manufacture of nitrogenous fertilizers is an energy-demanding process and the cost of fertilizer N is closely linked to the cost of energy on the world market (Figure 1). Over the last decade there has been a steady rise in the cost of energy and this upward trend seems set to continue. During this period the cost of fertilizer N has increased by approximately 60% (Figure 1). Concurrently, there has been a steady decline in the farm-gate price received for milk being only 90% of that in 1998 (Figure 1). The overall impact of these changes has been a doubling of the cost of fertilizer N relative to milk price during the last decade. In other words, during 2006 on a typical dairy farm in Ireland it was necessary to sell three litres of milk to purchase one kilogram of fertilizer N, whereas the same quantity of fertilizer N could be purchased by the sale of one and a half litres of milk a decade ago.

This price:cost squeeze has contributed to a decrease of 21% in the average amount of fertilizer N being used on Irish farms since 1998 (Figure 2). Nevertheless, this decrease has not been sufficient to offset rising costs and, while fertilizer N use has fallen, average expenditure on fertilizer N on Irish farms has risen by 27% (Figure 2). The competitiveness of Irish dairy production in a European context is largely based on our capacity to grow and efficiently utilize large quantities of low-cost grazed grass over a long grazing season. The production of large quantities of pasture per hectare is predominantly determined by input of fertilizer N. The rising cost of fertilizer N is contributing to the erosion of the profitability of Irish grass-based systems of production.

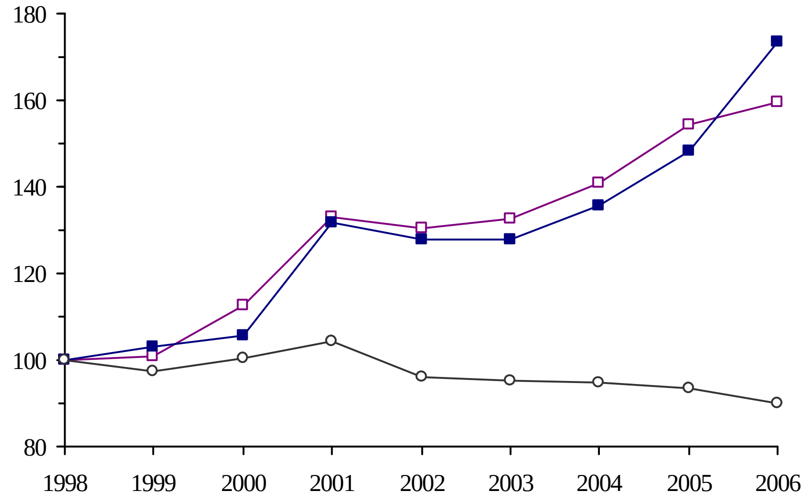

Figure 1. The unit cost of energy (■), fertilizer N (□) and milk (○) relative to 1998 baseline.

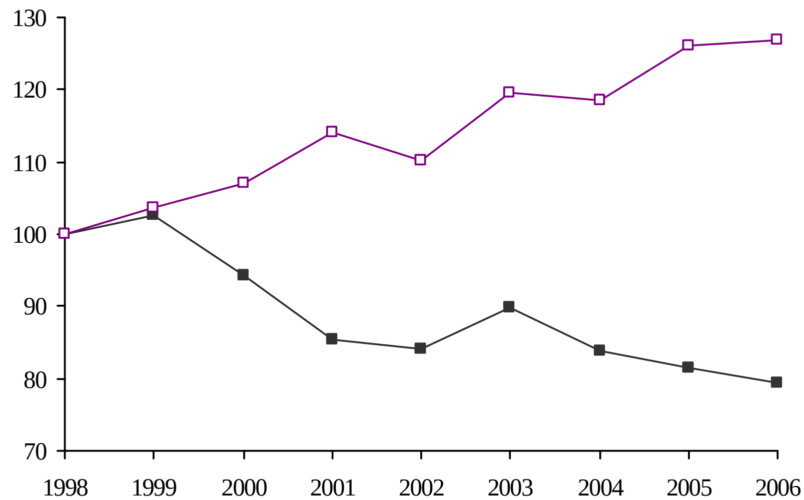

Figure 2. The annual quantity of fertilizer N used (■) and annual expenditure on fertilizer N (□) on Irish farms relative to 1998 baseline.

White clover has very high nutritive value. It has the highest nutritive value of any grassland species including perennial ryegrass (Wilman and Riley, 1993; Castle *et al*., 1983; Thompson, 1984; Wilman and Williams,1993; Harris *et al*., 1998; Yarrow and Penning, 2001). White clover has relatively low structural fibre concentration in herbage dry matter (DM) (50% of that of perennial ryegrass). This is associated with higher digestibility, which combined with a relatively high crude protein concentration in the herbage DM leads to rapid particle reduction and increased rate of passage through the rumen. These characteristics contribute to higher intake and milk production by cows grazing swards containing white clover (Thompson *et al*., 1985; Wilkins *et al*., 1991). It is often difficult to maintain the digestibility of grass-only swards receiving low inputs of fertilizer N. White clover can generate its own supply of N and thrives under low fertilizer N input; the less fertilizer N that is applied the higher will be the clover content of the sward. Higher clover contents result in swards with higher nutritive value.

The capacity of white clover to fix atmospheric N, its high nutritive value under low fertilizer N input and compatibility with the Rural Environmental Protection Scheme indicates that white clover-based systems offer considerable advantages to a substantial number of Irish farmers.

Objectives

The objective of this project was to evaluate the capacity of white clover-based swards receiving fertilizer N inputs of 90 kg N per ha to supply herbage (pasture and silage) to meet the requirements for dairy production from grassland stocked at 2.0 cows per ha per year and supplemented with approximately 0.5 t concentrate per cow per year.

A second objective was to examine the impact of clover-based swards compared with grass swards on residual mineral-N in the soil at the commencement of drainage in the autumn and on losses of nitrate-N from soil to drainage water during the winter.

The Experimental Systems

This experiment was conducted at Solohead (Latitude 52° 51’ N, Longitude 08° 21’ W; soil association 39) between February 2003 and February 2007.

The swards

There were three systems. During 2003 each system was stocked at 2.0 cows per ha (Table 1). Two systems were based on grass-only swards and contained <30 g white clover per kg pasture DM in the spring. One of these systems was the control system (FN) and received fertilizer N input of 220 kg per ha per year during 2003 (Table 1). The other grass-based system received fertilizer N input of 150 kg per ha during 2003. This system known as the conversion to clover (CC) system was progressively converted over to clover between 2003 and 2006 (see below). The third system (WC) was based on established clover-based swards containing 140 g white clover per kg pasture DM in spring 2003.

The stocking rates on the FN-control and WC systems were increased by 10% to 2.2 cows per ha during 2004 in order to increase the pressure on the WC clover swards to supply pasture and silage. These higher stocking rates were maintained on these two systems during 2004, 2005 and 2006. Annual fertilizer N input to the FN-control system was approximately 226 kg per ha and to the WC system was approximately 90 kg per ha during these years. There were higher than target fertilizer N inputs to each system during 2006 because of the below-average grass growth experienced during that year. In order to maintain the clover content of swards, white clover seed was over-sown onto 20% of the area of the WC system each year using methods described by Humphreys and Lawless (2006).

Table 1. Stocking rates and annual fertilizer N input

	Control Fertilizer N (FN)		Established Clover (WC)		Conversion to Clover (CC)	
	Stocking rate (cows per ha)	Fertilizer N (kg per ha)	Stocking rate (cows per ha)	Fertilizer N (kg per ha)	Stocking rate (cows per ha)	Fertilizer N (kg per ha)
2003	2.0	220	2.0	88	2.0	150
2004	2.2	224	2.2	84	2.0	109
2005	2.2	219	2.2	89	2.0	90
2006	2.2	240	2.2	99	2.0	99
Mean		226		90		112

The stocking rate on the CC system was maintained at 2.0 cows per ha during the four years of this experiment. However, white clover seed was progressively over-sown into approximately 40% of the area of this system each year as a means of introducing clover into this system using the same methods as above (Humphreys & Lawless, 2006). Concurrently, annual fertilizer N input was progressively lowered from 150 kg per ha in 2003 to a target of 90 kg per ha in 2005 and 2006. Average annual fertilizer N input to the CC system during the four years of this experiment was 112 kg per ha (Table 1).

The cows

There were 24 cows per system. Each spring cows were divided into four main groups on the basis of lactation number (1, 2, 3 & ≥4) and then sub-divided into sub-groups of three on the basis of calving date. From within each sub-group one cow was randomly assigned to each herd. Herds were randomly assigned to each system. Milk output per cow in the third week of lactation was used as covariate in analysis of variance. Mean calving date was 22 February. Cows were assigned to each system each spring and remained within that system until the end of lactation. At the end of lactation, cows not in calf were sold off the farm and the remaining cows-in-calf were managed as one herd indoors until the following spring calving period (late January to mid April).

The aim in each system was to supply sufficient herbage DM to (*i*) meet the cows feed requirements over the grazing season (early Feb. to early Dec.) and (*ii*) provide the winter feed requirements as silage. The target quantity of silage stored was 1.4 t DM per cow per year. Stored silage was calculated as 75% of herbage harvested for silage. The remaining 25% was attributed to losses such as field losses during harvesting, respiration, fermentation etc. (Gordon, 1988). Concentrate fed (DM per cow per year) amounted to 480 kg in 2003, 300 kg in 2004, 360 kg in 2005 and 750 kg in 2006. Concentrate input varied with weather, grass-growing and grazing conditions experienced during each year. Average annual concentrate DM fed during the four years of the experiment was 473 kg per cow.

Nitrate losses to water

Mineral-N (nitrate-N and ammonium-N) concentrations in soil were measured in late September, late November & mid-February during the winters 2003/2004 and 2004/2005. It was measured in late September and late November 2005/2006. Measurements were made in four grazing plots and four silage plots within each system each year. At each sampling 15 soil cores were taken to a depth of more than 1.0 m from each plot. These were subdivided and bulked at each of three depths (m): 0 to 0.3, 0.3 to 0.6 and 0.6 to 0.9, within each plot. Each sample was extracted in 400 ml of 2M KCl (1:2 w per v) and shaken continuously for 2 hours before filtering. Nitrate-N and ammonium-N concentrations were determined using automated colorimetric procedures and converted to kg N per ha using the soil bulk density at each depth.

A bulked sample of water was taken once each week from four piesometers that were installed vertically to a depth of 1 m in the soil within each of the plots where measurements of mineral-N were made (outlined in previous paragraph). Resident water was extracted by suction and the peisometer was allowed to refill for 2 hours before sampling. Nitrate-N concentrations were determined using automated colorimetric procedures. Between February 2004 and the end of the experiment samples of water in field drains draining the experimental area were taken on a weekly basis at 12 locations around the farm. These samples were analyzed for nitrate-N as outlined above for comparison with the concentrations in water collected from the peisometers.

Results and Discussion

Milk production

There were no significant differences in milk production or milk composition between the three systems during the experiment (Table 2). Furthermore, there were no significant differences in body condition score, body weight or in the number of cows in calf at the end of lactation in each of the herds over the four years of this experiment. There was no evidence that the clover in the clover-based swards resulted in higher performance from the cows grazing these swards.

Table 2. Milk Production and composition.

	Fertilizer N (FN-control)	Established Clover (WC)	Conversion to Clover (CC)	Sig.	SEM
		Annual milk production (kg per cow)			
2003*	6573	6561	6710	NS	177
2004	6549	6611	6486		
2005	6389	6401	6462		
2006	6487	6447	6581	NS	165
		Annual production of solids-corrected milk (kg per cow)			
2003*	6411	6404	6467	NS	156
2004	6445	6363	6423		
2005	6405	6386	6387		
2006	6405	6432	6455	NS	137
		Annual production of milk fat (kg per cow)			
2003*	267	269	271	NS	7.1
2004	274	266	275		
2005	273	277	274		
2006	271	268	275	NS	6.3
		Annual production of milk protein (kg per cow)			
2003*	238	233	237	NS	6.0
2004	235	233	232		
2005	231	227	229		
2006	234	228	234	NS	5.2
		Annual production of milk lactose (kg per cow)			
2003*	314	314	318	NS	8.8
2004	310	314	306		
2005	306	301	305		
2006	309	306	311	NS	7.7

*Statistical analyses of data from 2003 were conducted separately whereas data from 2004, 2005 and 2006 were combined with year as a factor in the model. NS = no significant differences.

Length of the grazing season

Cows were turned out to pasture by day as they calved and were turned out fulltime (day and night) depending on pasture supply and on ground conditions. Only calved cows were turned out to grass in spring and therefore it is generally mid-April before all of the cows were calved and finally out on grass. Occasionally cows had to be housed by night during the main grazing season due to very wet weather conditions leading to high risk of excessive damage to the soil surface. For example, exceptionally wet conditions during May 2006 meant that cows had to be housed on 15 consecutive nights during that period; hence the large number of extra nights that cows had to be housed during 2006 (Table 3). Overall the number of total days out grazing averaged 254 days across systems and years and there were little difference between years although calving date was brought progressively earlier each year during the four years of the experiment.

Table 3. Dates of turnout of calved cows in spring and housing for the winter, extra nights housed during the main grazing season (to avoid excessive damage to the sward) and total days grazing where one day = out grazing day and night and one half day = out grazing by day only.

	Turnout in spring		Housed for winter		Extra	Total days
	by day	fulltime	by night	fulltime	Nights	Grazing*
			2003			
Fertilizer N (FN-control)	05 Feb	14 Mar	09 Nov	28 Nov	5	253
Established clover (WC)	05 Feb	14 Mar	09 Nov	28 Nov	1	255
Conversion clover (CC)	05 Feb	14 Mar	09 Nov	28 Nov	3	254
			2004			
Fertilizer N (FN-control)	02 Feb	20 Mar	18 Nov	04 Dec	17	254
Established clover (WC)	02 Feb	20 Mar	18 Nov	04 Dec	17	254
Conversion clover (CC)	02 Feb	20 Mar	18 Nov	04 Dec	17	254
			2005			
Fertilizer N (FN-control)	31 Jan	18 Feb	29 Oct	01 Dec	22	256
Established clover (WC)	31 Jan	18 Feb	22 Oct	27 Nov	22	250
Conversion clover (CC)	31 Jan	18 Feb	29 Oct	27 Nov	22	254
			2006			
Fertilizer N (FN-control)	26 Jan	28 Feb	14 Nov	01 Dec	27	255
Established clover (WC)	26 Jan	28 Feb	14 Nov	29 Nov	34	251
Conversion clover (CC)	26 Jan	28 Feb	14 Nov	01 Dec	27	255

*There was no significant difference in grazing days per year between systems replicated over years; SEM = 0.9.

Silage production

The number of grazing days per year ranged between 250 to 255 days (Table 3) and therefore silage had to be supplied for the 110 to 115 days that cows were kept indoors. Assuming that each cow consumed an average of 11 kg silage DM per day and waste an additional 10%, this means that 12.2 kg silage DM has to be supplied per cow per day indoors. Over 115 days this amounts to 1.4 t silage DM per cow. Silage production on the FN-control was more than sufficient to meet these requirements during the experiment (Table 4). During 2003 large surpluses of silage were made on both the FN-control and WC systems and this was the reason that stocking rate was increased to 2.2 cows per ha on these two systems during the later three years of the experiment. Averaged over the later three years of the experiment (2004 – 2006) silage production on the WC system was below target and not sufficient to meet the requirements of the higher stocking rate. Silage production on the CC system was sufficient on average during the experiment, although below target during 2005.

Table 4. Silage Production (t DM per cow)

	Fertilizer N (FN-control)	Established clover (WC)	Conversion to clover (CC)	Sig.	SEM
2003	2.26	1.87	1.67		
2004	1.57	1.30	1.47		
2005	1.62	1.39	1.30		
2006	1.48	1.06	1.41		
Average 2003-2006	1.73	1.41	1.46	$P < 0.05$	0.072
Average 2004-2006	1.56	1.25	1.39	$P < 0.05$	0.065

Grassland productivity

The FN-control system had higher grass DM production than the other two systems each year during the experiment (Table 5). Averaged over the four years the FN-control system out-yielded the WC system by approximately 1.0 t DM per ha and this difference was reasonably consistent across years although DM production varied from year to year; drought conditions lowered DM production across systems during 2006. Averaged over the later three years of the experiment, the FN-control out-yielded the CC system by approximately 1.6 t DM per ha. This is a difference of approximately 13% in DM production. The difference in stocking rate was 10%.

Table 5. Annual dry matter production (t DM per ha), white clover DM production (t DM per ha) and recovery of biologically fixed N in herbage >5cm above ground level (kg N per ha)

	Fertilizer N (FN-control)	Established clover (WC)	Conversion to clover (CC)	Sig.	SEM
		Dry matter production (t DM per ha)			
2003	13.19	12.18	11.69		
2004	12.97	12.09	11.50		
2005	12.95	12.16	10.88		
2006	11.63	10.22	10.43		
	12.68	11.66	11.12	$P < 0.001$	0.148
		Clover DM production (t DM per ha)			
2003	0.87	2.91	0.73		
2004	0.86	2.45	1.08		
2005	0.58	2.74	1.57		
2006	0.76	2.10	1.72		
Mean	0.77	2.55	1.27	$P < 0.001$	0.0124
		Biological N fixation (kg N per ha)			
2003	9	139	34		
2004	9	132	75		
2005	9	123	74		
2006	6	115	106		
Mean	8	127	72	$P < 0.001$	9.01

The FN-control system resulted in a surplus of silage production each year including the difficult year of 2006, albeit with higher than target inputs of fertilizer N and concentrate. Assuming concentrate supplementation of 475 kg concentrate per cow per year, total annual DM production from grassland of 12.15 t per ha was needed to meet the requirements of the higher stocking rate of 2.2 cows per ha. Therefore the FN-control system produced approximately 104% of these requirements. On the same basis, the WC system produced 96% of requirements. Indeed, the WC system produced sufficient DM from grassland to meet requirements in two years out of four. It could also be argued that the FN-control system offers greater potential to lower concentrate input, however, concentrate supplementation partly depended on other aspects of grazing management than pasture availability, such as difficult grazing conditions, supplementing the diet of cows housed at night on silage etc. Of the four years encompassed by this experiment, 2006 was the most difficult year in terms of grass growth and the WC system struggled to meet DM production requirements from grassland in terms of silage production and also for grazing. This latter aspect was evident in the number of days grazing per year (Table 3). The WC system had less grazing days per year in 2006, although there was no significant difference between the systems when averaged over the four years of the experiment.

Assuming concentrate supplementation of 475 kg per cow per year, total annual DM production from grassland of 11.0 t per ha was needed to meet the requirements of the lower stocking rate (2.0 cows per ha). The CC system was able to meet these requirements on average over the four years, but fell short during 2006 and was a little below this target in 2005 (10.88 versus 11.0 t DM per ha). Silage production from the CC system was on target in 2006 only because concentrate input was increased to 750 kg DM per cow. This concentrate was mostly fed to compensate for the serious shortfall in pasture supply during the drought conditions. On the other hand, the WC system, on average over the four years, produced 106% of requirements of the lower stocking rate. It produced sufficient DM from grassland to meet these requirements in three years out of four; the exception being the exceptional 2006. At a stocking rate of 2.0 cows per ha, the WC system offered the potential to produce a surplus of silage and/or the potential to lower concentrate input, as was clearly evident from the grassland DM production from this system during 2003. Taking good grass-growing years along with poor-grass growing years and carrying some silage from the good years to the poor grass-growing years it can reasonably be concluded that clover-based swards receiving fertilizer N input of 90 kg per ha will result in sufficient DM production from grassland to meet the requirements of a stocking rate of 2.0 cows per ha or an organic N load of 170 kg per ha.

The clover content of swards and recovery of biologically fixed N in herbage DM

The production of white clover DM in the FN-control system was approximately 0.77 t DM per ha during the experiment compared with 2.55 t DM per ha on the WC system. On average the clover content of swards on the WC system was approximately 22%. The production of white clover on the CC system increased as increasing areas of the farm were over-sown with clover and more-or-less in line with lower fertilizer N inputs. The uptake of biologically fixed N in herbage also increased on the CC system during the experiment, from 34 kg per ha during 2003 to 106 kg per ha during 2006 (Table 5). The relatively low improvement of N fixation in the CC system during 2005 compared with 2004 can be partly attributed to the relatively poor success of over-sowing during 2004 (Humphreys and Lawless, 2006). Uptake of biologically fixed N by herbage on the FN-control system remained low during the experiment averaging 8.5 kg per ha whereas on the WC system uptake of fixed N averaged 127 kg per ha. Lowest annual uptake of N fixation by herbage on the WC system was recorded during 2006. It is apparent that the drought conditions during 2006 may have impeded N fixation.

The quantities of biological N fixation presented in Table 5 represent the proportion recovered by the herbage harvested for silage or by grazing. A proportion of fixed N also accumulates in the clover stolon at the base of this sward and in the roots and nodules within the soil. Approximately 2.0 t per ha of stolon DM can accumulate at the base of the sward containing approximately 60 kg N per ha (or approximately an additional 30% to the fixed N recovered by the sward) (Humphreys *et al*., 1997). This stolon accumulates during the summer months and declines over the winter and following spring releasing N into the soil as the stolon decays. Up to 75% of stolon accumulated during one summer can senesce during the winter and hence the stolon acts to transfer N from one growing season to the next. Increasing soil temperatures during the spring hasten the decay of senescent stolon and hence there tends to be a flush of N release in the soil during the late spring (April and May) under clover-based grassland.

Soil Mineral N concentrations and nitrate N concentrations in drainage water

During the winter 2003/2004 the WC system had higher soil mineral N concentrations than the other two systems, which were not significantly different from each other (Table 6). During the winters 2004/2005 and 2005/2006 there were no significant differences in soil mineral N concentrations between the three systems.

Table 6. Soil mineral N (kg/ha) in the upper 90 cm of soil between September 2003 and November 2005

	Fertilizer N (FN-control)	Established clover (WC)	Conversion to clover (CC)	Sig.	SEM
		2003/2004			
Late September	80	116	81		
Late November	90	169	72		
Early February	75	104	66		
Mean	82	130	73	$P < 0.001$	7.9
		2004/2005			
Late September	47	48	46		
Late November	57	60	55		
Early February	61	55	50		
Mean	55	55	50		
		2005/2006			
Late September	43	49	42		
Late November	67	44	42		
Early February	–	–	–		
Mean	55	46	42	NS*	7.5

*Statistical analyses of data from 2004/05 and 2005/06 were combined with years as a factor in the model. NS = no significant differences

Very high quantities of mineral-N in soil were recorded during the winter 2003/04, particularly under the WC system. The high levels of mineral N across treatments during the winter 2003/04 compared to the other two winters may have been due to the high levels of net mineralization of soil organic matter (SOM) during 2003. Measurements of net mineralized SOM-N at Solohead were 160 kg per ha during 2003, compared with 132 kg per ha during 2001, 136 kg per ha during 2002 and 134 kg per ha during 2004 (O'Connell, 2005 and unpublished data). This exceptional net mineralization of SOM-N during 2003 probably contributed to the high levels of mineral N in the soil during the following winter (2003/04). On the WC system clover production was also highest during 2003 compared to the later years (Table 5). This resulted in high levels of N fixation and high levels of stolon production at the base of the sward. Senescence and decay of this stolon contributed to the high mineral N in soil under the WC system compared to the other two systems that contained relatively low clover contents during 2003. A further contributory factor to the high concentrations of mineral N beneath the three systems during 2003/04 was that the winter was relatively dry with low volumes of drainage recorded during that period. The volumes of water draining form the soil was 306 mm during the winter 2003/04 compared with 460 mm during the winter 2004/05 and 350 mm during 2005/06. Lower drainage lowered losses and facilitated the retention of high quantities of mineral-N in the soil over the winter.

Nitrate-N concentrations in piesometers between the start of drainage in the winter 2003 and the end of drainage in the spring 2006 ranged between 1.0 and 8.0 mg per litre (Figure 3). Median concentrations were 3.59 mg per litre in the FN-control system, 3.79 mg per litre in the WC system and 3.66 mg per litre in the CC system and there was no significant difference in median concentrations between the three systems. On some individual sampling dates there were occasional significant differences (Figure 1) but these differences were not consistent.

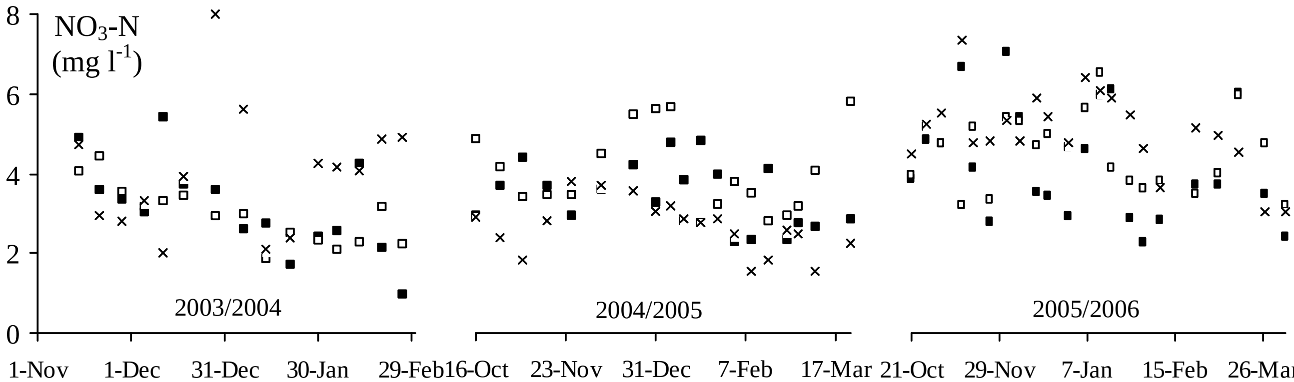

Figure 2. Nitrate-N (mg per l) in drainage water between November 2003 and April 2006: Fert. N-control (■), established white clover (×) and conversion to clover (□), Date x N-input: $P < 0.001$. SEM = 0.57

Table 7. Losses of in as nitrate-N in drainage water in peisometers

	Fertilizer N (FN-control)	Established clover (WC)	Conversion to clover (CC)	Sig.	SEM
		(kg N per ha)			
2003/04	10.2	14.2	9.4		
2004/05	19.7	12.6	20.2		
2005/06	21.6	26.1	20.7		
	17.2	17.6	16.8	NS	1.3

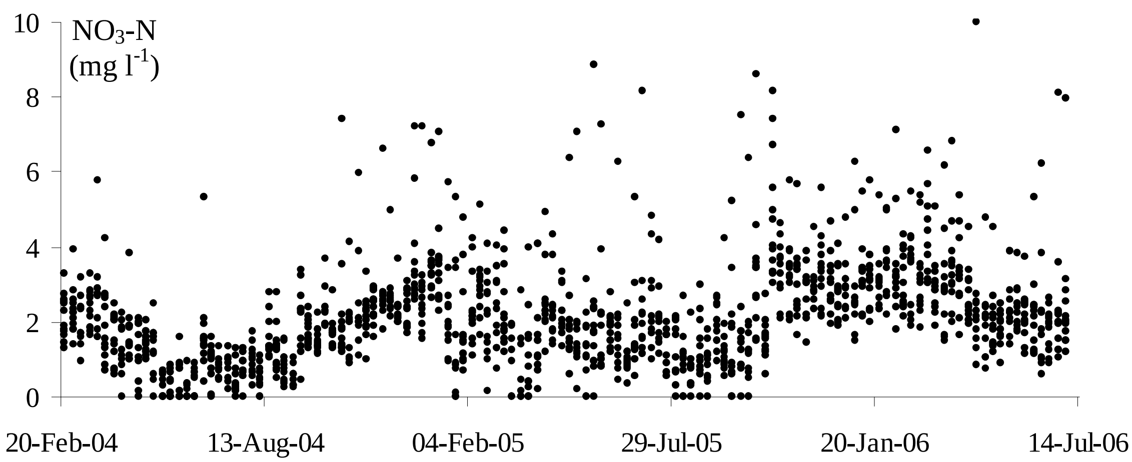

Figure 4. Nitrate-N in field-drains draining the experimental area between February 2004 and July 2006

When losses of nitrate-N to water were converted to kg N per ha there was no difference in losses between systems when averaged over three winters: 2003/04, 2004/05 and 2005/06 (Table 7). The relatively low losses during the winter 2003/04 was partly due to the relatively low volumes of water draining from the system during the winter (see above). Differences between systems within years from year to year were probably also due to error associated with sampling rather than true system differences. The deposition of urine is a major pathway for nitrate-N leaching in drainage water. Variation in urine deposition in relation to the location of peisometers probably had an important bearing on the results. However, when averaged over three seasons, significant differences between systems were not apparent.

Median nitrate-N concentrations in field drains draining the experimental area between February 2004 and July 2006 were 2.0 mg per litre. Higher median concentrations were recorded during the winter drainage periods being 2.28 mg per litre during winter 2004/05 and 3.06 mg per litre during winter 2005/06 (Figure 4). These concentrations are lower but not dissimilar to the concentrations of nitrate-N measured in peisometers and presented in Figure 2 above.

Nitrogen Balances

The organic N load (minus ammonia emissions) for the cows used in this experiment averaged over the four years of the experiment was 95 kg per cow, which is 12% higher than the standard value of 85 kg per cow estimated to be the national average for Irish dairy cows. This is because milk output from the cows at Solohead is approximately 6,500 kg per year or 41% higher than the average yield of the Irish dairy cows which is approximately 4600 kg per year. In terms of both milk production and organic N output, the cows at Solohead represent the upper end of the range of dairy cows in Ireland.

Table 8. Organic N loads per ha, N inputs and output, surplus N and efficiencies of N use

	Fertilizer N (FN-control)	Established clover (WC)	Conversion to clover (CC)
Standard value organic N (kg per ha)	187	187	170
Actual organic N load (kg per ha)	212	208	191
		N inputs (kg per ha)	
Fertilizer	228	90	112
Fixation* + Deposition	8	168	94
Concentrate	35	46	32
Total inputs	271	258	238
		N output (kg per ha)	
Milk	80.3	79.0	72.5
Meat	5.2	5.2	4.8
Total output	85.5	84.2	77.3
		Surplus N (kg per ha)	
Surplus N	185	174	160
Residual mineral N in autumn	54	50	46
Nitrate-N in drainage water	20.7	19.4	20.5
		Efficiencies of N use	
Utilization (output divided by input)	0.32	0.33	0.33
Residual N divided by Surplus N	0.29	0.29	0.29
Drainage N divided by Surplus N	0.11	0.11	0.13

*fixed N recovered by the sward multiplied by 1.3 to account for biologically fixed N in stolon and root material

Nitrogen balances for the three systems are presented in Table 8. Data from 2004, 2005 and 2006 are used for the FN-control and WC systems. Data from the four years of the experiment are used for the CC system. Fertilizer N input is taken from Table 1. Biological N fixation is taken from Table 5. However, it has been pointed out above that the fixed N in Table 5 represents the fixed N recovered by the sward. This is multiplied by a factor of 1.3 to estimate total fixed N, which includes the N accumulated in stolon etc. It is important to account for this N because as the stolon senesces and decays over the winter and spring, N is released into the soil can potentially be lost to the wider environment over the winter as well as being taken up by the sward during the following spring. Nitrogen in milk is taken from production of milk protein presented in Table 2 and divided by 6.39 to give N in milk. Nitrogen in meat is calculated from live-weight gain of the cows each year multiplied by 0.024 and from average calf weights multiplied by 0.029 to give N in meat exported from each system.

The difference between inputs and output leaves the surplus N that is not used by each system. Nitrogen exported in products as a factor of N inputs to each system was used with an efficiency of 33%. Surplus N ranged between 160 and 185 kg per ha and of this surplus between 46 and 54 kg per ha was residual in the soil at the end of the grazing season. This indicates that between approximately 114 and 131 kg per ha of N was mostly lost as gaseous emissions (ammonia, di-nitrogen, nitrous oxide etc.) during the grazing season. Residual N in the soil averaged 50 kg per ha across systems and of this approximately 20 kg per ha ended up in water as leached nitrate-N (approximately 12% of surplus N). This indicates that a further 30 kg per ha was lost as gaseous emissions during the winter period – most likely as a result of denitrification.

General Discussion and Conclusions

Between 2000 and 2002 approximately one-third of the farm at Solohead was converted over to clover-based grassland using over-sowing to introduce the clover into swards. This section of the farm was used for the WC system between 2003 and 2006. During the present experimental period, another one-third of the farm was converted over to clover using the over-sowing technique – effectively repeating the previous conversion process. This clearly indicates the potential of this technique as a low-cost method of converting grassland over to clover. Of all the years between 2000 and 2006, 2004 was the year that over-sowing was least successful. This is because seed over-sown during late May 2004 germinated shortly afterwards. Very dry conditions experienced during June 2004 resulted in substantial losses of seedlings. This setback delayed the conversion process to a certain extent; nevertheless, such setbacks are to be expected using this technique. Surprisingly over-sowing worked reasonably well during 2006. This is because conditions got very dry very quickly after over-sowing in late May 2006 and seeds failed to germinate. Seeds lay dormant at the soil surface during the dry summer months. Shortages of pasture supply meant that swards were grazed very tightly and this favoured seedling establishment when the rain returned in late August and September. It can be concluded that grassland can be efficiently converted over to clover using the low-cost over-sowing technique. Further details of this technique and how to go about a planned conversion process are available (Humphreys and Lawless, 2006).

The results also indicate that it is possible to carry a stocking rate of 2.0 cows per ha on clover-based grassland receiving fertilizer N input of 90 kg N per ha per year. This equates to a standard value organic N load of 170 kg per ha within REPS-3 and the Nitrates Directive where an Irish dairy cow is defined as producing and organic N load of 85 kg per cow per year. In fact the cows at Solohead are more productive than the national average producing annual milk output of approximately 6500 litres per cow (Table 2) and organic N output minus emissions of ammonia of approximately 95 kg per cow. A better way of considering the issue of stocking rate might be to classify it on the basis of milk production per ha. Milk production per cow at Solohead amounted to approximately 6500 litres of milk or 500 kg of fat & protein per cow, the clover-based system had the potential to support a stocking rate equivalent to output of 13000 litres of milk or 1000 kg of fat & protein per ha – as a more appropriate indicator of potential output.

The high organic N loads per cow means that organic N loads per ha on the experimental systems ranged between 191 and 212 kg per ha. However, median concentrations of nitrate-N in water in piesometers in the various systems ranged between 3.59 and 3.79 mg per litre. In reality, when the contribution of fixed N is fully accounted for, the differences between these systems in terms in soil N supply and stocking rate are relatively small, hence the relatively small differences in organic N loads outlined above (191 and 212 kg per ha) and in median nitrate-N concentrations (3.59 to 3.79 mg per litre). Taken as a whole, median nitrate-N concentration in peisometers in the experimental area was 3.66 mg per litre. This compared with median concentrations in the field drains of 2.28 mg per litre during the winter 2004/05 and 3.06 mg per litre during the winter 2005/06. That the values in the field drains are lower could be due to dilution by water from other sources or due to attenuation and denitrification of nitrate-N at deeper depths in the soil as the water in piesometers moved from a depth of approximately 1 m in the soil to a depth of approximately 2.5 m in the field drains. One way or another, nitrate-N losses from the experimental area carrying a high organic N load of between 191 and 212 kg per ha were quite low and much lower than the Maximum Allowable Concentration (MAC) of 11.3 mg per litre.

This low vulnerability of the soil at Solohead to nitrate leaching losses can be attributed to the high clay and organic matter contents, mild winter temperatures and moderate drainage status (hence the need for a network of field drains) which combine to lead to high rates of denitrification. At Solohead, slurry is applied to approximately two-thirds of the farm area in January and to another one third of the farm area in late March, at which point most of the slurry has been applied. A mixture of slurry and dirty water is applied after first cut silage in May. This approach to slurry management aims to optimise the efficiency of nutrient use in the slurry (within the constraints of efficient grassland-based dairy production) and minimise losses – particularly losses of N in ammonia gas. It is estimated that losses of N in ammonia gas amounts to around 20% of the N surplus outlined in Table 8, or between 32 and 37 kg per ha. Taking into account that approximately 20 kg per ha is lost as leached nitrate-N this leaves between 108 and 128 kg per ha, which was probably lost as a consequence of denitrification. Loss by denitrification amounts to approximately 65% of the N surplus, a proportion that is in good agreement with the conclusions of Smith *et al*. (1995) in their examination of the proportion of N lost by denitrification from grassland soils in Northern Ireland.

Average N fixation by white clover that contributed to grassland DM production on the WC system amounted to an average of 127 kg per ha. At a replacement value of CAN fertilizer (€0.82 per kg N) this level of fixation can be valued at €104 per ha. The annual cost of maintenance of the clover content of swards by over-sowing is between €4 and €5 per ha per year. (This consists of 5 kg clover seed per ha at a cost of between €8 and €10 per kg of seed applied to one-fifth of the farm area each year, or applied to individual paddocks every one year in five). Hence, the potential net benefit of having white clover-based grassland is approximately €100 per ha.

Table 9. Stocking rates and fertilizer N use on Irish grassland farms

Stocking rate (kg per ha of organic N)*	No. farmers (‘000’s)	Average Fertilizer N use (kg per ha)
< 100	85	<100
100 – 170	33	100 – 185
>170	8	>185

*one dairy cow = 85 kg per ha, one suckler cow = 65 kg per ha, etc.

The vast majority of Irish grassland farms (94%) are stocked at less than 170 kg organic N per ha (Table 9). The results of this experiment clearly indicate that the inclusion of white clover in swards offers the opportunity to offset the escalating fertilizer N costs on farms and help to maintain or improve sward quality.

Conclusions

- White clover based grassland receiving 90 kg per ha of fertilizer N per year has the capacity to carry a stocking rate of around 2.0 cows per ha producing approximately 13,000 litres of milk or 1000 kg of fat & protein per ha.
- The net saving in fertilizer N at 2006 prices associated with white clover in the sward was equivalent to approximately €100 per ha. On farms of 40 to 50 ha, the potential saving is between €4000 and €5000, which, in the context of average annual income on dairy farms in 2005 of approximately €35,000, can make a considerable contribution to profitability on farms.
- The organic N loads on the different systems in this experiment ranged between 191 and 212 kg per ha. Median nitrate-N concentrations in water draining from these systems ranged between 3.59 and 3.79 mg per l. These low concentrations are due to the heavy soil at Solohead; a far higher proportion of losses of nitrate from the soil at Solohead is attributed to gaseous losses due to denitrification rather than as nitrate leached to groundwater.
- Losses of N from the white clover-based grassland (WC and CC) were similar to losses from the grassland receiving higher inputs of fertilizer N (FN). These losses were directly proportional to the amount of N cycling within the systems regardless of the original source of N: manufactured fertilizer N or biologically fixed N.
- From a broader environmental perspective, the white clover based swards offer the potential of lower greenhouse gas emissions at similar stocking rates to fertilized grass swards because substantially less fertilizer N is applied to the clover swards, lowering the CO_2 emissions associated with the manufacture, transport and applications of the fertilizer N (Schils *et al*., 2005).

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